THE CONTROL OF QUALITY IN MANUFACTURING

By

G. S. RADFORD

Consulting Engineer; Member, American Society of Mechanical Engineers; Society of Naval Architects and Marine Engineers; American Society of Naval Engineers

NEW YORK
THE RONALD PRESS COMPANY
1922

To My Parents

PREFACE

There is an erroneous but wide-spread belief that quality and high cost go hand in hand. The existence of this feeling is readily explained, because it is the general practice to advertise quality as something worth paying for. From the purchaser's standpoint this is very true, but it does not follow by any means that quality is costly to produce. Very high-grade "quality" products are often high priced, but lower grade and less expensive articles also possess their own quality standards.

In the factory, quality is a costly thing to neglect, yet it is the usual experience to find a disproportionate emphasis being placed upon quantity of output, in the effort to effect economies. Often this is not so much due to lack of proper intent as it is to the failure to realize what the quality approach means. To establish and maintain definite and sensible standards of quality requires care and thoroughness. These are the very things which remove obstacles to production and thus decrease costs—quite independently of whether the product is high grade or low grade, high priced or low priced.

In the following pages, presenting the results of an intensive study of quality in manufacturing, it has been the intention to show that the control of quality is the correct starting point for economy (as well as to obtain higher standards for their own sake), since if quality is under positive and continuous control, increase of output follows as a by-product advantage. Hence one of the central thoughts of the book is that increased output and decreased costs are more certainly attained when manufacturing problems are approached with quality, instead of quantity, as the primary guide and objective.

It is well-nigh impossible to pass a store window, or to ride in a street car, or to glance at the pages of a magazine without encountering the word "quality." Yet there is no formal literature about quality in manufacturing—nearly all of our attention having been devoted to quantity. Therefore, in constructing this book the introductory chapters, I and II, discuss the general relationships of quality to manufacturing.

When it comes to controlling quality, inspection plays a large part. Chapters III to XI, accordingly, are intended to insure a clear understanding of the various forms of inspection. In sketching the relationship of inspection to the control of the flow of work in process, the idea of planning with material in physical form is advanced as an advantageous extension of the usual planning systems.

With this earlier portion of the book as a foundation, Chapter XII, *et seq.*, takes up definitely the relation of measurement to quality and the development of quality standards in the various types of manufacturing, using the methods for controlling dimensional quality as the principal example. Dimensional work has been reduced to very precise regulation in the industrial arts and thus permits of exhaustive treatment. Hence most of the illustrations throughout the book are drawn from that source as best typifying the principles involved in quality control generally.

Among the important characteristics of manufactured articles there are many other qualities which as yet have not been brought to the same perfection of control as dimension. Color, the control of which is just now beginning to receive close attention in many industries, is discussed as typical of these other qualities.

The concluding chapters present the author's idea of the best method of attack for approaching, and bringing under control, *any* quality problem whatever, regardless of the particular industry or the particular product which may happen to be involved.

Throughout the text a careful effort has been made to give credit to the many firms and individuals who have supplied technical information and illustrative matter. Probably this book would not have been written if Mr. L. P. Alford, Editor of *Management Engineering*, had not requested me to do so, and then assisted in its preparation with his usual thoughtful and competent advice. It only remains to be said that doubtless many of the conclusions presented in the subject matter were influenced by professional conversations with several former associates. It is a pleasant duty in this connection, to express my obligation especially to Messrs. William B. Ferguson, H. H. Pinney, D. C. Seagrave, Brigadier-General John T. Thompson, U. S. A., retired, and Captain R. M. Watt (C. C.) U. S. N., formerly Chief Constructor and Chief of the Bureau of Construction and Repair.

G. S. Radford

New York City,
September 1, 1922

CONTENTS

CHAPTER PAGE

VII INSPECTION'S RELATION TO PLANNING—*Continued*

LIST OF ILLUSTRATIONS

THE CONTROL OF QUALITY IN MANUFACTURING

CHAPTER I

INTRODUCTION

The Changed Industrial Demand

The years 1919 and 1920 marked definitely the end of a period in manufacturing and industry. It was characterized by the demand for "maximum production," for quantity or volume of manufactured goods. The means and agencies of production—material, equipment, and labor—were planned and directed to satisfy this end. But with the close of this period has come a great change which will vitally affect industry and manufacturing of the present and immediate future.

The new demand is for effective unit production, that is, a maximum useful and marketable output per machine, per hour, per man. "Useful, marketable" production implies a different characteristic from that associated with mere quantity. This characteristic is quality. It is destined to distinguish the great purpose in present and future manufacturing, in the same way that quantity demand distinguishes the period which has closed.

At the outset it must be recognized that both quantity and quality are general or "universal" characteristics in that they apply to all manufactured goods. The horizon of quality is just as broad as the horizon of quantity. This is their similarity—they both belong to all kinds of goods and articles. Quality belongs to those articles which are inexpensive no less than to those which are costly. It is closely associated with usefulness and marketable possibilities. It is a characteristic emphasized again and again in advertising and sales literature, but has no direct connection with cost or selling price. A point to note is that whether the article costs much or little, quality and the reputation for quality establish the market which will make possible quantity production and its attendant advantages.

Quality a Distinguishing Characteristic of Goods

The term "quality," as applied to the products turned out by industry, means the characteristic or group or combination of characteristics which distinguishes one article from another, or the goods of one manufacturer from those of his competitors, or one grade of product from a certain factory from another grade turned out by the same factory. Quality serves to identify an article. It is the characteristic which measures the evenness of a specific grade. Quality is used in this sense whenever we say that the same factory produces the same article in several different qualities, or that the output of certain factories is graded according to quality.

It is evident that the group or combination of characteristics which form the quality of an article includes such elements as design, size, materials, workmanship, and finish.

To consider some of these elements—so far as size is involved, quality is concerned with precise adherence to size. For instance, one pair of shoes of a specified length and width must be like another pair of shoes of the same length and width. In this case quality depends upon adherence to a particular characteristic. The same requirement holds in regard to the raw materials from which the article is made and to the workmanship applied in the manufacturing. A manufacturer to secure and maintain quality attains uniformity or evenness in the raw materials which enter his product and in the workmanship applied. This adherence to established requirements is a major responsibility of the manufacturer.

Uniformity the Essence of Quality

The purchaser's principal interest in quality is that evenness or uniformity which results when the manufacturer adheres to his established requirements. No matter when or where the purchaser buys an article he expects the same definite and proper return for his money, not only at the time of purchase but through a reasonable period of use. He is justified, no doubt, in expecting a gradual improvement from time to time in the quality of all the articles which he buys, but at any one time his chief expectation, as regards quality, is that it shall be the same for like articles. No shoe must be either better or worse than its mate. The quality of two pairs of the same grade of shoes, or of ten or a thousand pairs for that matter, must be practically identical.

The manufacturer himself as a purchaser of raw materials, supplies, and equipment, views the matter in the same light, perhaps with even greater insistence upon uniformity and evenness of grade. Thus he requires that all lots of a given kind of steel shall have the same characteristics from lot to lot; and, as just indicated, the evenness of characteristics and the degree of precision with which they are attained are what determines quality. As a matter of fact, the manufacturer is often more concerned with obtaining uniformity in raw material than he is in getting an improved quality, because it is easier to produce uniform results from material which is uniform to begin with, and uniformity of product is what he is after.

Standardization Does Not Bring Quality

At this point it is important to realize that standardization of products or articles does not of itself influence quality. Unfortunately, these two terms are frequently confused in use, but they are not synonyms. One signifies a characteristic, the other a process.

Standardization in American industry has been applied in general to the proportions of articles and is frequently referred to as "standardization of proportionality." An excellent example is the United States standard screw thread. This was adopted many years ago and is generally used throughout American industry. However, it is possible to make United States standard threads of poor quality, good quality, or of any intermediate quality. If the proportions are the same throughout this range of quality, all of the screws would be "U. S. S." Another example, appreciated by everyone, is presented by our railroads. A standard railroad gage is almost universally used throughout the United States, yet everyone has discovered that there is no standard in the quality of these standard-gage roadbeds. That is, while the gage is standard, the quality of the roadbeds varies. The distance between the rails is only one of a number of elements which make up the quality of the roadbed itself. So far as the gage is concerned, the requirement of quality is attained when the rails are maintained at the standard distance apart. But the smoothness of the roadbed depends upon many other things, which grouped together give characteristics or quality.

The quality of an article, therefore, is made up of a large number of characteristics or attributes, some of which may be standardized for convenience or economy. It is quite possible to have two articles, both standard, which appear alike, but whose quality differs essentially. In the case of raw materials, ordinary city water undoubtedly is handled in greater bulk than any other standard commodity. When collection and filtration are completed, the water is said to be distributed in standard form; but even then its quality differs widely from place to place and from time to time. Although alike to all outward appearances, the water supply in two cities may be far different in essential quality, because the ingredients which cause a quality difference are usually incapable of detection by human senses. In this instance also, quality depends on the consumers' requirements. Thus water may be satisfactory for cooking but not at all satisfactory for many industrial and technical purposes.

In the case of manufactured articles the same difference must be recognized between standards and quality. Referring again to shoes as an example, the purchasing public requires footwear in a great variety of sizes and kinds, and exact satisfaction of each individual's wants would result in almost as many kinds of shoes as there are persons. To avoid making such an indefinite number of varieties and sizes it is necessary to standardize some of the elements through striking a compromise. The effect of this process is to create a sufficient volume of like work to permit of using the method of quantity production. This compromise for the purpose of securing the economy of repetition manufacturing takes place when shoes are classified in a standardized series of styles, sizes, and widths. A little reflection will show that this process of compromise or standardization is quite different from the establishing of quality or qualities which define the character of any particular make and grade of shoe regardless of size and of style.

Uniformity Requires Continuous and Positive Control

In meeting and satisfying the purchaser's expectations, the manufacturer's problem would be very simple indeed if quality were some definite thing which could be easily and accurately measured out so much to an article—but it is not. On the contrary, quality tends to slip away, to change and, in fact, be almost everything except what it should be. The perversity of inanimate things and the fallibility of animate persons are always at work to render quality fugitive. In this respect quality differs markedly from quantity. It is comparatively easy to say that we will make a thousand articles and to proceed to make them. The problem becomes difficult only when we are required to make them alike within precise commercial limits and with minimum variations from standard.

This difficulty in attaining uniform standards of quality in manufacturing makes the control of quality so vitally important. The advertised claim of quality is one thing but the *positive* and *continuous* control of quality to definite standards in the factory is something altogether different—as many people have discovered in recent years. By "positive control of quality" is meant that form of management or direction which establishes the quality requirements and then sets up the organization and selects the personnel capable of securing that quality. By "continuous control of quality" is meant the vigilant maintenance and direction of the organization and personnel set-up to make the control positive.

The resulting and final quality of a manufactured article is created and influenced by a great number of things. In fact each element of the business plays some part in the final result. Consequently the control of quality must be positive in action in order that all the factors and agencies involved may be co-ordinated. If one factor gets out of control, the entire system is thrown out of adjustment, errors accumulate, and quality suffers.

The control must be continuous because quality is not one of those things which once established stays put for all time. Its tendency to slip away is incessant. But a single serious slip in quality may result, in some businesses—for example in the manufacture of foodstuffs—in the destruction overnight of a good-will which has required years to build up.

Instance of Failure in Quality Control

In most successful and long-established industries it has become a fixed habit to consider quality as basically necessary and thus to take it for granted. Most of these people sincerely believe that they have quality under control, and that once having attained a certain standard nothing more is necessary to perpetuate it indefinitely. Not long ago an engineer happened to spy a small sewing machine in the window of a Fifth Avenue store. It was of a standard make and therefore presumably of standard quality. It happened that he had a place where such a machine might be used advantageously so he purchased one, which was handed to him in the original container. Upon trial, however, the machine proved to be very stiff and jerky in its action. So he personally took it back to the store and was informed that such a thing could not be.

"Every one of our machines is inspected before it leaves the factory, but you may take it to Miss X at the repair desk in the rear." Miss X took one look at the machine and said, "Yes, the looper shaft is not straight. We get a good many that way. I'll give you another one."

The second machine proved to be only a little better than the first. By this time the engineer was interested in the problem as an engineer, so he proceeded to take the machine apart and discovered that the shaft had nothing to do with the trouble but that a slight filing and fitting of three other parts remedied the difficulty, so that his machine finally "ran like a sewing machine." He was especially interested to note, however—and this is the point of the story—that all of these difficulties should have been corrected and could easily have been corrected in the manufacturing of the parts, with a probable reduction in cost of assembly. This, it may be noted, is quite aside from the question of the reflection on this particular manufacturer's reputation for quality, for it is obvious that the engineer referred to is not going to buy a life-sized machine of that particular make until he has made sure that other manufacturers do not market a more uniformly satisfactory product.

The experience just recited is significant of what happens with many concerns. The manufacturer in question has had a long-established reputation for a satisfactory product and it would be an extremely difficult and painful undertaking to make him believe that his control of quality had slipped badly in this instance. He probably believes that he has always had quality and consequently that he always will have it. He regards it as a part of his fixed assets.

In order to get quality under proper control it is necessary to note that every phase of the business from designing to shipping is involved and requires critical examination. It is not merely a matter for the inspection department to take care of. For example, here is a factory which sets up a very high standard of dimensional accuracy on paper. The plans call for splitting thousandths of an inch in the manufacturing processes. It has an elaborate and expensive inspection department, but it lacks the modern mechanical methods for checking the accuracy of its measuring instruments. It cannot possibly attain the dimensional precision called for by the plans, because of the failure to provide a comparatively inexpensive bit of apparatus. Yet the people in the factory think that they are doing remarkably fine work, while as a matter of fact they are only fooling themselves. Their measuring instruments read to the precision required but they do not measure to that precision—which is something entirely different—and there is no positive way of checking them when they wear. In this instance, as a matter of interest, the management was not even aware of the fact that their dimensional checking arrangements were deficient and antiquated.

Here is another factory which is in nearly the same situation but for a different reason. It has all of the apparatus and all of the provisions for inspection that are necessary, but the work in process is under such unsystematic regulation that the inspectors are frequently unable to tell you with certainty what parts have been rejected for minor defects and what parts are satisfactory and up to standard. Disorder in the shops has been carried over into the quality of the output.

These are by no means isolated examples, nor are they exceptional cases.

Figure 1. Full Set of Johansson Gage Blocks

Set No. 1, consisting of 81 blocks; 300,000 different dimensions are possible with this set. There are other sets, but this is the one most used in America. Millimeter sets are also to be had. All blocks are accurate to within one-hundred-thousandth of an inch per inch of dimension.

Advantages of Considering Quality at Outset

The idea seems to prevail that, because quantity production has been desired, quantity itself is the proper starting point in attacking production problems. This idea is seemingly supported by the honest belief in many industries, both large and small, that everything which should be done in regard to quality is being done. As a result, quality control has been disregarded and the demand for quantity has been kept in the forefront.

Now the fact of the matter is that in concentrating directly on quantity production and hence taking quality very much for granted or treating it as a secondary consideration, we have been overlooking an opportunity; and the oversight is costly in more ways than one. This is proved at once if we stop to consider the advantages which accrue from approaching management problems with quality instead of quantity as the primary criterion. There are immense and as yet largely undeveloped economies to be found when management is critically scrutinized from the quality standpoint. These resulting advantages are quite apart from the direct advantage of quality for its own sake, since they result in better labor relationships, increased output, and decreased costs.

Improved Labor Relationships

Let us consider the point of labor relationships. These present an ever and most pressing factory problem. The moment you endeavor to get an increase in output (which is attacking the problem from the standpoint of quantity) the question of bargaining enters and provides an occasion for dispute. On the other hand, if the workman is taught to better his product, and is urged to be more careful, and to be sure that his work is performed correctly, a common meeting ground is provided. It is a poor mechanic indeed who does not take sufficient interest in his work to join you in improving the results of his craftsmanship.

Suppose now for the moment that this greater attention to quality, requiring thoroughness and attention to detail as it does, will result in an actual increase in output for the same effort. I say "suppose" that it does, although as a matter of fact it will be proved presently that there is no supposition about it. But assuming for the moment that more attention on the part of the workman to quality will bring about an increase in output, have we not secured that increase in a much pleasanter, more effective, and more permanent way than if we had made a direct request for increased production? It is in every way more satisfactory to discuss a factory problem on a basis in which both sides are mutually interested and moving in a common direction which brings them closer together.

In order to carry out such quality discussions intelligently, the management must be informed, and very thoroughly informed at that, about the technical side of the business. Certainly this alone is a desirable thing. This method of approach is bound to lead into a study of the technical details of the business, to the mutual edification of both management and men. Failures to attain quality standards take the form of variations in the characteristic qualities. These errors in manufacturing must be listed and evaluated, and the basic causes of the errors located and cured, all of which is bound to be both stimulating and intensely interesting. It is about the only sure basis for offsetting the well-recognized danger of the modern industrial system. Men cease to be mere automatons when they think in this way about their work.

It is a fact that the manager who strives to interest his organization in improving the quality of the work done will find that the process will work out to be a wonderfully effective co-ordinator. When the men are trying for better and more careful workmanship, there is small chance of those disputes and arguments which so frequently arise when pressure is applied for more output. There is a world of difference between bargaining and appealing to the pride of craftsmanship. By the very reason of his being an artisan the worker is interested in improving his work.

Testimony

In 1912, a report was submitted to the American Society of Mechanical Engineers on "The Present State of the Art of Industrial Management," which quoted an earlier paper by L. P. Alford and A. Hamilton Church on "The Principles of Management,"[1] setting forth the latter as:

1. The systematic use of experience,
2. The economic control of effort, and
3. The promotion of personal effectiveness.

Both of these papers dwelt upon "the conscious transference of skill" (which necessitates that the management must first have the skill to transfer) as a vital step in promoting the personal effectiveness of the worker. There thus begins to appear an attitude toward management, which, when translated into general practice, is bound to have a profound influence on the labor situation. The evidence is strong that managers are leaning more and more towards this point of view, accentuated by a stronger and growing realization of the value of stressing quality.

At the annual meeting of the American Society of Mechanical Engineers in December of 1919, Robert B. Wolf (then manager of the Spanish River Pulp and Paper Mills, Ltd., of Sault Ste. Marie, Ontario) presented a paper on "The Use of Non-Financial Incentives in Industry," which was recognized at once as containing many original and

---

[1] *American Machinist*, May 30, 1912, Vol. XXXVI, p. 857.

thought-provoking ideas that were widely discussed. The following is taken from Mr. Wolf's paper:

> Such records can be grouped under three main headings: quantity records, quality records and economy or cost records. Quality records which occupy the middle position, are, perhaps of the greatest importance, for they bring the individual's intelligence to bear upon the problem, and as a consequence, by removing the obstacles to uniformity of quality, remove at the same time the obstruction to increased output. The creative power of the human mind is, however, not content simply to produce the best quality under existing conditions of plant operation. The desire to create new conditions for the more highly specialized working out of the natural laws of the process demands expression, and this expression at once takes the form of suggestions for improvements in mechanical devices.

Only recently a paper was presented by W. N. Polakov entitled, "Making Work Fascinating as the First Step Toward Reduction of Waste."[2] This paper is carefully worked out and will repay reading with the general attitude of mind which recognizes the great desirability of organizing work "so that the worker's intelligence and his creative or imitative instincts will be brought into play. This requires: (1) analysis of jobs and processes to bring out the interrelation of causes and effects, and (2) the education of operators in conscious control of these forces and relations so that they can at will influence the results." This quotation is indicative of Mr. Polakov's attitude, but the reader is referred to the original text for a more thorough presentation of the subject.

Increase of Output and Decrease of Costs

Let us now consider the effect which the control of quality produces in increasing output and decreasing costs of manufacturing. The statement has already been made that such an increase in the volume of production does result

---

[2] *Mechanical Engineering*, Nov. 1921.

from the establishment of adequate quality control, and that it further results in a decrease in the cost of production as well. This idea was advanced in brief form in a paper by the author, published in October, 1917.[3] Time and a subsequent study of a number of manufacturing enterprises have only served to strengthen these significant conclusions.

Before exploring the basis of these conclusions, it is wise to remember that quality of itself is not a costly thing. For example, one buys a Ford car, not necessarily because it is cheap, but because it is built to a rather definite standard of quality and the purchaser has every reasonable assurance of obtaining a known return for his investment without reference to price or time. Although the Ford car is comparatively inexpensive, it has definite quality.

The misapprehension that quality is costly doubtless arises from the fact that it is used as the chief inducement to make people spend money. In current use, moreover, the phrase "quality production" as distinguished from "quantity production" does not imply the idea of manufacturing to certain predetermined standards of quality so much as it does that the quality of material and workmanship is of unusually high grade.

From this latter mode of thinking has arisen a widespread belief that quality is expensive and that it is always cheaper to make things to a lower standard. So it is, if we are working intentionally to a lower grade and definite standard; but usually a lower grade article implies indefinite and inaccurate standards, poor material and slipshod workmanship, and little, if any, inspection. In such case the output is lower and the work more expensive than if the thing were done correctly and well in the first place. It is axiomatic that it is always cheaper to make things right at the start.

---

[3] "The Control of Quality," by G. S. Radford, *Engineering Magazine*, Oct. 1917.

Carnegie's Maxim

One of our greatest manufacturers clearly understood that quality by itself is not necessarily costly, but it is always expensive to ignore; as the following quotation indicates. Almost everyone knows that the success of Andrew Carnegie was founded in meeting the "impossible" requirements of the United States Navy Department for a much higher grade of steel; so it is interesting at this point to note what he has to say relative to quality in his "Autobiography":

> We were as proud of our bridges as Carlyle was of the bridge his father built across the Annan,—"An honest brig" as the great son rightly said.
>
> This policy is the true secret of success. Uphill work it will be for a few years until your work is proven, but after that it is smooth sailing. Instead of objecting to inspectors, they should be welcomed by all manufacturing establishments. A high standard of excellence is easily maintained and men are educated in their effort to reach excellence. I have never known a concern to make a decided success that did not do good, honest work, and even in these days of the fiercest competition, when everything would seem to be a matter of price, there lies still at the root of great business success the very much more important factor of quality. The effect of attention to quality, upon every man in the service, from the president of the concern down to the humblest laborer, cannot be overestimated. And bearing on the same question, clean, fine workshops and tools, well kept yards and surroundings, are of much greater importance than is usually supposed. "Somebody appears to belong to these works" remarked one of a party who passed through the works. He put his finger there upon one of the secrets of success.
>
> The surest foundation of a manufacturing concern, is Quality. After that, and a long way after, comes Cost.

Experience of War Time Manufacturing

The analysis of enterprises which were intensified by war conditions illustrates the point vividly. It is now more generally realized that the specifications furnished for war

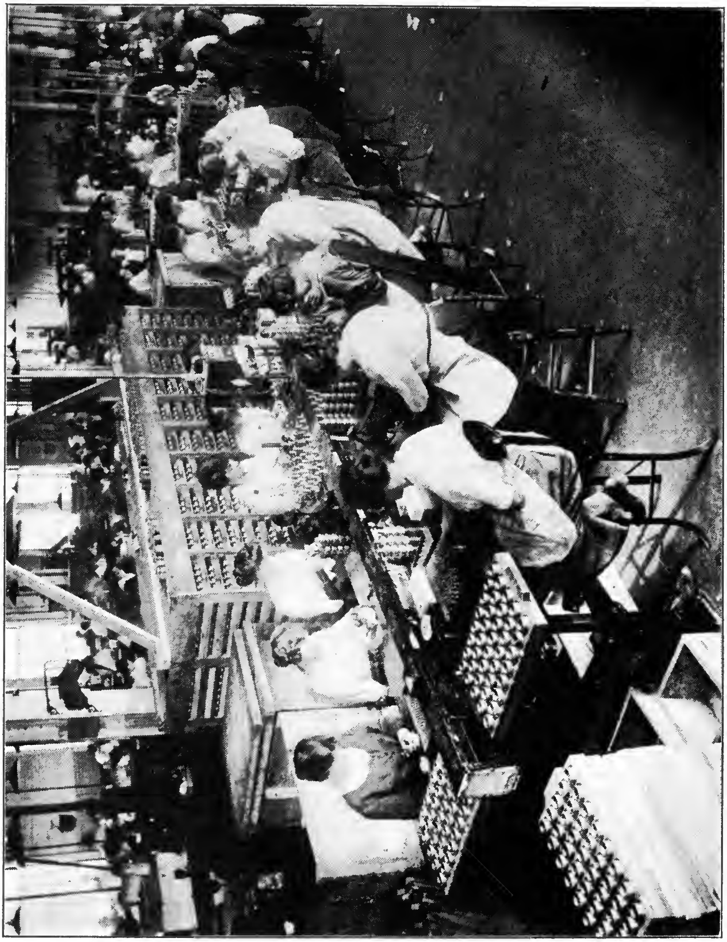


Figure 2. Time Fuse Manufacture of the American Locomotive Company

A great war time success.

material (unfortunately for the manufacturer) were inexact in many cases, so that great latitude existed for the application of judgment by inspectors, this being specially true in the case of the earlier contracts for foreign material. When the contractor failed to clear up all doubtful points affecting quality at the start, and plunged boldly into large-scale manufacturing, the resulting failure of the good old methods of quantity production came as a distinct shock to both engineers and manufacturers.

The lessons to be drawn from these experiences are manifold, but close examination will reveal the fact that the manufacturers who were more careful in all matters determining and affecting quality, reaped a greater harvest in the end, although they usually took longer to get started. The most clearly marked contrast between those who achieved results and those who did not do so well is to be found, in every case, in more exact definitions of quality backed up by an inspection service and general control of quality adequate for safeguarding the standards established. It is undoubtedly true, moreover, that when the precautions just stated were taken and when, in addition, a very high grade of dimensional accuracy was adhered to, the quantity of output was astonishing.[4] The fact that these enterprises dealt with large-scale interchangeable manufacturing in no way weakens the general applicability and truth of the principles involved; which serves to show that the method of planning for large output at low cost with quality as the basic and primary guide is more than vindicated by the results.

Control of Quality Basic

The facts demonstrate that when manufacturing arrangements are made first and primarily with the intention of controlling manufacturing to definite and uniform stand-

---

[4] Typical examples of war time production successes are set forth in Chapter XII.

ards of quality, quantity of output will follow. Briefly, if we first take care of quality, quantity will take care of itself.

This does not mean that there is no need of the various modern devices for increasing and controlling production, because all of these things have their place. What it does mean, however, is that quality should be the basic guide and that, like quantity, it is an integral part of all the manufacturing operations and demands recognition accordingly.

In this connection the effect of losses of work in process on quantity of output alone is all too frequently overlooked. These losses seriously affect production in a direct way, but they still more seriously slow down production, reduce output, and increase cost in certain indirect ways which are much less apparent and hence, by reason of this obscurity, more difficult to detect and to remedy. A piece that is wholly spoiled represents a loss of all the work expended in its manufacture up to the point of spoilage; yet, even so, its outright loss is frequently cheaper than a partial injury which requires the attention of the best men in the shop to repair the defect, while their regular work meanwhile is at a standstill. In other words, the generalization that it is always easier to do a thing right in the first place, holds equally well in the factory.

The Quality Bonus

As further indications of the trend toward recognizing the value of the quality approach, a few cases may be cited where managers have had the courage to go so far as to establish a wage payment based definitely upon quality. Even when a quality bonus is superimposed upon a piece work system which contemplates payment for good work only, the results obtained by a separate payment for quality have been astonishingly satisfactory. In two instances which were merely isolated mechanical operations, where the rejections were exceedingly numerous, shifting the piece work rate to a reward for quality reduced rejections to a negligible amount almost overnight. The following examples, however, deal with quality bonus payments which are in effect on a much greater scale, and which represent a radical departure from currently accepted practice.

Experience of The Shelton Looms

Some time ago The Shelton Looms, under the progressive control and guidance of Sidney Blumenthal, established a quality bonus for weaving. This mill is engaged in making high-grade, deep-pile silk and woolen fabrics and of course a great deal of attention is paid to quality. At a certain stage of development the manufacturing problem was approached from a new angle, and the quality bonus for weaving was adopted. The improvement in both quality and quantity is indicated by contrasting the following figures[5] (which are for the first quarters of the years stated):

	1917	1920
Number of men.................	1,784	1,645
Hours per week...............	50½	47½
Yardage......................	107	154
Quality	73⅓%	90+%

Mr. Blumenthal has been quick to take advantage of suggestions for improving management methods and to follow them up with care. Consequently, it is interesting to note that he summarizes the experience of his company in the matter of paying for quality by saying, "Attention to quality demands thoroughness, and thoroughness removes the obstacles to production."

Experience of the Armstrong Cork Company

As a further example in the field of wage payment based primarily upon quality, the experience of the linoleum divi-

---

[5] Furnished through the courtesy of L. DeK. Hubbard, Operating Vice-President, and F. Stolzenberg, Mill Manager of The Shelton Looms.

Figure 3. An Object Lesson in Quality
Drawn by an employee of The Shelton Looms.

sion of the Armstrong Cork Company, Lancaster, Pennsylvania, is equally interesting.[6] As everyone knows, "battleship linoleum" is a standard product of established quality, and it is natural that its makers should view the matter of production with quality as a guide.

The bonus system for quality production was conceived and installed in 1914, and has been in successful operation ever since. The primary object of the plan was to decrease the quantity of seconds produced and at the same time to guard against a decreased production per man. The result has been a consistent increase in quality each year, so that from the early part of 1914 to date the increase in output of first-quality goods is 30 per cent greater than when the quality bonus was started.

During this period the production per man increased slightly, but this was not one of the motives for installing the system. Since production in this industry is determined almost exclusively by the speed of given machinery, the special aim was to see that the production governed by the speed of the machines was not reduced by the efforts of the men to turn out perfect goods. This has been successfully accomplished. In fact, during the war period when the man-efficiency in industry generally reached a very low ebb, the experience of this plant was the exact opposite, for the efficiency per man throughout the various departments increased perceptibly. This experience under the trying conditions of the period in question is a further vindication of the managerial judgment which makes quality the basic criterion for attacking production problems.

Decreased Selling Costs with Quality Goods

The results obtained by The Shelton Looms and by the Armstrong Cork Company certainly warrant a wider study

---

[6] From information supplied through the courtesy of John J. Evans, General Manager.

and application of quality payment; for, in addition to improved quality itself, the resulting increase in production means decreased costs—both directly and through the elimination of various sorts of losses.

There is, moreover, another phase of lowered cost when quality receives attention, which should not be overlooked, and that is the lessened selling expense which is a direct result of supplying goods of standard quality. Such articles sell themselves at the factory.

There is evidence on every hand that the purchasing public is applying much finer and more intelligent discrimination in its buying. Even the non-technical press is full of advertising matter setting forth in detail the reasons why the goods advertised possess the characteristics claimed for them. In other words, the average purchaser is becoming a better inspector. Consequently, work which is held to standard is being more and more appreciated and the sale of such merchandise is immensely simplified.

The element of quality enters into a number of things which are not a part of production. When the buyer realizes that nobody else's goods come to him as well packed or in such an economical form for him to handle, it is easier to sell to him. So quality enters into packing. And it is not a far extension of this idea to say that quality enters into shipping as well; because prompt deliveries by the cheapest routes are certainly factors which are influential in the reputation of your goods almost as much as the satisfactory quality of the goods. Also, quality in "service" generates reliance in the firm which really stands behind its goods.

In fact, anything that tends to control quality to more definite and satisfactory standards, whether in the goods themselves or in service connected therewith, increases selling power just that much. Thus the statement that quality goods are sold at the factory becomes a reality.

CHAPTER II

THE APPROACH TO QUALITY CONTROL

The Starting Point—Determining Nature of Product

Quality, being a characteristic or group of characteristics of a product, is intimately a part of the product. Therefore, the only safe and orderly starting point for any endeavor to bring quality under exact control is the product itself. We may be sure of successful results if we begin at this point. This procedure differs radically from the usual approach when quantity production is sought directly. In the latter method of attack on the problems of manufacturing there is an ever-present tendency to begin with the statistics of the business. Records of past production, estimates of future production, and calculations as to what equipment, tools, materials, and labor are necessary to secure an increased quantity are brought to the forefront. It is only later that consideration is given, if time permits, to matters affecting routing, processing, inspection, and others.

Now the product is a final result of the orderly and coordinative working-out of all these things. Each makes a plus or minus contribution to quality. So the control of quality demands that the quality standards be determined first, and then that all the arrangements for creating the product be so made as to insure the realization of these standards. This means nothing less than shaping the means to produce the desired end, instead of permitting manufacturing system, methods, and what-not to determine the character of the factory output.

As L. P. Alford [1] has frequently stated in his excellent

---

[1] Editor of *Management Engineering.*

analyses of management problems: "The end of manufacturing is the production of goods." Let us select what we intend to make first, and then take up the processes, working arrangements, organization, and system necessary to achieve that result; for it is by the results and not by the means that our work is judged.

This procedure distinctly stresses the fundamental importance of establishing definitely the standards of quality which are to be followed, before we can know exactly what we are trying to make; for if there has been found any virtue in preplanning for production, it has been demonstrated that the more completely we know *what* we are trying to do, *before* we actually start doing it, the more easily and swiftly will the work be carried out. It is this wider idea of quality which exactly describes the features of a design with which we are chiefly concerned.

The Commercial Factors—Requirements of the Consumer

Quality, therefore, as referred to here, involves a very definite specification of the important characteristics of the product which enable it to fulfil the needs and demands of the customer in a satisfactory manner. The customer requires that the article be suitable for his purpose. That is, it must be reliable, it must be durable over a period of time, it must be economical both in first cost and in operation, and usually it must be pleasing to the senses as well.

The Design—Securing Consumer's Requirements

From the standpoint of the designer each of the commercial factors is created by the various features of materials of construction, shape, dimension, finish, and so on; and the quality of the final result is determined by these as well as by the degree of precision with which the design standards are realized. This involves processes and workmanship.

Needless to say, the product should be designed to meet the commercial requirements as nearly as may be consistent with economical manufacture; and in doing so the manufacturer is faced with the necessity for compromising in almost every instance. To solve the problem intelligently requires a knowledge of what we are trying to produce and why. The quality may be anything we choose, but as a starting point a clear idea of what we seek to accomplish is fundamental.

As an example of this process, what is so simple as an alarm clock? Like all other clocks an alarm clock may be expected to keep reasonably good time over a period of time. That is part of its job as a clock. But beyond that it has a very unpleasant duty to perform. It should begin with as gentle a tone as possible and still accomplish its purpose with certainty. Having attracted attention, the more pleasing its appearance the less likelihood of trouble. The least the manufacturer can do for an alarm clock is to prepare it for this part of its job, so he gives it a fine finish in nickel plate.

Now a certain manufacturer took great pride in the fact that he was making the cases of his clocks out of a high grade of brass, but he overlooked for the time being that the quality of the brass in the case was of no interest to the purchaser whatever. His real job as manufacturer was to provide a nickel-plated surface which would stand ordinary alarm clock service. When he investigated the matter from this point of view he discovered that a cheaper grade of brass would take a better nickel plate and hold it longer than the higher priced material he was using. Thus you will observe that the manufacturer, having first studied his product from the standpoint of the commercial factors involved, learned what he was trying to produce and why. This led him at once to the conclusion that he should carry the problem to the manufacturer of raw materials, who might reasonably be supposed to know more about such materials than anyone else, with the direct result of an improvement in quality accompanied by an actual economy in production.

Figure 4. A Common Method of Holding a Micrometer Caliper
Courtesy of Brown and Sharpe Manufacturing Company.

We are pretty sure to be on safe ground if we understand that quality requires accuracy and care, and that these things are less expensive than their opposites—inaccuracy and carelessness. Consequently, if it has been decided that the commercial requirements of the case call for a low-grade product, let us proceed on that basis but with the determination that the lower standards of quality are just as deliberately and intentionally selected as if they were of higher grade.

Provision for Improving Design

As has been pointed out, economy of manufacture and uniformity of quality standards go hand in hand; but there is no reason why the standards should not be raised from time to time without conflicting with the requirement of uniform standards during any one period or season of manufacturing. One of the desirable advantages of paying special attention to quality is that this method constantly reveals chances for improving quality without increasing costs. The stage is not likely to be reached where further advances are impracticable.

The manufacturer who is satisfied that his product cannot be improved is in a dangerous state of mind, because progress has not stopped in any art or in any science. If he thinks that the limit of improvement has been reached with the means available, then it is time to look for improved methods, because no business should stand still in any sense. Ordinarily when an art is not advanced, the reason is to be found in failure to provide, within the organization, for systematic and progressive improvement. Further, when someone says that the thing is impossible, that very thing provides an opportunity; for "the man who says that a thing can't be done nowadays, is pushed out of the way by someone doing it!"

From the design standpoint, the best way to provide for the systematic advance of quality, is to realize at the start just what the departures from the highest standard are going to be. Picture a lower grade product from the viewpoint of a *de*-graded high-grade article, in which the reductions in quality are known and have been made deliberately and with "malice aforethought." Then we are in a position to know the directions in which improvements can be made, and in great detail.

The path of future progress is thus made clear, and it will be found that the process of gradually refining and improving the product, step by step, will bear fruit presently and quite rapidly.

Materials

After the product has been thoroughly analyzed with reference to the qualities which it is desired to secure, and after the design has been carried through the stages of compromise made necessary by considerations of economy, the next step is the selection of materials of construction. Now the raw material of one manufacturer is the finished product of another. The manufacturer of the raw material has been through the same process of analysis and economical compromise. Hence it is not reasonable nor even possible to select materials which are 100 per cent right for our purposes, and we are faced again with the necessity for making up our minds. In fact this is just one step in a long series of compromises, all flowing from the fact that quality is something which is peculiarly subject to change and variation.

Since uniformity of result is the thing sought, the most desirable characteristic of the raw material, other things being equal, is uniformity. Once more, cost becomes a secondary issue, within reasonable limits of course. In the case of brass for alarm clock cases, it was noted that a cheaper brass took a more permanent and uniform nickel plating. But the same demand for uniform results, or for ease and certainty of working up the material may justify a higher cost. Thus it is currently reported that the lowest priced automobile made today contains the highest percentage of alloy steels, as a matter of economy.

Processes

With raw materials decided upon, the stage is reached where processes must be studied with the same mental attitude. Can the processes and their equipment possibly produce the results which are desired? If not we should certainly understand just how they should be changed to bring the work to our predetermined standard, with economy.

It will invariably be found that certain approximations to the standard are necessary. In other words, the con-

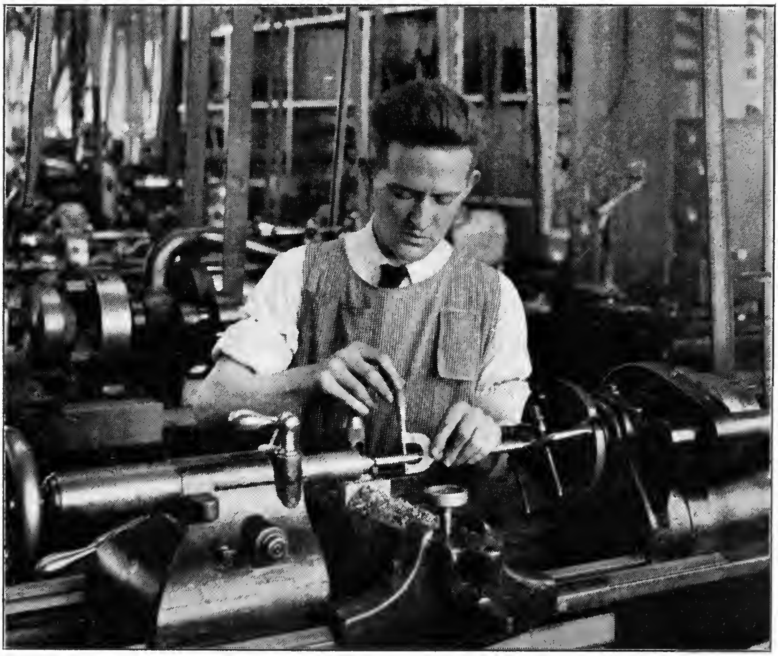


Figure 5. Measuring a Turned Piece in Lathe
Illustrating another correct way of holding micrometer caliper. Courtesy of Brown and Sharpe Manufacturing Company.

sideration of the problem requires another compromise as soon as the selection of manufacturing processes is made. This fact holds true no matter how sensibly the processes are selected or how simple they may be. Quality varies, and the design must be modified accordingly to suit the processing, by stating the permissible variations from standard which will be tolerated. The idea of tolerances and limits for variations from standard thus enters the manufacturing scheme. Whatever the other conditions may be, the processes must be chosen to permit reasonable control of the resulting work to the degree of uniformity allowed by the tolerances in question.

Workmanship

Intimately associated with the study of processes is the matter of workmanship, which involves all questions associated directly or indirectly with the proper application of the machinery provided for production. It is not infrequently the case that the foreman says his tools are all right because he has personally used them to make satisfactory articles. On the other hand, all he has proved by using the tools himself is that an expert workman can get the results with the equipment available. But the only labor obtainable for using these tools may be quite incapable of attaining equally satisfactory results without changing the tools or without very careful instruction, or without change in the surrounding conditions of inspection or other means in use to safeguard the production. "Transfer of skill" and "the promotion of personal effectiveness" at once come into action.

Operating Organization and Records

Evidently this same process of intensive investigation of the manufacturer's problem from the standpoint of quality will now carry us to the study of the organization for operating the factory and finally to the system of records of performance, which are used in controlling the organization in a way to result ultimately in production in accordance with the quality standards as set. It goes without saying that each and every factor entering into the production problem requires sufficient study to insure definite ideas as to how each of these factors can be positively and separately controlled. When this control goes into effect in the qualitative refinement of the industry, production problems for the most part will be found to have been solved in the process, simply because quality is so fundamental in its nature that it requires a consideration of all the factors involved in the business.

Inspection an Essential

If we were starting a new project the preliminary study of quality which has been outlined in the foregoing pages would be made before and during the starting of the factory. Once manufacturing has begun, however, the same continued investigation must be supplemented and assisted by some sure method of bringing to the surface information relative to the errors and failures to attain quality standards.

This is a situation in which every factory finds itself. The factory is running along under pressure of production, and quality is always tending to slip away from the standard and to get out of control. Consequently there is an urgent need to bring to light immediately, and to evaluate the deviations from the desired quality, in order that prompt steps may be taken to limit and correct them.

As an instrument for the prompt and perpetual analysis of the quality situation, and thus for assisting in the control of quality, a proper inspection service is necessary. But to render such service, as well as to carry out its many other important functions, the inspection department must be placed in a position to act effectively. That is only common sense. Yet the fact remains that there is a very general failure to appreciate the possibilities of inspection, although war experience has helped considerably to dispel this lack of appreciation for what inspection can do if given a chance.

The subject is one which has received far too little attention from the standpoint of systematic study. There is practically no literature or philosophy of inspection. In view of this situation let us now examine some of the various characteristic peculiarities of inspection as an introduction to the further study of quality and of methods for the control of quality.

CHAPTER III

INSPECTION—THE NEED FOR INDEPENDENT SCRUTINY

Maintaining Standards—Measurement and Control

To set up standards of quality, no matter how thoroughly and carefully it is done, is one thing; but to realize those standards in the actual work in the factory is quite another thing, for the mere stating of what is wanted will not secure the result. Suppose that a design has been proved out in a thoroughly satisfactory working model or that an article is found to be acceptable to the market; that the working standards have been determined with experience based on the best practice and guided by the highest mechanical engineering skill; that the equipment is adequate and installed in keeping with the requirements of economical and high-grade manufacturing; and then suppose that the factory is started to operate with nearly all work on a piece rate or similar basis, with schedules of desired daily output in the hands of each department head—in short, with the usual great pressure for quantity production. Under these circumstances will the product measure up to the working standards of quality so carefully determined and clearly described? Certainly not, unless means are provided for measuring the quality of the work as it is made, together with the necessary organization for seeing that the work is held to standard within economical bounds.

To control quality so as to realize the working standards as nearly as may be, requires both logical thinking and masterly management. The seriousness of the task increases rapidly with the degree of accuracy or grade of quality required and with the complexity of the product. It is made still more difficult if the manufacturing operations are conducted on a large scale, for this is one of the things which becomes magnified in the large plant in a ratio that increases much more rapidly than does the size of the plant itself.[1] There are certain problems which are solved in the small shop with comparative ease, because of the directness with which they can be seen and the simplicity and promptness with which they can be handled; yet these same problems become serious difficulties in the large plant.

When we are surrounding the work as it flows through the factory with an environment that makes for quality production, someone must exercise the duty of viewing the work closely and critically so as to ascertain the quality, detect the errors, and present them to the attention of the proper persons in such a way as to have the work brought up to standard. This function of carefully scrutinizing the work as it progresses through the various stages of manufacture, and of pointing out the unsatisfactory work, is the principal purpose of inspection; and by "inspection" is meant inspection conducted as a function of the factory organization, and not by some outside organization employed by the purchaser.

The Instrument for Measuring and Controlling

One of the first things brought to light by a study of the problem of measuring the quality of work and establishing the necessary organization to secure and maintain this quality is the fact that inspection is, first, the instrument for quality measurement, and second, that it is a powerful factor in quality control. It is like the keystone of the arch.

---

[1] "Production as Affected by Size of Plant," by G. S. Radford, *Management Engineering*, Aug. 1921.

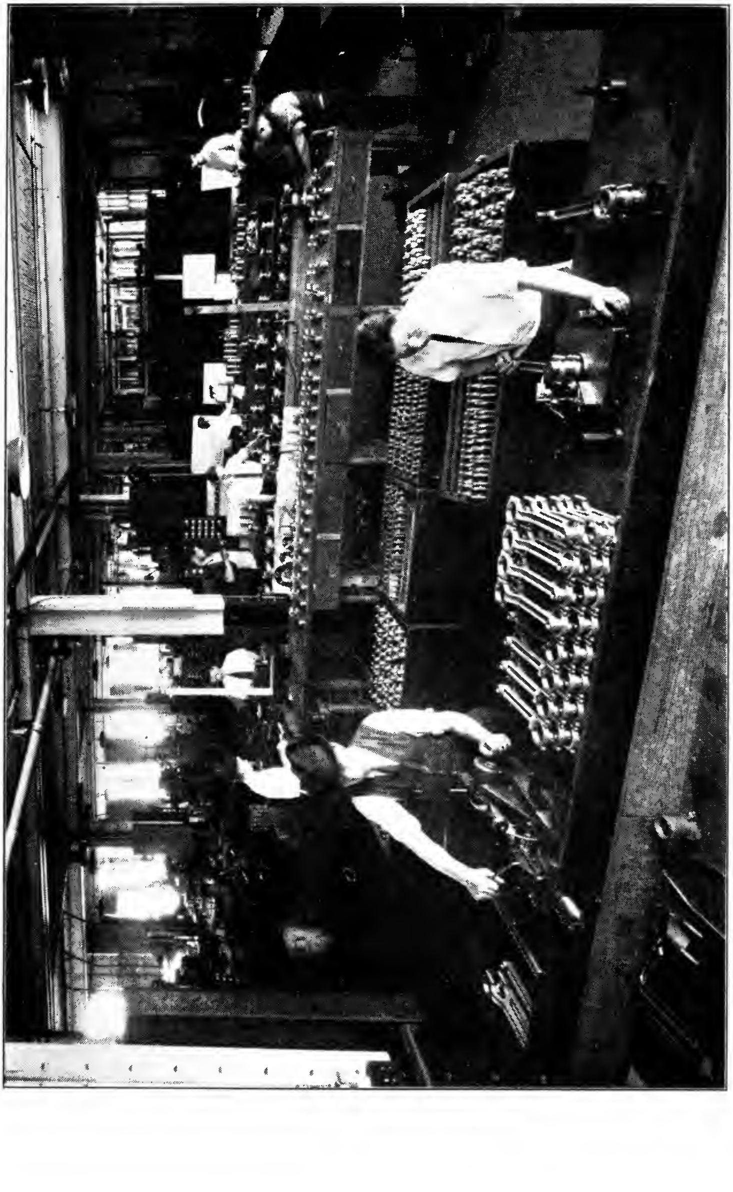


Figure 6. A Centralized Inspection Point in the Lincoln Motor Company's Plant

You can get along without it, but the supporting false work which must be left to take its place is crude, clumsy, less effective, and more costly.

Its relation to quality is indicated by this thought. Quality may be likened to a globule of mercury—it is always tending to slip away. You can hold mercury in a given position or on a particular line with a certain degree of success without resorting to control. In the same way it is possible to secure quality of a certain kind and degree without inspection, but in the factories which stand as leaders in their respective lines there is always a well-developed, scrupulously maintained inspection service.

Convincing the Management

Every chief inspector must first realize, with entire conviction, that inspection is a necessary step in the great process of manufacture. Then it becomes his painful duty to get this idea across to the management. The latter task is usually difficult. The inspector is responsible for quality to a very great extent; he is the management's guardian against spoilage and waste; and when quality slips he is conveniently at hand to receive the blame. In many plants where his true relationship to quality is not clearly understood, this latter "duty" of receiving the blame for errors in work constitutes a large part of his daily job.

That such an attitude toward the inspector is untenable is proved by a moment's reflection on the fact that the inspector never puts his hand to the work except to look it over or to measure it. The inspector enforces quality by refusing to accept poor work, but this act of rejection is passive as regards enforcing the production of good work. The quality or lack of it must necessarily be worked into the material by the production department which controls production processes. How then can we blame the inspector for lack of quality? In this regard his duty is complete when he passes upon the quality characteristics of the goods and reports his findings. It may be noted parenthetically that this very fact is one of the reasons why quality cannot be placed under control until every department of the factory has been reviewed from the quality standpoint and brought into proper alignment and co-ordination.

Growing Importance of Inspection

The kind of inspection, the manner of its application, and the extent to which it is used are conditioned, of course, by the circumstances in each case. One must first determine what it is desired to accomplish by inspection and then consider the several different ways in which the desired result may be obtained, always with a view to selecting the most economical method. There is such a thing as too much inspection as well as too little, but a proper degree of inspection is always an economy because it stops leaks by the early detection of errors and thus prevents unnecessary loss. From a strictly business standpoint it is justified as an insurance of that part of "good-will" which is cultivated and retained by the delivery of goods made to a definite standard.

The evolution of inspection is both interesting and illuminating. In early factory practice (and, for that matter, in many plants today) inspection involved merely looking at the work. Dimensions were scant or full. Then through a gradual development, following in step with the attainment of greater accuracy in the mechanical arts which was made possible by more accurate measuring devices and better machinery, we began to measure in hundreths of an inch, then thousandths, then ten-thousandths, and now in hundred-thousandths, if necessary. Such progress in material ways calls for adequate and similar adjustments in organization; but the development of an inspection force within the factory organization, and hence paid for by the manufacturer, has not kept pace with the technique of manufacturing except in a rather limited way.

The fact is that inspection in the past has been applied in many cases by the purchaser, and often, especially in government work, in a manner to give rise to the feeling in the manufacturer's mind that inspection should be regarded as a necessary evil. Without question, a purchaser's inspector can cause ruinous conditions in any factory, especially if there is a lack of practical control, and if the specifications and other data under which the work is being performed are inexact or conflicting.

Inspection Often a Necessity, Always an Economy

It is generally recognized that it is a paying proposition for the large purchaser of materials to provide his own inspection force. Yet it is even more to the interest of the manufacturer to establish an inspection organization for himself. He gains all the advantages secured by the purchaser and many more besides through his ability to control and direct the activities of his own inspecting force into the channels most useful to him.

If you who are neither an architect nor a builder are about to erect an expensive house or construct a new factory building, do you inspect it yourself or do you employ someone who is competent? Of course you adopt the latter method and consider the money expended for supervising the inspection well spent. You do this no matter how trustworthy or careful or reputable your builder may be. Now consider carefully why this expenditure is a good business proposition, and then apply the reasoning to your own factory. You cannot make everything yourself, nor even view it in a cursory way; nor can your superintendents and foremen, for they are occupied with many other things principally connected with human relations and quantity of output. The average workman himself is least of all concerned with safeguarding the quality of your product, unless you make special provision to keep his work up to standard. In many cases nowadays, he has not the ability, of his own motion, to furnish the result you desire. Thus inspection becomes, oftentimes, a necessity. In any event an inspection service properly adjusted to the needs of the case, is an economy as well.

Comparatively few factories had their own inspection services prior to the war, but many of those operating under war contracts were forced to provide such service as a matter of protection and have learned thereby its value. It is to be hoped that much of the old and prejudiced attitude toward factory inspection as an expense to be avoided if possible, has disappeared; and that there will be realized the large return in both quality progress and decreased costs which are made possible only through the application of a proper system of factory inspection, and not otherwise.

Need of Intensive Study of Inspection

Inspection, to be sure, is only a part of the control of quality, but it is an essential part. For quality can be controlled properly only through a factory inspection service—adequately organized and applied with an appreciative understanding of the philosophy behind it.

Inspection is being more generally used than ever before, but is its function thoroughly understood? At present there is evidence that inspection methods in many plants are being overhauled to meet the oncoming and more critical demands of commerce. In some cases, inspection depart-

Figure 7. Tool and Gage Inspection at the Packard Motor Car Company's Factory

ments as such are being provided for the first time, and existing inspection is being brought into line with the best modern practice, for closer acquaintance with a good inspection service is bound to prove its sound business value, not only in raising quality but also in lowering costs and increasing output.

In view of this situation one might expect to find considerable attention being paid to the theory and practice of inspection, but the engineering profession has been slow to give it the same serious study that it has shown in other lines of work. For example, the last ten years have witnessed the intensive development of a literature concerning itself, from the standpoint of the engineer-executive, with the business of management in all its details. This literature is full of references to standards of quantity of output per man per day, and contains countless methods, schemes, and devices for increasing output and decreasing cost, all by the route of laying stress primarily on quantity. Much is said about how to determine the proper standards for quantities of output under given conditions. Much more is said about how to attain these standards of quantity through all the varied means management engineering has developed; for while it is a difficult task to determine just what the standard quantity of output should be; by the same token it is much more difficult to put these standards into effect; just as it is harder to keep trains running on schedule than it is to lay out the timetable.

Study of Theory Needed

But with all this intensive study of industry, how little attention is paid to the discussion of how to fix upon and realize standards of quality in production, and the relation of inspection to this problem! The Society of Industrial Engineers recently, and very properly, defined the activities under which candidates for membership shall qualify.[2] Some twenty industrial subjects were listed. An examination of the subjects so set forth indicates that no mention is made of inspection, and that little if any consideration has been devoted to quality control in production—certainly nothing like the attention devoted to questions principally affecting quantity of output. This, moreover, is merely typical of the general professional attitude, although this is not the first time that something has been used practically, before the underlying theory has been investigated. Planning was always done in effect, but it was not performed with the greatest economy until the engineer separated it out of manufacturing as a whole, for individual and exhaustive inquiry.

Can we afford in this instance, to neglect so important a matter any longer, especially in the face of existing conditions? The answer would seem to be strongly in the negative. The size of modern inspection departments alone would warrant careful investigation of the subject. In many well-established plants 5 per cent of the entire working force is employed in the inspection department and frequently the percentage is considerably higher. In many cases it could be made higher with advantage, until quality is under such control that the amount of inspection can be reduced.

Further, the sphere of influence of the inspection service is far greater than its numerical relationship, for it reaches into every department and touches all the detailed factory operations having to do with creating and maintaining quality standards. These facts alone, it is submitted, should indicate the need for careful study of the theory and practice of inspection, by all who have to do with the management of industry.

---

[2] *Industrial Management*, Jan. 1920, p. 55.

Functions and Limits of Inspection

If one is going duck-hunting it is just as well to take along a shot gun, but having the gun does not mean that the hunter will return with a bag of ducks. Unhappily this truism holds for many things besides duck-hunting and leads to frequent misunderstanding of the inspector's function. It has its limitations like everything else. Its purpose is to measure quality and in this and in other ways to assist in quality control; but it does not create quality.

In this preliminary study of the need of inspection it should be noted finally that inspection itself is not a fixed and definite function or process except as regards the principles which are involved. In contrast to being fixed, it is very flexible and may be applied in many different ways.

CHAPTER IV

THE TYPES OF INSPECTION

Conformity with Special Factory Situation

The factory is guided toward production in accordance with the working standards, by inspection, which measures quality, applies discriminating judgment in close cases, and in short forms an environment that continually sorts out defective work while allowing satisfactory work to proceed. Naturally the kind of inspection most suitable for a particular situation depends on the character of the work, the standards of quality, the skill of the workmen, and similar matters relating to the given manufacturing conditions and circumstances. The thoroughness of inspection varies from a casual viewing of samples taken at random in the shop, up to the analysis, testing, or careful measurement in separate inspection rooms, of each part after each mechanical operation. In large plants engaged on high-grade, interchangeable work, almost every one of the many possible kinds of inspection will be needed at some stage in the process of manufacture.

Material Inspection

Little need be said of the inspection of raw materials. The development of highly standardized material specifications has been made possible through a previous and progressive development in applied physics and chemistry. The methods of the physical and chemical laboratories which originated the data for the standard specifications in the first place, are thus available in turn for testing and analyzing the materials themselves. It is most unusual to find a plant of even moderate capacity without some sort of laboratory in which samples of each lot of raw material received by the stores department are carefully inspected before being passed for issue to the factory.

A chemical works with a single product as simple and cheap as silicate of soda has its own laboratory for inspecting both raw materials and finished product. A flour mill using the method of mixtures to secure a definite quality standard, measures in the laboratory the food values of each lot of grain, in order to secure data for the proper balancing of its output. A paper mill makes microscopical examination of fibers. In a great metal-working plant we find an assemblage of thoroughly equipped laboratories—chemical, physical, and metallurgical. So it goes throughout the great range of the arts. Even small shops may avail themselves of facilities for inspection of materials by patronizing the commercial testing laboratories to be found in every important manufacturing center.

When the local conditions are such that there seems to be no method or apparatus already in existence for this important work, the scientist should be called upon to work out the problem. There is no reason today why means should not be developed to meet almost any requirement for inspecting and grading material.

Office Inspection

It is common practice, also, to provide an inspection service in the drafting-room, especially in the tool-designing section, so that the work of the "detailers" and other subordinate draftsmen is carefully gone over by the "checkers." It is perhaps not too far from our subject to note that the application of similar methods has been carried into large general offices in the form of an inspection of outgoing mail. When department heads sign outgoing mail originating in their departments, it is not unusual to find a further checking up, through carbon copies of such mail being sent to the office of the general manager.

Tool Inspection

Factory inspection first appears in the tool-room. The value of a careful inspection of all special tools, fixtures, jigs, and gages, is quite evident, whether they are made in the factory's tool-room or purchased outside. If the tools are not correct, nothing is surer than that the work will not be correct. As an additional check on the tools, even if the work is simple, it is good practice in quantity production to make an inspection of the first piece (and the last) produced by a new machine tool set-up. A theoretically correct tool

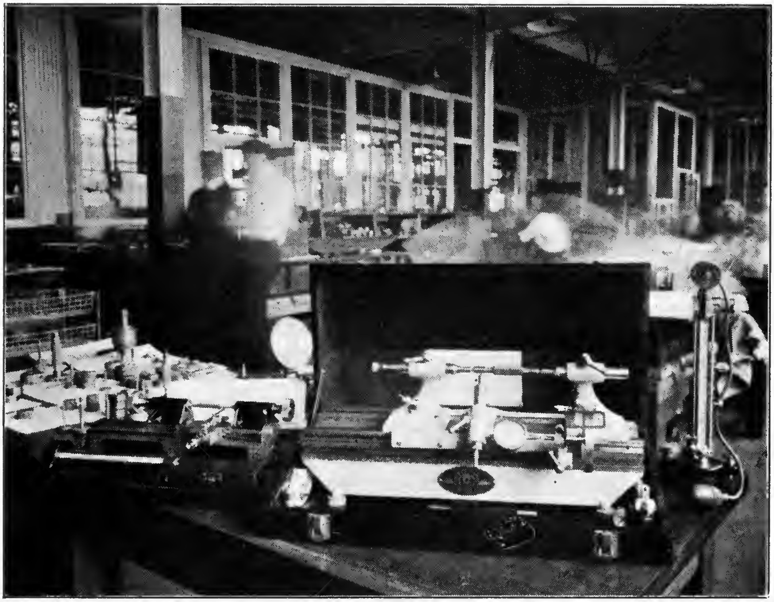


Figure 8. Some of the Special Equipment of the Tool- and Gage-Checking Room—Lincoln Motor Company

West and Dodge lead tester and Shore scleroscope in foreground.

may not produce correct work, due to some peculiar interrelation between the tool and the way it is applied to the stock. In many cases this *first-piece inspection* may be performed by the mechanic who sets up the machine. This duty sometimes falls to a special inspection service, however, if such a body exists.

The subsequent periodic inspection of tools, and in fact of all manufacturing equipment, should be provided for systematically, so that nothing will be overlooked, special attention being given to the points where wear is rapid or likely to cause the most trouble. Where gages are in use, as in small interchangeable work, or when specially accurate measuring instruments are used, as on close work of a size beyond the accuracy of special gages or of too small a quantity to justify the cost of gages, then, of course, the greatest attention must be given to verifying gages or instruments. The questions which arise in gage-checking involve an individual practice, and therefore will be dealt with in a separate chapter.

Process Inspection

Coming now to the inspection of work in process, the first question to decide is *where* the inspection is to be made. This ordinarily involves either choosing between two types of inspection which are fairly well known under the respective names of "floor-inspection" and "central inspection" or using some combination of the two systems. Floor-inspection means inspecting work at the machine or near it, while central inspection is the term used to designate the system under which the work to be inspected is carried to special spaces or rooms devoted entirely to inspection purposes.

Central inspection involves the physical separation of inspection from production, but it may exist in any one of several forms. Convenience rarely permits all inspection to be centralized in one place for the entire factory, so that the ordinary method of using central inspection involves setting aside a place for it in one or more convenient locations in each shop.

Floor-inspection may vary from a sort of patrolling supervision which scans the work at the machines, up to the taking of very careful measurements and minutely scrutinizing the work. It begins to merge into central inspection when the inspector is furnished with a special inspection bench or similar station located near the machines whose work he inspects. The inspection point may be located between machines in the line of flow of the work, just as if it were a machine itself. If the separation between inspection and production is clearly defined, we have a distributed form of central inspection. In its most highly developed form central inspection implies that all of the work of inspection in a shop is *centralized* in a separate place, usually a room or enclosure, to which the work is brought.

Advantages of Centralized Inspection

The most evident difference between the two types of inspection is that, in one case the inspector goes to the work, while in the other case the work is brought to the inspector. But this apparent difference is by no means the greatest dissimilarity. Centralized inspection has characteristics differing markedly in many other and more important ways from inspection that is scattered by reason of being done on the site of the work. Central inspection, in general, permits the use of a less degree of experience and skill than floor-inspection, because the supervision of the work of the individual inspector is made easier. Frequently division of the labor of inspection is possible, and economy of inspection results.

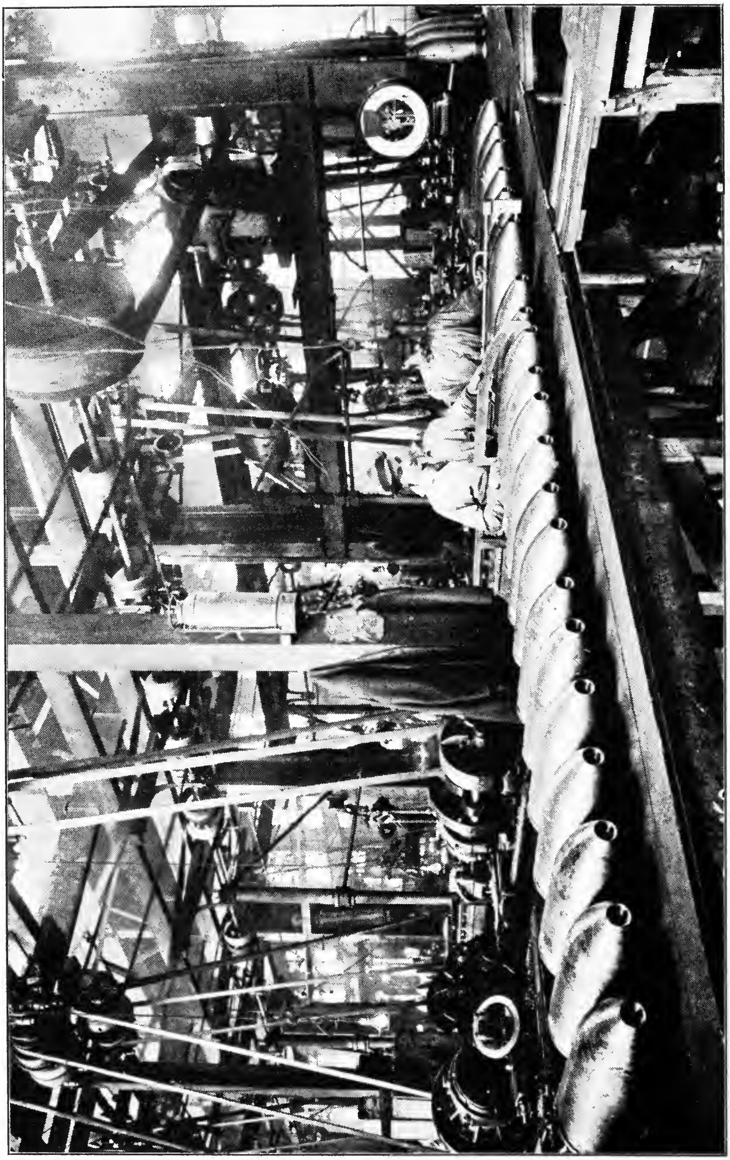


Figure 9. Inspection of 9.2-inch Shells—American Locomotive Company

Similarly the work of inspecting may be performed more thoroughly, as there is less likelihood of interferences. More important still, the inspector and the producer are not able to "get together" to anything like the extent possible in floor-inspection. Accordingly it is much easier to control quality to definite standards, as well as to obtain a better control of the flow of work by means of central inspection, as will be indicated in more detail in Chapter VIII.

Highly centralized inspection is the ideal type, for it is the specialization of inspection carried to the limit. Its use is not justified when parts are large or relatively few in number, nor when the production work requires such skilful mechanics that detailed inspection of their work is not required. With massive work, of course, the inspection must be made at the place where the work is performed. As the size of the component parts of the work decreases, and transporting them becomes less difficult, a stage is reached when central inspection in some form is both possible and desirable. For example, the last or final inspection of large automotive engine parts would naturally be made in a separate room or space, through which the parts in question pass after being finished in the shops where they are made. In high-grade work of the same class it is good practice to remove these parts to the inspection room after each of a few operations in the course of manufacture. In this case the operations selected for central inspection are those in which close and complex work is performed, and whose influence upon succeeding operations may be very serious in accumulating errors.

When many operations are used in making one part in quantity it is usually better to reinforce central inspection by a floor-inspection in sufficient quantity to locate costly errors more quickly.

Inspection Combined with Remedy of Defects

Inspection takes another form in many manufacturing processes where it is expedient to merge it with production. Ordinarily this involves an inspection for defects in combination with the repair of the defects by the inspector. In the manufacture of fabrics, for example, the work may be rerolled on perches under the eye of an operator who repairs broken threads and similar defects as he finds them. A very simple case of allied nature is to be found in the testing of tanks, or water-tight compartments in ships. The portion of the structure to be tested is subjected to water pressure, inspected for leaks and "weeps," and the leaking rivets and seams caulked.

Use of Special Mechanical Devices

Inspection of large quantities of small pieces is sometimes done economically by the use of special machines. In this kind of inspection, the operation is best considered as a part of the manufacture of the part. Strictly speaking, of course, no work is done on the part, inasmuch as the part is not changed by the process of inspection, although the quality of the factory output is improved thereby. The making of rifle balls and small cartridge cases offers examples of this sort. In one plant rifle bullets were carried on an endless belt (originally designed as a bean-sorting machine) before a number of inspectors, so that obviously defective ones might be detected easily and removed quickly. Similarly, cartridge shells with surface defects are more readily located by the use of special machines which roll them before the inspector's eyes in an endless procession. Scrutiny is made more certain by mirrors suitably placed in the machine, to show all parts of each shell as it is rolled by. The opportunity for making an inspection operation more effective and less costly is often revealed when consideration is given to developing mechanical devices to assist in the work of inspection.

The Amount or Quantity of Inspection

Intimately associated with the question as to the kind of inspection to be used, is the determination of *how much inspection*—a question that must be settled in the light of economy, for evidently we should provide the least inspection which will accomplish the purpose.

The necessary amount will vary, of course, with the progress that has been made in the particular factory toward a better control of quality. If special attention is paid to quality, the amount of inspection can be reduced gradually. When this has been done, however, the inspection should be reconstituted before the manufacture of a radically new model is undertaken, for reasons that would not seem to require detailing.

In the first place it should be realized that the inspection department must use judgment—"horse sense"—without that it is only too possible for the department to tie the factory up tight. The abuse of inspection through having too many inspectors represents, of course, a dead loss from the direct cost of inspection. It is chiefly to be feared, however, because of the deadening influence on production of the attempt to get too large a percentage of the work up to standard. Incidentally this error will illustrate the value of a clear appreciation of inspection's function in the control of quality.

Quality, as we have seen, is a variable. It is not practicable, therefore, to conduct manufacturing operations in such a way as to produce nothing but good work, i.e., work that is in accordance with the specified standards. Inevitably there will be some bad work. If inspection is applied with a view to reducing the amount of bad work to the absolute minimum, the effect will be to slow down the quantity of production to such an extent as to increase costs out of all proportion to the value of the few parts that might otherwise have become scrap. As a matter of economy, to do a certain amount of unsatisfactory work is practically necessary, paradoxical as this might seem on first thought.

The Danger of Becoming "Fussy"

In many cases where the standard is difficult to set exactly, and judgment must enter to a large extent, as in the case of inspecting for finish and surface defects, there is a fertile field for trouble of this sort. A factory manager, who was a man of unusually wide experience in many lines of interchangeable manufacturing and an alert and discerning observer as well, once said with reference to a case of this sort, "If you pass a hundred parts through the hands of a hundred (or even fewer) inspectors, not a single part will escape rejection. Every piece will be rejected by at least one inspector."

This point of view was vindicated soon afterward in the following manner: A large quantity of sword bayonet blades were rejected for the alleged defect of not being straight, especially near the pointed end. Perfect straightness was, of course, impossible. The permissible variations from perfect straightness were purely a matter of judgment. Inasmuch as the blade was flexible, was of variable thickness, and curved both lengthwise and transversely, it had not been practicable to design a satisfactory gage, or other checking instrument. It should be said, by the way, that the purchaser's chief inspector was very competent, reasonable, and fair minded. The working inspectors under his supervision were unusually well controlled. He had personally examined several blades and rejected the lot of several thousand. On the manufacturer's side, however, the same blades had been passed by a carefully trained corps of inspectors who were in the factory's employ. Their foreman had reinspected a quantity of these blades, and passed them all.

Here was a large plant running under pressure for production, with several days output stalled in the middle of the road because the purchaser said the work was wrong, while the maker insisted that it was right. The purchaser, of course, held the whip-hand, and it was of no avail to plead that there was little military or other practical advantage in such a degree of straightness as was required for these blades. The problem was one of finding the quickest way out of an embarrassing impasse.

The cure for the difficulty, however, was simple. The purchaser's inspector was told that the factory management felt the standard had been stiffened by imperceptible increments until it had become impracticable. It was requested therefore that he examine 20 blades which were presented for his inspection, and designate those that he considered straight.

The 20 blades in question were obtained in this way—each of five of the company's best blade inspectors were asked to select, from the rejected lot, 10 blades that he knew were straight and 10 that he felt equally sure were not quite straight. In this way there were then accumulated 50 "straight" blades and 50 "crooked" ones. A committee consisting of three of the factory inspection department's expert supervisors then agreed upon 10 blades from each lot of 50, and marked them accordingly with secret marks, 10 as "straight" and 10 as "crooked."

The result was that the purchaser's chief inspector passed 19 of the blades and rejected the twentieth for a surface defect not in any way connected with straightness. Of course, he was promptly told the whole story, and in a fine spirit of fair play he immediately ordered the entire lot inspected and accepted nearly all.

This episode is related here because it exemplifies so clearly a number of inspection phenomena of the sort that must be taken account of, in determining what is to be avoided.

Unnecessary Inspection

Another thing which requires attention is the elimination of unnecessary inspection. Many operations require no inspection whatever, or else the inspection of work after a given operation may cover also the work of several preceding operations. Similarly, and especially in the case of floor-inspection, if the first several parts inspected are found to be right, the inspection of the rest of the lot may be waived. The procedure is safer, however, if a few of the last parts made are inspected in the same way.

Other parts may be of such minor importance and slight cost as to make it advisable to drop the inspection in favor of the more certain test of their use in the assembling department. This is true of most small screws and similar minor screw machine products.

The Percentage of Inspection

As to the quantity or amount of inspection that should be used and when it is to be applied, a safe general rule is this: Use 100 per cent inspection (i.e., the inspection of every piece in a lot as regards all essential qualities of the standard) when the work done largely affects other work that is to follow, as in the case of drawings, tool-room output, gages, etc., or when any part may unduly affect the integrity of the entire assembly. Furthermore, apply 100 per cent inspection at points where an operation is subject to serious errors, or when one operation may control or markedly influence many subsequent operations.

Figure 10. Rough Stock Inspection—Packard Motor Car Company

Sampling—The Theory

If less than 100 per cent inspection is used, we are brought to the consideration of sampling. For the most part, inspection is made possible economically by applying the theory of this method. This involves the assumption that a piece selected at random probably is representative of the rest of the lot, or that a portion of a quantity of some substance probably is like the remainder. The word "probably" here is to be noted. It is sound theory to assume that if something happens under given conditions, exactly the same thing always will happen again under the identical conditions, which is one way of stating the law of similarity in nature. In manufacturing, however, we are not dealing with a theory, but rather with a very practical condition of things, which is changing and varying all the time.

Every portion of an ingot of metal, for example, differs from every other portion. This is so well recognized in the inspection of raw materials that very exact practices have been evolved for taking samples or "drillings" of metals for analysis; also for selecting samples of coal and similar substances.

No such definite practice is practicable for sampling in shop inspection. The best we can do is to assume, in the case of *first-part inspection*, that if the first part made, after the tools are set up, is satisfactory, the following parts probably will be right; or to assume likewise that one part, taken at random from a lot of the same parts, probably will exemplify the condition of all of them. This, however, is not necessarily true. We should remember that one of the most common fallacies of reasoning, well known to students of logic, is that of arguing from a special case to a general conclusion.

In sampling, this fallacy takes a peculiar form. You may say to yourself, for example, "This bolt which I hold in my hand, is well and correctly made. Therefore all the bolts in the box from which I took this one are correct." If, on the other hand, it happens that the bolt is not correct, you are not nearly so willing or quick to conclude that all the bolts are not correct, so you select one or two more from the box; and if they are correct, you promptly assume, as at first, that all the rest are correct, although you are not quite so certain.

Such optimism may perhaps show a commendable spirit, but the plain fact remains that your conclusion may not be true, although it probably is. It is usually well to give everyone and everything the benefit of the doubt. It might be said when a conclusion based upon sampling is not true, that the case in hand is exceptional and that "the exception proves the rule," but the inference is wrong. This is a very old expression in which the word "proves" is used in its original sense, as in proving a gun. In reality the exceptional case tests the rule.

Safeguards for Sampling

The use of sampling, especially in important and costly work, must be surrounded and reinforced with certain independent safeguards. This makes possible the great economy which sampling permits, while protecting the conclusions from most of the probable errors, provided hasty deductions are avoided.

Among such safeguards are the following:

1. Mention has been made of the desirability of having the first and last few parts from each machine set-up checked by the tool-setter or taken to the inspector for checking. This can be extended by a continuous, random floor-inspection or patrolling supervision.

2. Parts may be taken at random from current product

and tried by actual assembly, thus discounting the danger due to the wait in shops and in component stores.

3. Parts in stores may be similarly checked at random from time to time.

4. The two-bin principle should be applied wherever work is piled up, either in process, or in stores, in order to insure an uninterrupted flow of work. (See Chapter VIII.)

5. A sort of blind, double inspection can be tried occasionally, in order to check a doubtful inspection point, by sending the same parts through the same inspector twice without notifying the inspector. The practice often gives a valuable insight as to what is really going on.

6. Each day a good part and a reject may be collected at random at each inspection point and carried to the central gage-checking point for independent verifying.

7. One or two pieces may be quickly routed through all operations, being carried from machine to machine by the foreman inspector so as to discount the delays between operations. As each operation requires, roughly, a day for a lot of parts to pass it, a part requiring fifty operations will ordinarily take fifty days to pass through the shop. A "quick routed test part" or "pilot part," which can be put through in a day, will be found an excellent device for detecting trouble under certain circumstances.

Other Economies in Inspection

The cost of inspection may be reduced in a direct way by combining it with other duties, but any work so added to the duties of the inspector should preferably be of the sort that is best separated from actual production. The exception is in the case of a combination of inspecting and repairing, as referred to earlier in this chapter.

It is not unusual to have the inspector certify as to the amount of work done by each workman whose work he inspects. It is believed that this combination of duties should be more extensively used, especially in steel construction and similar large outside work. The employment of higher grade men for both purposes is permitted by the combination of duties.

In a highly developed central-inspection system the counting of work done is handled by the inspector as a matter of course. In addition, the collection of useful information, the custody of work in process, dispatching the same, and otherwise assisting the shop, are all things inspection is specially suited to take charge of. Other services, more indirect, which may be allocated to the inspection department with profit will be mentioned later on.

CHAPTER V

THE INSPECTION DEPARTMENT IN THE ORGANIZATION

Vital Importance of Inspection

Effective use of inspection necessarily is predicated upon its recognition and elevation to a point where it is a real factor in management.

The importance of inspection should be recognized in a practical and concrete way by assigning to it a place in the organization commensurate with the vital duty of safeguarding the quality of the product, whatever that may happen to be. When this has been done it is possible to give quality the attention it deserves. For it seems beyond question that the most prominent feature in the progress of factory practice in the future should be the greater and more general appreciation of the possibilities of quality control, the development of refinements in its application, and the consequent attainment of both higher standards of quality and greater fidelity to such standards, with a decided gain in economy.

The last few years have witnessed the evolution of a science of management and its translation into an engineering practice covering planning in its widest sense, the determination of standards of output, and the methods of handling a complexity of human relations, rapidly changing under the reaction of labor to the new situations introduced into industry. The machinery thus created and developed will now be used to accelerate the progress of industrial management, with care for quality more and more as the guiding principle. It is but in the natural course of events that the greater mechanical accuracy made more generally possible through development under stress of war time, together with the experience of manufacturers during that period, will now result in an intensive application of these new forces in the betterment of the work of the industrial world. The reaction on labor alone will be worth the effort. As stated, this attitude on the part of managers leads toward better inspection, which in turn will have to be preceded by a deeper understanding of the inspection function.

Every student of industrial management must recognize that the late Dr. Frederick W. Taylor made a remarkably clear and powerful analysis of the elements of manufacturing, although he may not entirely accept the Taylor methods for handling the elements thus disclosed. It is therefore interesting to note that Dr. Taylor's analysis of the duties of foremen, even in ordinary machine shop practice, resulted in the separating out of inspection, as a function calling for an independent foreman. In other words, he recognized the necessity for an inspector or quality boss, just as he provided for a "speed boss" to look out for quantity, and a planner to do the thinking and prearranging necessary to co-ordinate subsequent effort. This analysis is evidence of a realization that someone should attend to inspection, and that so important a duty is best carried out independently and therefore with authority.

The Engineering Department

Suppose that we analyze some great manufacturing enterprise into its most general terms. Our problem is to make, let us say, a large number of engines, or motors, or guns, or other articles assembled from component parts which must be made to rather definite standards of accuracy and finish. What the industry happens to be makes little difference, because all involve the application of labor to an

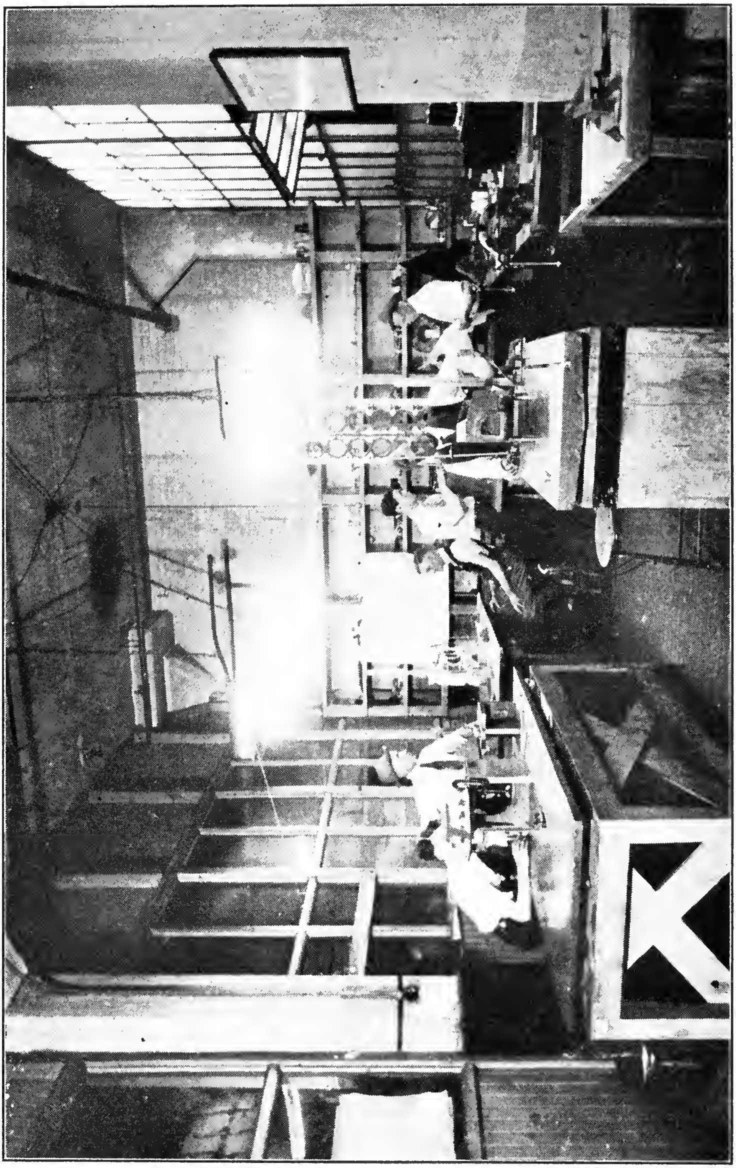


Figure 11. Sample Checking Room—Packard Motor Car Company

assemblage of raw materials. Perhaps the first large duty or group of duties that we would segregate in our minds would be the *engineering* group, whose duty is to make plans for something that is to be done in the future, and to concentrate on the practical and intensive application of anticipatory imagination.

This work is warranted because it reduces the cost of production through describing exactly what is to be done and thus avoiding waste of effort on the shop's part in doing things that are not wanted. This passion for visualizing work before it is performed and preparing plans showing what should be done, is resulting in the transfer of more and more work from the domain of "trial and error" in the actual fabrication of the work, to its more scientific treatment in the engineering department. All doubtful questions are settled as a part of *preparation* for production and before the latter begins, and a sharp line is drawn between experimental or research work and the business of making things. Vexatious and costly delays are confined to the laboratory and the engineering office in order that production may flow on without interruption from such things.

Thus the designing engineer works out his plans on paper, describing in great detail what the shops are to make; the production engineer makes plans on paper covering the things to be done to obtain greater productive efficiency, and so on. None of this effort is expended in doing the physical work of production, but it does result in a much greater output from the whole organization. It pays amazingly. It is cheaper to correct mistakes on paper before they have been worked into steel.

The Production Department

Continuing the analysis of manufacturing, probably the next great function that will attract attention, if our minds are proceeding in an orderly manner, is that of production, which has the duty of applying human effort to the execution of the plans made by the engineering group. The latter's work is now subjected to the acid test—it is convertible into action, or it is not.

The time element, it may be noted, is significant here, for production is most seriously engaged with meeting the pressing necessities of the present, just as engineering deals principally with the future. Production solves its problems as it meets them in the actual physical performance of manufacturing, while the machinery is running—engineering solves just as many problems as it can mentally visualize and work out on paper before any wheels are turned.

The Inspection Department

It would seem that the next logical step in this process of analysis must reveal *inspection*, which has the duty of passing upon the results of *production after* the latter has endeavored to carry out the plans of *engineering*. Inspection work is retrospective. It is performed after work has been done.

Each of these three main groups of functions calls for special experience and for its own characteristic and peculiar attitude of mind. Engineering and inspection are the primary contributories of production, while all other factory activities are secondary in the sense of being merely general service duties.

A Parallel with Governmental Organization

It is not difficult to find a parallel case in a field of administration much older and wider than the industrial organization. The experience of men in evolving governments for social administration has developed the necessity for three main functions, which assure stability through mutual independence of authority in action, but with interdependence and mutual helpfulness through balancing each other, just as there must be three points of support for stable equilibrium. The three governmental functions referred to are, of course, the legislative, executive, and judicial. It is easy to trace their correspondence with engineering, production, and inspection, respectively, which have the same general relationships. Inspection is judicial because it is measurement *plus judgment.* If it were easy to distinguish between the right and the wrong execution of either laws or plans, there would be little need of applying independent judgment, but in very many cases it is not easy. In the one as in the other, in the factory as in civil procedure, the best results demand for their attainment that the final application of judgment be made with authority subordinate only to the supreme controller of all three functions.

Inspection's Relation to Engineering and Production

If there is any one thing that the management of a large industrial enterprise needs in its business, it is the unvarnished truth about what is really going on in the plant—not the reports from an espionage system, but the plain facts brought frankly into the open as to where errors are most frequently made, the extent to which they occur, and the causes of production choke-points. It is just as useful to know in detail what has been done as the work proceeds, as it is to know what you are going to try to do before you begin. If an engineer-executive has the facts he usually can cure the trouble. Yet ordinarily this information is the hardest to obtain, either promptly or accurately. The chance of getting it is much better, and under good management it is assured, if there is competent personnel in an unbiased position to observe, locate, and report the difficulties as they appear. This is a duty that the inspection department is best able to perform by reason of its freedom from responsibility for anything except passing upon quality. Here is another reason why the inspection department should be subordinate only to the management. There is a great value in having inspection in what might be termed, to follow the above analogy, a judicial position; but that value is seriously abridged if inspection is subordinate to either the engineering department or the production department.

Failure to obtain both the standard of quality and the scheduled output will occur from faulty engineering or from a failure of the production department to carry out properly the engineering plans. If inspection is subordinate to engineering, the faults of engineering will not come to light when they should. That is only human—but it is not scientific. Worse still, if inspection is subordinate to production, not only the latter's faults will be concealed but also there will be a strong tendency to skimp quality. When once quality is allowed to slip, costly losses will soon result in fact, although frequently not detected.

Purpose Help—Not Mere Criticism

When, however, inspection is raised to its proper position and is assigned the important duty of bringing the facts to the surface, it should be clearly shown to the other departments that the purpose is one of mutual helpfulness and service, and not one of destructive criticism. Facts are necessary to solve problems. If they are presented in a spirit of helping to conquer difficulties, surely no one can take offense.

Quality is a variable. Everyone makes mistakes. It is immaterial who is to blame for them. It is folly to be forever in search of a "goat" when things go wrong; the precious time thus spent should be used more constructively. It is essential merely that the mistakes be promptly located, recognized, and cured before loss piles up. The group of workers in the best position to do this are those in the least prejudiced situation and hence best able to see things as they really are. There can be but one conclusion, namely that the inspection department should perform this service. But it cannot do that efficiently if its hands are tied.

The Real versus the Apparent Organization

In the majority of factories, especially before the war, factory inspection received little recognition. Even now, in very few factories indeed is it given a chance to demonstrate its greatest possibilities for service. In nearly all plants, however, even those which are comparatively small, the latent possibilities of inspection can be developed if the real organization is made more nearly like the apparent organization. The difference between the two is often considerable.

What may be termed the "apparent" organization is that shown by the assignment of duties in the form of an organization chart, or perhaps by the titles given to the various department heads and their assistants. Often, however, the actual work is not carried out in accordance with the apparent organization. Certain individuals will be found to be exerting a far greater influence than their assigned positions would seem to indicate. If the organization chart were redrawn to show the true way in which duties are carried out rather than how they are assigned in theory, and to indicate clearly a relationship between individuals in accordance with their proportionate contribution to the enterprise, then it would indicate the *real* organization.

If an organization is analyzed with this test in mind, the discovery will probably be made that the inspection department's contribution is greater than the apparent organization would seem to indicate. If it is exalted to a position

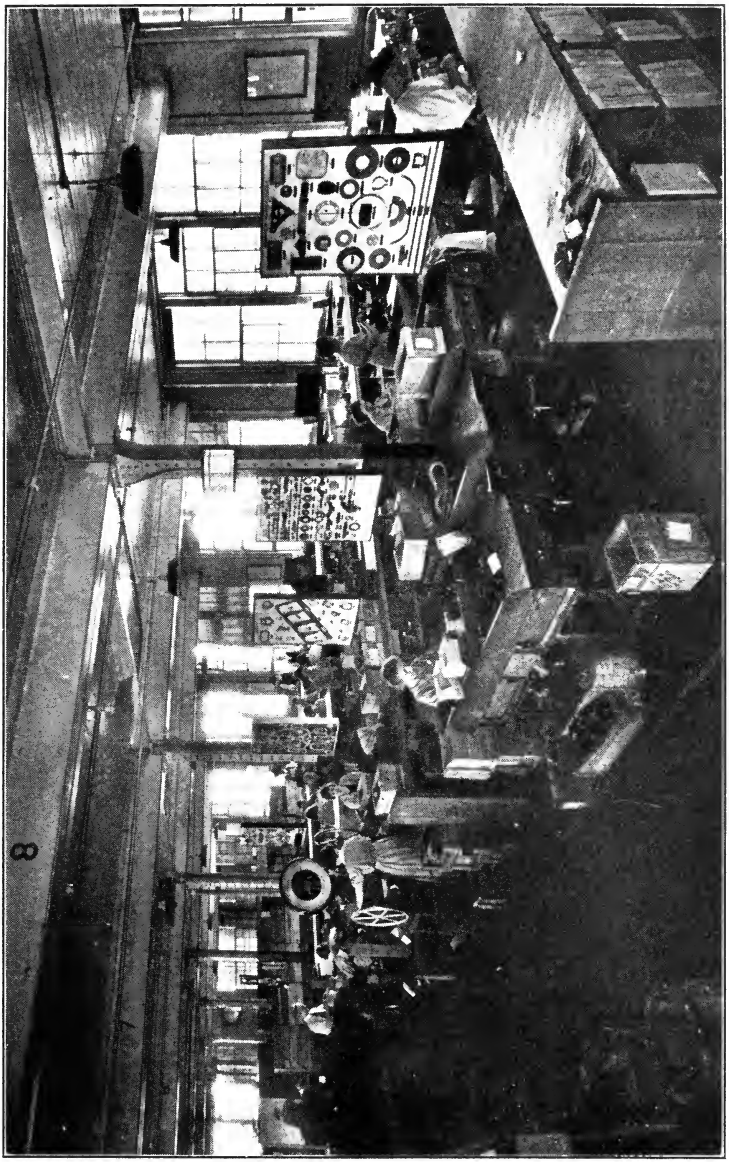


Figure 12. Inspection Room—Lincoln Motor Company

equal to that of production and engineering, it will give a still greater return. If it is subordinated, its greatest potentialities will be lost.

Engineering and Inspection

As has been stated elsewhere, the working or practical standards of quality are furnished in the main by the engineering department. These standards serve well enough for work that is plainly seen to be well inside the limits or well outside the limits. The difficulty in fixing standards of quality accurately arises from the large proportion of work which falls close to the limits.

At this point the engineering department must be released in favor of the inspection department, for in such cases, in the last analysis, someone must make up his mind as to whether the work should be passed or rejected. Thus the element of personal judgment enters, and a specialized technique must be cultivated and applied. For judgment varies as between individuals, and in the same individual at different times. To this fact may be ascribed many of the phenomena of the inspection of close work, where only a small percentage of parts are made that cannot be rejected on some technicality. This is the case with respect to dimension, and still more with respect to matters of finish, because judgment is accentuated so much more in inspecting for finish. Now the value of judgment depends upon its freedom from influence.

Production and Inspection

The inspection department's relation to the whole organization is judicial rather than creative. It is responsible to the management for detecting failures in quality, and in that sense it bears a very heavy responsibility for the maintenance of standards. It does not manufacture, however, and therefore when poor work is produced the production department cannot usually shift the blame to the inspection department. The production department should be made to realize that it is itself responsible for the quality of its product—it makes the work right or it makes it wrong. If the production force is organized by operations, the individual subforeman, tool-setter, or adjuster in charge of each operation should be made to feel that he is responsible for the quality of the work produced under his direction. In addition to checking the work frequently in person, he may be required to bring the first two or three pieces made after each new machine set-up to the inspector for verifying, but merely as a guide in his own work. Both departments then bear a definite responsibility to the management for quality, but independently and in different ways.

It is a well-accepted principle that responsibility should be re-enforced by adequate authority. Accordingly, if inspection is charged with the responsibility of stopping losses from work not up to standard, it must be given the authority to stop machines. When this authority is granted, it is only good judgment to specify an exact procedure for advising the responsible production executive, also for putting the machine back into production. It hardly need be added that such authority is not likely to be used if the inspection department's freedom is restricted by its subordination to production.

In fact, if inspection is to develop its greatest possibilities for service, it requires room to work and a free, fair chance to solve its problems. If you believe in inspection sufficiently to have an inspection department, why not give it a chance to show what it can do?

CHAPTER VI

INSPECTION'S CONTRIBUTION TO GENERAL SERVICE

The Collection of Useful Information

One of the greatest benefits of the inspection service comes from its power to bring promptly to the attention of the management information as to the true state of affairs in the shops. No tool is so useful to the manager as knowledge of the facts, yet nothing is so hard to obtain. The foreman-inspector of each shop is very close to what is going on in that shop, and is likely to be in the most unbiased state of mind because he is an observer rather than a producer.

Counting the work done and certifying to it is part of the inspector's duty as a matter of course. Summarizing this information for reports to be used for the purposes of the pay-roll, the cost records, and the production records may or may not be a part of his duty, depending on the character of the work. If this warrants a well-developed inspection system, it is quite likely that the foreman-inspector of every sizable department will require clerical assistance. If so, this clerk may just as well assemble the count of work performed in his department, before it is transmitted to the general factory offices. When production and cost data are assembled and analyzed by the use of power-driven tabulating machines, the data may be collected at the original sources and its accuracy certified to by the inspectors, with the obvious advantage of securing competent assistance in gathering the information together with the resultant saving in clerical expense. The additional burden on the inspector is slight, and the added duty may even be beneficial because it tends to bring him closer to his job.

There is another sort of information of equal or of even greater importance, which the inspector evidently is in the best position to obtain; namely, the location of production troubles, the isolation of their causes, and frequently the offering of suggestions for their cure. Production difficulties ordinarily appear in the form of too great losses in spoilage, or through the slowing down of production at some operation, thus creating a choke-point or a partial choke-point. It is essential, of course, to correct the difficulty as soon as possible, but to do this it is necessary to develop and bring to light the true causes.

Trouble Reports

A very useful device for the prompt collection of such data may be secured by providing a printed form of "trouble report" to be made out and sent by foremen-inspectors of shops to the chief inspector, who will transmit such facts as seem worth attention to the department that should correct the trouble—the management being furnished with a copy. The trouble report should read preferably as shown in Figure 13.

A detailed list of usual soruces of trouble, such as tools, gages, material, and so on, may be added for convenience, but the essential idea is to make the foreman-inspector feel the responsibility for promptly reporting the facts and nothing but the facts. Hence the requirement that he must state either that he "knows" or that he merely "thinks" that the trouble is due to the cause stated in his report. For the trouble report to be used successfully, the foreman-inspector must have confidence in the judgment, fairness, and courage of his chief—he must feel sure that he

From . . . . Foreman-Inspector

To Chief Inspector

Shop . . . . Date . . . .

Operation . . . . Hour . . . .

I report the following trouble . . . .

. . . .

I know think (scratch out one) that the trouble is due to the following

cause . . . .

. . . .

Figure 13. Trouble Report

will be backed up if he is right. Further, the management should make quite clear that it is looking for facts in order to cure troubles, and not to find someone to blame. There is no surer way to put a premium on the concealment of facts than by trying to fix the blame on an individual, nor does blaming someone help to cure the trouble. Presumably each executive holds his job because he is the best available man for the position. If he is not, the management will know it much sooner if he and his associates are not continually placed in the position of being called upon to make excuses.

The Inspector's Sense of Responsibility

Certain phases of the psychology involved in trouble reports deserve more detailed consideration at this point. In the first place, if the device of the trouble report is to be successfully applied the inspector must be made to feel that he is exercising a trust, and that the management reposes unusual confidence in his impartiality and adherence to accuracy. This feeling on his part has two very practical results: first, the information will be more truthful; second, the inspector will perform his other duties with the increased efficiency that flows from a stronger realization of his value to the organization. There are very few men who will not rise, in spirit as well as in act, to meet increased responsibilities.

At the same time the inspector should be made to know positively that accuracy will be insisted on. The latter purpose is accomplished by requiring him to state in each report whether he *knows* what he is talking about, or merely *thinks* the situation is thus and so. Quite a distinction is involved, of course, both in the report itself, as well as in the action likely to be taken. On the other hand, provided the inspector truthfully states the degree of his belief as to the facts, it is of comparatively little importance which form the report takes.

A Typical Instance

Experience with the trouble report as used in a very large and highly organized inspection department developed some very interesting reactions. This form of report was designed to meet a special set of conditions, first, because it was vitally important to get the best available information about a complex manufacturing situation as soon as possible; and second, because stiffening up the morale was judged to be the most important thing in reorganizing this particular inspection department. A few days after the form of report was placed in the hands of the foremen-inspectors, reports began to come in without either verb "know" or "think" scratched out. That was to be expected, as the inspection force had been led to feel that its work might be performed negligently or otherwise without visible effect on the running of the plant. All such indefinite reports, however, were returned promptly with the request that they be corrected in this respect. The inference was clear that the reports were considered of value and were to be used. Some of those which had been returned never came back, as was hoped, and the total number of reports became less. But *over 90 per cent of those which did come in read "I know."* This is the thing to note especially. When the management began to take action on the more important reports, the inspectors' growing feeling of responsibility was confirmed by seeing things begin to happen, and the effect on the morale of the entire department was very marked.

Reception of Trouble Reports

As stated at first, the use of such reports carries with it the necessity of using them in the spirit in which all scientifically trained minds should work. They should be received as being presented in a spirit of helpful and constructive criticism and as the opinion of an impartial observer reporting things as he views them. The department whose work is most involved must be made to feel that this is the way the report is offered, and to accept it in the same spirit. If the report is not well founded, no one is reflected upon so much as the inspector. If the report is correct no one should be so glad to discover, and to correct the trouble as the department responsible for the trouble. To secure this co-ordination and, in fact, to require a spirit of mutual confidence and good-fellowship, is distinctly the duty of the management. This is apparently a small point, but it is vital.

The use of some such report will yield just as valuable returns in many other kinds of work than factory inspection in its more limited sense. Figure 14 is an example of a form adapted to use in a great ship assembling plant.[1]

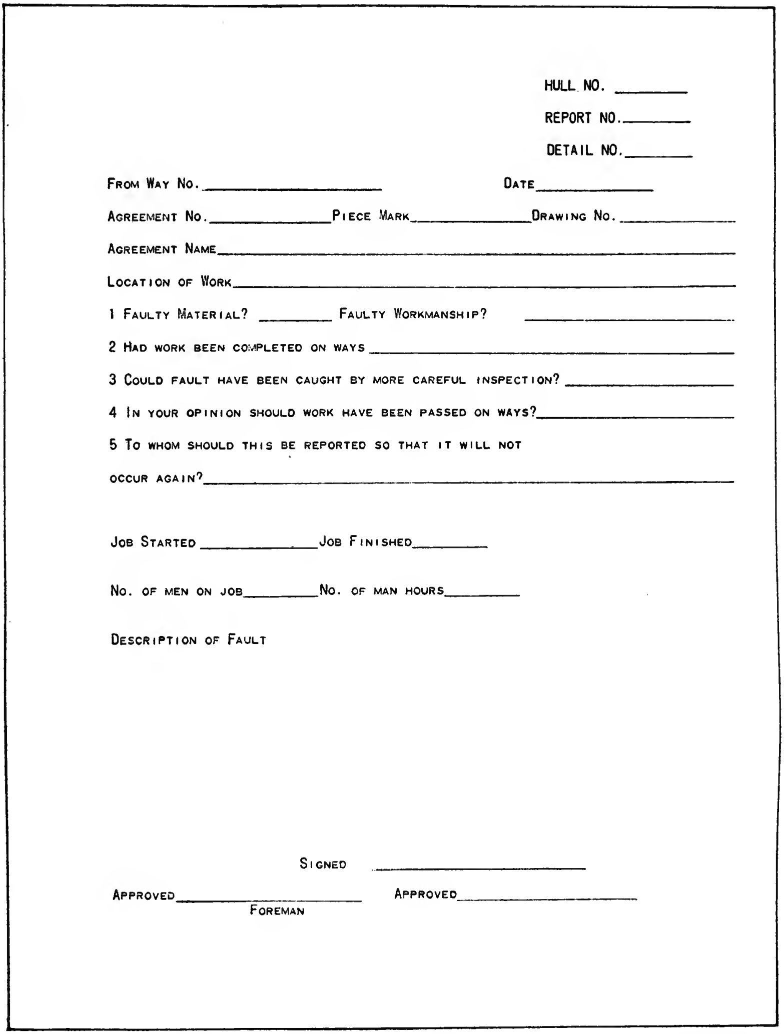
Inspection and the Assembling Department

After the various component parts have passed inspection in the respective parts-making shops and have been placed in the finished-parts stores prior to being issued to the assembling department, it may be assumed with reasonable assurance that they can be assembled satisfactorily. There is an ever-present tendency, however, for work to slip away from the desired standards of quality, and to do so by such small daily increments that the changes are difficult of detection. Measuring devices, whether gages or precision instruments of more general type, and cutting tools, are subject to wear like everything else. The fact that the wear does not take place rapidly or evenly makes the process all the more subtle and insidious. Then there is always the chance of a gage being accidentally injured, and work incorrectly disposed of, in consequence. In close work, as already noted, these troubles are accentuated by personal errors and by a multitude of other influences.

The net effect is, that in spite of every reasonable precaution quality will slip, and the errors may not be detected until the parts are issued for assembling. If the errors are due to gradual wear or similar cause, the condition will be manifested first by a slowly increasing difficulty in assembling, which is more dangerous than an absolute failure to assemble. For example, a part may assemble satisfactorily, and even pass final tests in the assembled mechanism, and still be just enough outside the lowest permissible limits to wear into a non-functioning shape after a short time in actual service.

---

[1] Furnished through the courtesy of William B. Ferguson, formerly Assistant to the President and Manager of the Division of Standards, American International Shipbuilding Corporation (Hog Island).



HULL NO. ________

REPORT NO.________

DETAIL NO.________

FROM WAY NO.____________________ DATE______________

AGREEMENT NO.______________PIECE MARK______________DRAWING NO.____________

AGREEMENT NAME____

LOCATION OF WORK____

1 FAULTY MATERIAL? ________ FAULTY WORKMANSHIP? ____________________

2 HAD WORK BEEN COMPLETED ON WAYS ____________________________

3 COULD FAULT HAVE BEEN CAUGHT BY MORE CAREFUL INSPECTION? ______________

4 IN YOUR OPINION SHOULD WORK HAVE BEEN PASSED ON WAYS?______________

5 TO WHOM SHOULD THIS BE REPORTED SO THAT IT WILL NOT
OCCUR AGAIN?____

JOB STARTED ______________JOB FINISHED__________

NO. OF MEN ON JOB__________NO. OF MAN HOURS__________

DESCRIPTION OF FAULT

SIGNED ________________________

APPROVED______________________ APPROVED______________________
FOREMAN

Figure 14. Inspection Form—American International Corporation, Hog Island

There was a particular make of engine of excellent and even very advanced design, which nevertheless failed in certain cases, most unexpectedly, after being used for a short time. A cursory viewing of the factory's inadequately controlled inspection system revealed an obvious reason for the service troubles which were killing future business. Parts of the mechanism of the engine in question required very accurate work. Some of these parts, with proper inspection lacking, were found to be just good enough to pass factory tests, but not good enough to stand up long in actual use.

Benefits to Entire Factory

With a highly organized inspection service in the shops and extending into the subassembly and final assembly rooms, a means is provided for avoiding such difficulties. The direct work of inspecting in the assembling department is often of less value, however, than the collection of information of value to the rest of the factory. The assembling rooms are a particularly fertile field for revealing errors, and the inspection department, for the reasons previously stated, is specially in a position to catch these errors and to pass the word about them back into the factory for the help and guidance of all. Time is a vital factor in such matters, and a well-organized inspection service will be able to send the warning back along the line with the proper speed. The possibilities of such a service are so great that it may be the part of wisdom to place the assembling under the general control of the head of the inspection department, especially if such a combination of duties will serve as a further reason for selecting a man of larger caliber for that important position.

Curiously enough, if the work is not strictly interchangeable there is often a greater reason for increasing the importance of the inspector's position in the assembling department. In this case, of course, selection of parts becomes necessary. Very often it can and should be made a separate operation from that of putting the parts together. The work of choosing parts that will mate properly involves measuring the parts and then sorting them out in a systematic manner into a few groups, each of which is made up of parts of very nearly the same dimension. The process is simpler if the work is of a character to warrant the use of selective gaging. It is merely an extension of division of labor to separate this work of sorting from that of assembling, and the sorting is more closely allied to inspection than it is to production.

An Example of Selective Assembly

An example of this kind is to be found in the manufacture of rifles or pistols which have raised sight-bases integral with the barrel. The barrel has a milled thread which screws into a similarly threaded opening in the receiver or frame. The barrel must screw into the frame so that the sight-bases are in line with the vertical plane of the frame (to insure correct alignment of the sights); and, in addition, the barrel and receiver must be drawn together at a given tension, this "draw" being required to be between given limits expressed in pounds for a stated lever arm or length of wrench. Both barrel and frame require many operations before they are ready for assembling, and several of these operations are referred back to the location of the milled threads and sight-bases. Needless to say, it is not always the simplest matter in the world so to locate and mill the threads as to fulfil the two conditions of sight alignment and draw of threaded joint, while still conforming to full interchangeability. Therefore, if a proportion of the parts demand selective assembling, a very considerable amount of work can be saved if the parts are separately gaged, with gages provided with, say, 10 numbered stages, to indicate corresponding positions in relation to the draw marks when the gages are set up with a fixed turning moment of, say, *n* pounds at the end of a wrench *a* inches long. The female gage applied to the barrel and the male gage applied to the frame are so calibrated that barrels drawing to point 8 on the barrel-gage, for example, will properly mate with frames drawing to point 8 on the frame-gage, and so on; and the parts will be sorted accordingly before issuing to the assemblers.

This method may be applied in principle to many cases in which economy in making the parts indicates the desirability of selective assembly. It will be noted that what really happens is that by means of the inspection and sorting of parts the assembling advantages of true interchangeability are secured.

The Custody of Work in Process

Many factories possessing very complete systems for production control are more concerned with the paper records of the system than they are with the systematic and orderly arrangement of the work in process of manufacture in the shops. The machinery may very likely be arranged to secure the best possible compromise for straight-line routing. If the work is large in volume and concentrated on one product, the machines are arranged in the order of the operations, so that work flows from machine to machine in regular sequence. If the work is varied in character, the machines are arranged by classes, as lathes, planers, millers, and so forth. In either case it is likely that planning and routing are well cared for in any modern shop. It is a common fault, however, for the work in process to be piled all over the shop. Even if the work flows directly from machine to machine, it is no unusual sight to observe parts rusting at the bottom of a pile where they have lain for months, or other parts in like condition under an inspector's bench.

The first point to be determined is whether this condition should be corrected. In certain instances, as in a great shipyard machine shop, the change may not be practicable. In most cases, however, it is worth while to make the effort; nor need it involve much expense, provided there is an effectively organized and managed inspection department to which this duty can be turned over. If central inspection is in use the job is readily taken care of. If not, the inspector at least can guide the work into a more orderly arrangement if he is given the authority to have work moved to the next machine after he has passed it. The placing of work naturally carries with it the custody of work in process. A little encouragement of the inspection department will develop a "fatherly" interest in the work itself, from which will flow a more orderly shop.

Stimulus to Order and Cleanliness

While considering the advantages obtained by a more systematic arrangement of the shop as regards work in process, the effect of order (and the greater shop cleanliness it permits) upon the working force should not be overlooked. An artist's temperament may be suited, perhaps, to doing good work under messy conditions, but the average man does better work if his environment is orderly and clean. It is well recognized that a desk covered with papers is not desirable. It has come to be regarded as an indication of a mind in the same condition as the desk. Does not the same criterion hold in the shop?

The first step in securing order, if a reasonably good shop arrangement exists, is the prompt sorting out of work as it leaves the machine, followed, of course, by a systematic placing of the work after it has been sorted.

The Analysis of Work in Process—"Good" and "Bad"

Sorting out work in process by inspection requires the guidance of some sort of classification; the matter cannot be dismissed by merely saying that work is good or bad. The parts or pieces of work that are passed by the inspector may be designated as "good parts" or "good work," as this terminology is brief, and the term "good work" is definite and accurate enough, provided we remember that the work is probably up to standard. As there is, of course, the mental reservation that the inspector may be wrong, there is a necessity for applying sampling tests to good parts from time to time, and for surrounding the inspector's work with safeguards, as set forth in Chapter IV. Parts obviously good require no other treatment than to be passed on to the next stage in their manufacture, assuming that some definite place is assigned for their temporary storage until the succeeding operation.

"Rejected work," that is to say, "bad work," calls for analysis into several classes with appropriate definitions for each class. As in the case of good work, allowance must be made for the possibility of error on the inspector's part. Provision should be made so that work rejected on the first inspection may have some chance of reinspection. It is quite the usual thing in the inspection of all kinds of work, from shipbuilding to small interchangeable and high-grade parts, to have some of the rejected work really fit for passing.

Handling Rejected Parts

Next comes up the question of how the rejects should be handled—we are concerned principally with interchangeable parts because such work furnishes the widest range of examples illustrative of inspection. The first step is to sort out those which require only a remachining on the machine from which they just came. Usually too little metal has been removed, or further polishing is required, and the work can be made good by the shop itself. Ordinarily this work should be done by the machine operator who did the work in the first place, and on his own time. Of like nature are the instances of parts with certain operations missing; also those which are best repaired on jigs and fixtures available only in the shops.

The rejects remaining after taking out the "shop repairs" should be accumulated at some point in the shop, preferably in a space set aside as the shop *salvage* space and under the care of the inspection department. At this stage, when sufficient rejects are accumulated to warrant the work, a reinspection should be made, in which the parts are separated into two, or possibly three classes, as follows:

1. Spoiled parts, which should be sent to the factory salvage room to be kept under lock and key; for if this is not done, some of them, under stress for production, are apt to find their way back into process by some path or other. In the salvage department they will be carefully examined with a view to their conversion into the most marketable form, either as scrap or otherwise. Circumstances will indicate whether they should be mutilated to prevent their use except as scrap, or sold as they are for use in another article. Springs, for example, rejected as below your own standard of quality, may be sold to a consumer whose needs are less exacting. You can afford to supply him at a lower price than he would otherwise pay, and both of you make money. A cleverly handled salvage department, which classifies the scrap from a large factory in this way, and which is alertly in search of better markets for its goods, is a money-maker in itself.

2. Rejected parts which require special work to bring them up to standard but which exist in sufficient quantity to warrant such repairs should be sent to a separate parts-repairing department or "hospital," specially designated as such, and located clear of the regular production departments. This is the place for the all-round mechanic with a taste for improvising and inventing. Supply this little shop with a few general utility machines, welding outfits, and so on, and considerable loss will be avoided. Apply the most rigorous inspection both to its work during the repairs and to its output.

In the course of repairing some parts, occasions may arise when it is necessary for the repair department to send the work out into the factory for some treatment or process beyond the repair shop capacity. If this occurs, by all means provide a special routing card of distinguishing color to go with the work, and return the work to the repair shop for inspection. Otherwise the repair shop inspector cannot be held responsible for the quality of repaired work of this character. In addition, he knows best what defects to look for by reason of his previous acquaintance with the parts in question. Finally, the repair department should keep a follow-up record of all of its work so sent out.

It is suggested that very careful consideration be given to the matter of a separate repair shop for rejected parts. Too frequently the attempt is made to do such work, or a large part of it, in the parts-making shops. Then again, work is often scrapped that otherwise would have been restored to a perfectly satisfactory condition in a special repair shop, whose working force is skilled in such things and proud of its ability to accomplish the apparently impossible.

The effect on production of having repairs made in the local parts-making shops must also be considered. Such work calls for the more expert workmen, so that the repairs

Figure 15. Gear Inspection—Lincoln Motor Company

cost not only the direct time of such men, but also the indirect cost of lessened output due to their separation from the regular production work.

One more reason for the separate repair shop: When a great number of parts are turned loose in a large and complexly equipped shop, strange and curious things happen. Some parts are likely to run wild unless their fields of movement are carefully restricted. If repair work is superimposed on the routine production, some of the repairs are quite capable of running in circles. They are inspected and repaired, and inspected again. The same individual pieces are returned for repairs and then inspected, and so on indefinitely, until they give way under the strain of so much activity—the best disposition of them because really the cheapest. "Circling" is of more frequent occurrence than might be imagined, because it is exceedingly difficult to detect, unless the work is of such a character that the inspector stamps a mark on the work after each important inspection, and even stamping may not prove effective. The danger of circling, however, is obviated by rigorously excluding repair work from the parts-making shops.

3. Under some conditions it may be compatible with business policy to consider a third class of rejected work. This case occurs when some of the rejected work is suitable for use in a second-grade product. Presumably such a product will not be marketed under the company label and the necessary precautions will be taken to insure the protection of the reputation of the company's standard goods, as well as to insure that the manufacture of second-grade goods does not become the factory's principal occupation.

Quality as an Incentive to Production

With work classified by inspection as indicated above, it is no difficult matter to count the work of each class and tabulate the results. In this way the inspection force provides the usual production data, as referred to in the preceding chapters. The same information in somewhat modified form is the basic matter for the all-important quality records.

Certain of this information is of special interest to the individual workman, and may be used to great advantage in stimulating better workmanship and thereby greater production. In the first place, the output of good parts for the day, presented in simple form, may be posted on a shop bulletin board devoted to this purpose only. The results should be contrasted with the scheduled output desired, and to this may be added other significant information, such as the statement, for example, that "Operation No. 23 spoiled 20 per cent of its pieces today. This is a difficult process, but we will have to hustle tomorrow to meet the schedule." Workmen are interested in this sort of thing, much more so than might be supposed. If they are not, the fact is advance notice to the management to overhaul the things that affect the good-will of the so-called "human factor."

Bulletin boards, it may be said, can be made much more useful as an instrument of publicity if attention is given to taking down notices as well as to posting them. The shop bulletin board is too often plastered with papers and notices of ancient vintage. Its effectiveness increases remarkably if it is kept absolutely cleared except when something is to be put across quickly. Then post your notice, briefly worded and clearly printed in large type, and just as soon as it has served its purpose, have it taken down, and the boards left clear as before.

The Individual Worker's Interest

Much of the data accumulated by the inspection department is of greater interest to individual workers than to the entire shop working force, considered collectively. Bill

Jones's interest in his work can be stimulated very often by showing him the effect that his personal endeavors have had on the output of his shop. The inspection department's records will provide the excuse for Bill's production boss to discuss things with him in a friendly way. Good-fellowship is pretty sure to result and the chances are that both Bill and the factory will profit as he begins to react to this sort of encouragement.

I should hesitate to stress this thought, in view of the feeling of some executives, if I had not seen the results in practice; for this is not theory, but hard fact. We talk a great deal about welfare work and carry some of it into effect with very desirable results, but what can be closer to the workman's interest than his regular work? You must answer for yourself whether the opportunities for building up the worker's interest in what he is doing are utilized to the full in the plant or plants in which you are personally interested. I do not refer to creating "bread-and-butter" interest—that is the usual appeal of incentives for stimulating production—but rather to the pride of good workmanship and the satisfaction of personal achievement which go to make up the worker's "professional pride."

Interest in the Work Itself

The modern industrial system, with its minute division of labor, has been freely criticized for reducing machine operators to mere automatons, forced to eke out an existence of tedious and countless repetition of the same operation. It is alleged that this endless repetition results in bodily, mental, and spiritual fatigue. The system of manufacture cannot be abandoned, because the division of labor results in too great an economy of effort even to think of its elimination. On the other hand, there is one simple but very effective corrective measure that we can apply, namely to encourage the operator's interest in, and to excite his curiosity about, the work he is engaged in doing. Now the theme that runs through this entire subject is that quality is variable, hence no two pieces turned out by any machine operation are alike. The points of difference may be comparatively small, but to the eye of the trained expert these same differences grow to look much larger and to be very apparent and real. It is a question of relativity and of degree.

Expert Knowledge—Causes and Results

To the trained eye of an experienced inspector the interior of one rifle barrel is quite different from another, whereas the greatest difference you or I might note, after repeated trials, would be a slightly fuzzy spot resembling a pencil mark. The inspector would tell you that this barely distinguishable spot indicates a bad drill groove, but we should not be at all certain as to the degree of the defect, its location, or even its existence. In the course of time, however, and with much repetition we could learn to distinguish these and similar defects or differences. Things that appeared indistinguishably small at first would become of appreciable size, and finally they would take on individual characteristics. But the main point I wish to bring out is that we should never know about them at all, if they were not first pointed out to us by someone skilled in their detection.

Now, the same thing occurs with the average machine operator. He may drift along without noticing the results of his efforts except quantitatively. Especially is it likely that he will have very little idea of the fine points in the work which are subject to his control, nor of the things he is in a position to influence, nor why and how he can do so. It is no great trouble, however, for the inspector (or the production boss, if you prefer) to show him how each part differs a little from the next one; also what *different kinds of differences* exist and what causes them, so that he can see for himself what he is doing *qualitatively*. Thus he will learn how his failure to clean off the chips, when bedding a piece, throws out his own work and perhaps the next man's, and almost certainly makes unnecessary work for the polisher. Or perhaps he will see that forcing the cutting tool causes him greater personal loss in total output than if he used less apparent speed. The net effect, however, will be the widening of his viewpoint, the building up of an interest in his work, and the consequent and proportionate lessening of fatigue.

Interest in Quality versus Fatigue

Many men can play golf every day in the week including Sunday. They seem to enjoy the repetition without experiencing unhealthy fatigue, and the discouraging monotony of their novitiate is forgotten. The same thing applies in principle in our daily work, no matter how restricted its field; if it is interesting the resulting fatigue is a healthy one. But the work is only made interesting through an appreciation of its fine points. It may take years of application to be able to see for ourselves those fine points and small distinctions, or some more fortunate person may be kind enough to point them out to us early in the game.

The modern application of division of labor has brought with it an acute problem due to extreme limitation of individual tasks, but the apparent smallness of the field of work covered by any one machine operator can be changed into one of much greater interest and wider scope by suggesting a different viewpoint to the workman. The employer might well consider carefully the mutual benefit to be derived from educating the worker in the finer points of his job, and from doing so in a spirit of friendly helpfulness that will build up a feeling of mutual interest in a common task. The workman usually is not capable of doing it alone, but he can be helped to do it by means of the regular factory organization if the employer will direct the foremen toward this different attitude in dealing with their men.

A Phase of a Major Problem

It is suggested that this is one way to help correct one of the major problems confronting engineers, which Herbert Hoover recently expressed in the following language:[2]

> We have until recently greatly neglected the human factor that is so large an element in our very productivity. The development of vast repetition in the process of industry has divorced the employer and his employees from the contact that carried responsibility for the human problem.
>
> I am daily impressed with the fact that there is but one way out, and that is to again re-establish through organized representation that personal co-operation between employer and employee in production that was a binding force when our industries were smaller of unit and of less specialization.

---

[2] From Mr. Hoover's presidential address to the American Institute of Mining and Metallurgical Engineers, Feb. 1920.

CHAPTER VII

INSPECTION'S RELATION TO PLANNING

The Flow of Work in Process

It is quite the usual thing in factory parlance to use the term "flow of work in process." More frequently it is abbreviated to "the flow of work," or just "the flow." This little expression, which is used so readily and easily, covers a matter that is intimately interwoven with the whole fabric of manufacturing; for the flow of work is of the very essence of production.

Manufacturing results from the combination of labor, machinery, and material—remove one of the three and the process ceases. If we can keep the flow of the material under control, we are in a position to control manufacturing; or, as has been said many times, "planning begins and ends with material." Thus one of the principal aims of planning is secured by arranging for a continuous supply of material to each production point, and at a velocity or rate of flow set to permit the scheduled output for that point.

It would appear also that the economy of manufacturing is greatest when there is an even and uninterrupted flow of work all along the line throughout the factory. Uniformity seems to be generally desirable in manufacturing. Let us consider some of the reasons for this. In the first place, there is no advantage gained by pushing one operation ahead of the average scheduled rate of production. The average rate at which completely assembled mechanisms can be produced, and hence the average output of finished articles, is fixed by the average output of that component part which lags most in the manufacture. In fact, the rate

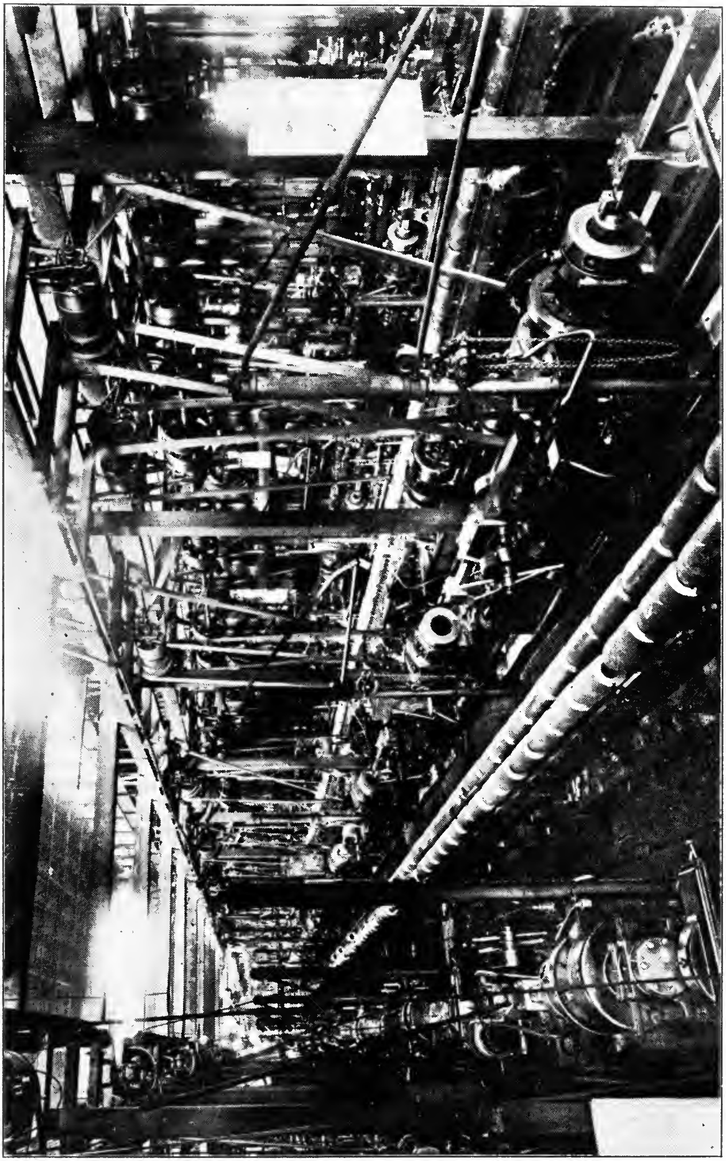


Figure 16. The Flow of Work in Process—Shell Work of American Locomotive Company

of total output is determined by the rate of flow of work through the single manufacturing operation or process that is lagging—"The speed of the fleet is the speed of the slowest ship."

Uneven Flow—Disadvantages

When assembling is permitted to proceed more rapidly than parts can be produced, it soon eats up the available reserve of parts and a famine results, with its accompanying pressure on the parts-producing shops. The first effect of too great pressure for quantity output is psychological—it amounts in practice to "getting everybody all worked up." The same thing happens when the train stops at an eating place—"twenty minutes for dinner—lots of time." All of us know what an iron nerve it takes not to hurry through with the job in half the time, at the expense of both appetite and digestion. When unusual pressure is placed on a shop the foremen stand over the men and hurry things along, with the net result of less output and of poorer quality. When a factory is run in this manner the cost of inspection for maintaining the set standards is much greater than it need be under more normal conditions. In the same way other indirect expenses are increased disproportionately. Thus transportation of work in process is much less expensive if carried on at a uniform rate, instead of being turned into the movement of many small lots of parts as soon as they are produced.

The ideal plan is so to protect the flow of work as to have fixed or scheduled quantities passing each production point during each unit of time. Unless we approximate to this ideal within reasonable limits, we shall have less production and at the expense of undue strain of the producers. When real emergencies occur they should find the organization fresh and ready to meet them.

Effects on Piece Work

Another serious defect resulting from an uneven flow of work arises from the fact that the continuous use of piece work is interfered with. Everyone knows that the output under a straight piece work or other system of payment based upon paying a man for what he does, is very much greater than when the man is paid for his time, on a day-wage basis. But the advantages of piece work cannot be fully realized unless there is a supply of material waiting at each machine for that particular operation. If there is a hitch in the chain of supply, workmen are soon to be seen standing round waiting for material to work on. It is not their fault, and they must be paid "day-work" for any appreciable loss of working time imposed upon them.

Supply of Raw Materials

Approaching the question from a different angle, we may note a similarity of situation in the supply of raw material. A prompt and continuous supply is always important, but during the war the procurement of material and supplies in the order and in the amounts required for continuous production assumed serious proportions. In the shipbuilding business especially, this matter of procurement took on a new value, and it is a safe statement that the speed of building in any yard was determined first and to a controlling degree by the efficiency of the preplanning for this purpose.

Even if the size of a factory's raw material storehouses and storage spaces were not influenced by a desire to be able to take advantage of favorable market conditions, it still would be necessary to set aside the space. A stock must be accumulated against possible failures in delivery, in order that machines may not have to be shut down for lack of something to work upon.

Material in Process

The identical principle applies to providing a supply or "bank" of material ahead of each manufacturing operation or production point, although this fact is not so generally appreciated. A proper flow of work can hardly be maintained with less than a half-day's supply ahead of each operation, although the amount of work in each bank is governed by local conditions. It is understood that the French small-arms arsenals were eminently successful in obtaining large output of high quality under very trying conditions; also that it was the practice to keep at least a day's supply of work (and two days' if practicable) ahead of each operation.

Breakdowns of equipment and other troubles are bound to develop choke-points from time to time, and an unbroken flow can only be insured by building up and maintaining reserves all along the line. These banks of material can then be drawn upon as needed to keep the machines going ahead of the choke-point, until the production point that is in trouble is restored to running condition. Then the reserves can be again accumulated by extra shift work.

From this point of view, there is a bank between the assembling room and the parts-making shops in the form of a finished component stores, which bears the same relation to the assembling department that the raw material stores bears to the parts-fabricating shops.

The quantity of parts to be kept in each bank depends, of course, on the likelihood of trouble at preceding operations, or other interruptions to production. For example, if it is probable that changes in design or method of manufacture are to be made, it must be remembered that a change of any sort means a serious interruption in the flow of work. To handle the situation, when a change must be made, requires special treatment in each case, and calls for masterly planning of the highest order. It is economy to take the time to do this planning before carrying out the change.

Insuring a Continuous Flow

The effect of a breakdown in production can be minimized at times by providing the factory with a chart showing approved alternative routings of the work. It is not safe, however, to route work more than two ways simultaneously, especially if there are many parts in flow. Special care should be taken when two routes are used to keep distinct the work sent over each route, and in this effort the inspection department can be of the greatest assistance.

Similarly, the inspection department, in its regular task of sorting out the defective parts, makes a large contribution to promoting a uniform flow of work, for it is essential from the standpoint of protecting the flow that rejected and condemned work be disposed of swiftly and promptly removed from the shop.

The control of supplies of material and of banks of work in process, and therefore the control of the flow of work throughout the factory, is greatly simplified if there is a systematic storage of work in process. This result cannot be secured by planning on paper alone, no matter how completely and extensively this planning is done. The work itself should be distributed in such a definite and orderly manner (and in a shop swept clean of everything not used in the business) that the condition of the flow can be vizualized by looking at the work—without reference to paper records. This brings us to a matter which deserves special consideration.

Planning with the Material Itself

In order to treat this matter thoroughly, it is necessary to trace the steps that must be taken to reach a position where planning with the material in process is possible. Planning, in the broadest sense in which the term is used, has developed certain mechanisms in addition to its first work of preplanning the routing of work. Thus it must be considered as inclusive of the preparing of schedules of quantities of work to be produced at given times; and of the dispatching of work at rates in conformity with these schedules. To this will now be added the planning of space assignments for work in process.

Only the high-spots can be touched upon, with reference to the details involved in such planning, but that is really all that is necessary, because the other details will readily suggest themselves when the general scheme is applied to a concrete case. It should be kept in mind concurrently that the inspection department can be made the principal instrument, and a most economical one, in giving life to the planning department's work, when the time comes to translate plans into action.

Master Planning

Let us assume now that an article has been designed and is ready for manufacture, and that the planning force is called upon to preplan for producing and bringing to assembly given quantities of parts which meet certain stated standards of quality, and for assembling these parts into the complete articles. It is assumed at the outset that the management, in conference with the principal department heads, has developed and approved a general plan for carrying out the project; also that this plan has been drawn up by the planning department in the form of a *master control sheet* or sheets for the guidance of all concerned. Among the data shown thereon would be a list of the things to be done (i.e., the whole project is analyzed into its parts), the department or individual responsible for carrying out each part of the work, and the time when each part of the work should be started and completed in order to secure co-ordination of all the parts.

As the drafting-room takes up the making of working drawings and special tool designs, the planning department in co-operation with the drafting-room should make up a complete list of parts and subassemblies, together with the tentative outlines of bills of material, which last may later be entered on the appropriate plans. The first draft of material requirements is then taken off for the guidance of the purchasing department and the storeskeeper, so that they may make their preliminary arrangements.

The Operation Mark or Symbol

With a complete list of component parts and subassemblies in hand, it now devolves upon the planning department to devise and apply a set of symbols, as some such device is a *sine qua non* to an orderly and systematic control of the flow of work. If the factory does not have a satisfactory symbol system already it is suggested that a combination of figures and letters may be used to advantage.

In building up such a scheme of symbolization it is important to distinguish between the symbol for a particular manufacturing operation, and the number which indicates the order or sequence in which the operation is to be performed. Such an operation may be defined as meaning any one application of a mechanical or other process in the course of making some one part. Drilling is a mechanical process. Drilling a hole for the hinge-pin in the shackle of a given model of a lock is an *operation*. In this case the mechanical equipment for the operation would be a light drill press, drills, a drill jig, and a limit plug gage.

The first layout for processing the job of making this lock shackle might list the drilling of the hole as the fourth operation to be performed on the pieces. Later on, the order of processing might be changed to permit of improvement, or for some other equally good reason. A way might be found to eliminate some of the earlier operations, or additional operations might have to be inserted, so that the operation of drilling the hole might become perhaps the third, perhaps the tenth in order of sequence. Now it is of considerable value to have some one *permanent* mark or symbol for designating the operation of drilling this hole, if for no other reason than cost-keeping. In shops where the attempt is made to make one symbol do for indicating both the operation and its sequence, the cost of operation No. 1103 may cover drilling this month and grinding next month. Consider the effect on the tool storage and supply system alone, as well as on all quantity and quality records.

Operation Mark to Remain Unchanged

It is to be understood then, that the *operation mark* is assigned once and for all to a given operation, *and never changed*. If the operation is abandoned, so is the operation mark. If there are twenty operations in making a part and it is found necessary to provide another operation, the new one is marked as the twenty-first, without reference to the place where it is inserted in the list of operations. This mark is then used in correspondence, on plans, in marking tools, tool storage bins, and so on, wherever and whenever it is necessary to refer to the operation or anything connected with it. As stated before, no attempt is made to make this symbol designate the sequence of the operation's application.

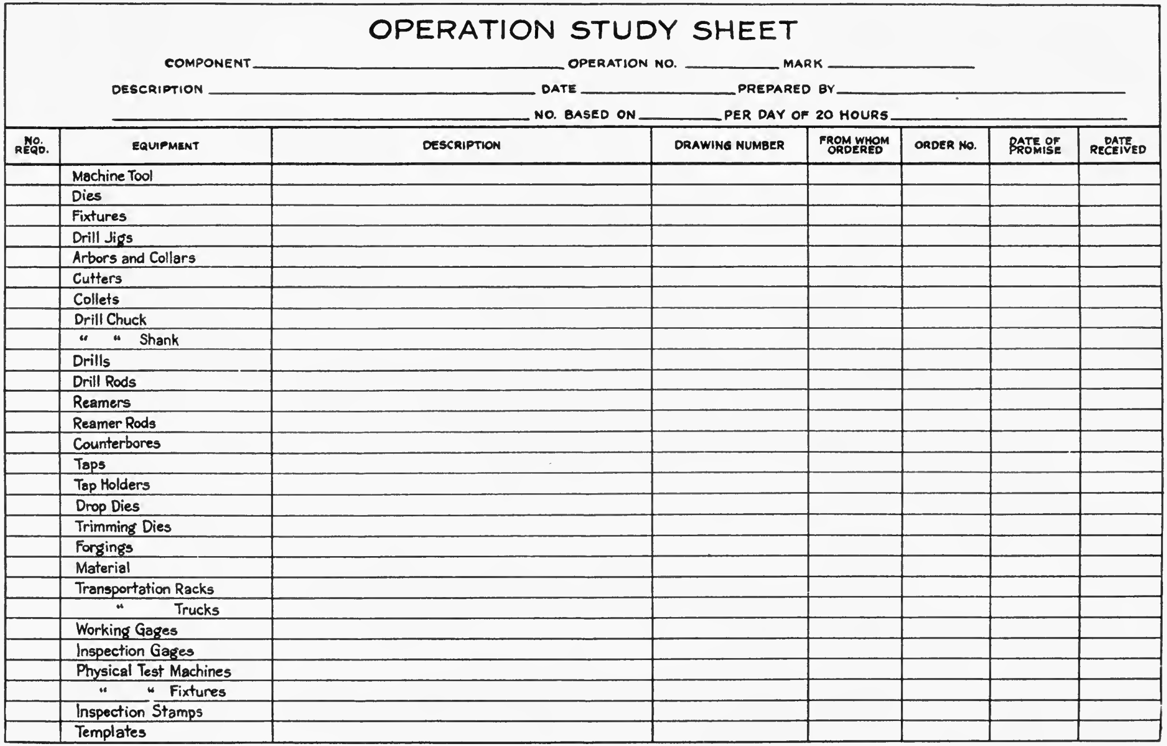
The matter of sequence is covered, when necessary, by a separate number entirely divorced from the operation mark; but the sequence number as such is not required to anything like the extent that the mark is. When the operations are listed, a separate column should be provided for entering the sequence number for each operation; and a corrected list should be furnished for the guidance of the shop when changes are made in the order of performance of operations. If route tags are used with each lot of parts, the sequence is indicated by the order in which the operation marks are listed, or the sequence numbers may be printed opposite the corresponding marks. (See Figure 19, page 108.)

This scheme for symbolizing applies to the factory product, its component parts, the operations used in manufacturing them, and the equipment strictly related to such operations. It does not apply to the symbol system used for designating parts of the factory itself, or the machine tool equipment, which should be provided for separately. If you have a system in use which is giving reasonable satisfaction, by all means use it in the shops as well as in the office, the important point being that something of the sort is necessary to bring order out of chaos and to permit a systematic and orderly arrangement of work in process.

The Operation Data Sheet

The next step in planning involves the assembling of all the information the shops should have relative to the processing that is to be followed in manufacturing the parts and putting them together. It is suggested that an operation study sheet of standardized form (see Figure 17) be used in developing and recording the process information for each part, and that from this there be compiled an *operation data sheet* (Figure 18) for shop use.

It is believed that the preceding discussion, relative to the distinction between the sequence of an operation and its distinctive mark or symbol, will make clear the data to be entered on this sheet. All the machine tool equipment will be labeled or otherwise suitably numbered and marked for inventory purposes at any rate, and these individual



OPERATION STUDY SHEET

COMPONENT __________ OPERATION NO. ______ MARK ______

DESCRIPTION __________ DATE ______ PREPARED BY ______

__________ NO. BASED ON ______ PER DAY OF 20 HOURS ______

NO. REQD.	EQUIPMENT	DESCRIPTION	DRAWING NUMBER	FROM WHOM ORDERED	ORDER NO.	DATE OF PROMISE	DATE RECEIVED
	Machine Tool						
	Dies						
	Fixtures						
	Drill Jigs						
	Arbors and Collars						
	Cutters						
	Collets						
	Drill Chuck						
	" " Shank						
	Drills						
	Drill Rods						
	Reamers						
	Reamer Rods						
	Counterbores						
	Taps						
	Tap Holders						
	Drop Dies						
	Trimming Dies						
	Forgings						
	Material						
	Transportation Racks						
	" Trucks						
	Working Gages						
	Inspection Gages						
	Physical Test Machines						
	" " Fixtures						
	Inspection Stamps						
	Templates						

Figure 17. Operation Study Sheet as Used at the Bridgeport Armory of the Remington Arms Company

OPERATION DATA SHEET

Revision No. 2, Sheet 3

Component, 32RF4
Name, Bolt

Seq. No.	Operation Mark	Description of Operation	Tools Used	No. Req. for 1000 in 20 Hrs.	Tools Marked	Machines Used	No. Req. for 1000 in 20 Hrs.
8	32RF4-10	Mill slot for ejector, lengthwise	Arbor	1	32RFA4-10	12″ B. & S. Milling Mach.	1
			Collar (adj.)	1	32RFA4-10		
			Fixture	1	32RFF4-10		
			Side Mills	6	32RFT4-10		
			Template	1	32RFT4-10/M		
			Gages		32RFW4-10		
9	-11	Mill bolt head holding slot	Fixture	1	32RFF4-11	#0 Bristol Hand Miller	1
			Collet	1	32RFH4-11		
			Cutters	50	32RFT4-11		
			Template		32RFT4-11/M		
			Gages		32RFW4-11		
10	-12	Mill flat side of ejector slot front end	Arbor and Collar	1	32RFA4-12	#3½ Fox Miller	1
			Fixture	1	32RFF4-12		
			Plain Mills	12	32RFT4-12		
			Gages		32RFW4-12		

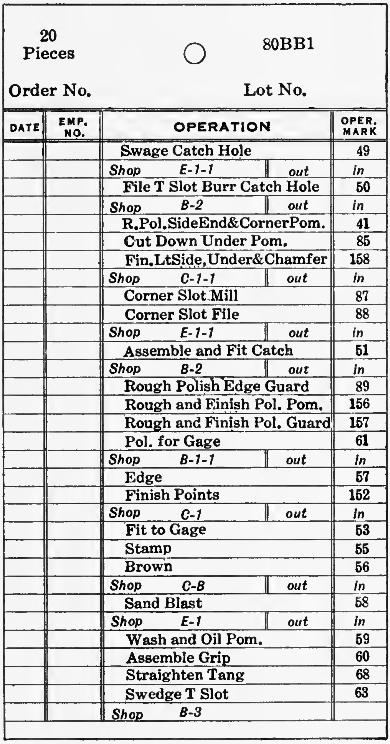
11	-13	Mill side ejector groove near rear end	Fixture	1	32RFF4-13	#2 Becker Vert.	1
			Collet (Spring) 5/16″ with mch.	1	32RFH4-13		
			Cutters	50	32RFT4-13		
			Gages		32RFW4-13		
12	-14	Mill side ejector groove (finish)	Fixture	1	32RFF4-14	#2 Becker Vert. Miller	1
			Collet (Spring) 5/16″ with mch.	1	32RFH4-14		
			Cutters	50	32RFT4-14		
			Gages		32RFW4-14		
13	-17	Mill cocking cam, rough, 1st	Fixture	1	32RFF4-17	#3½ Fox Milling Mach.	1
			Collet	1	32RFH4-17		
			Cutters	50	32RFT4-17		
			Gages		32RFW4-17		
14	-18	Mill cocking cam, rough, 2nd	Fixture	1	32RFF4-18	#3½ Fox Milling Mach.	1
			Collet	1	32RFH4-18		
			Cutters	50	32RFT4-18		
			Gages		32RFW4-18		
15	-26	Mill plane side of discharge groove (finish)	Fixture	1	32RFF4-26	#2 Becker Vert. Hand Miller	1
			Cutters (shank)	50	32RFT4-26		
			Template	1	32RFT4-26/M		
			Gages		32RFW4-26		

Figure 18. Operation Data Sheet

machine numbers may be entered on the operation data sheet, if additional clearness is required.

Special tests should be entered as separate operations. Inspection points may be mentioned in like manner, or referred to by some designating mark, or left out altogether, depending on the character and relative complexity of the work. Operation data sheets should be made out for each subassembly, and for the final assembly, just as in the case of each component part.

A similar sheet showing alternative routings, or sequences of operations to be followed in case of emergency, may be developed for each part; but as these will not be used frequently, it is probably simpler and better practice to show this information in chart form.



20
Pieces ○ 80BB1

Order No. Lot No.

DATE	EMP. NO.	OPERATION		OPER. MARK
		Swage Catch Hole		49
		Shop E-1-1	*out*	*in*
		File T Slot Burr Catch Hole		50
		Shop B-2	*out*	*in*
		R.Pol.SideEnd&CornerPom.		41
		Cut Down Under Pom.		85
		Fin.LtSide,Under&Chamfer		158
		Shop C-1-1	*out*	*in*
		Corner Slot Mill		87
		Corner Slot File		88
		Shop E-1-1	*out*	*in*
		Assemble and Fit Catch		51
		Shop B-2	*out*	*in*
		Rough Polish Edge Guard		89
		Rough and Finish Pol. Pom.		156
		Rough and Finish Pol. Guard		157
		Pol. for Gage		61
		Shop B-1-1	*out*	*In*
		Edge		57
		Finish Points		152
		Shop C-1	*out*	*In*
		Fit to Gage		53
		Stamp		55
		Brown		56
		Shop C-B	*out*	*in*
		Sand Blast		58
		Shop E-1	*out*	*In*
		Wash and Oil Pom.		59
		Assemble Grip		60
		Straighten Tang		68
		Swedge T Slot		63
		Shop B-3		

Figure 19. Route Tag—Remington Arms Company

Route Tags

From the operation data sheet it is a simple matter to work up printed route tags, if these are required, to go with each lot of parts. Under the system proposed, no mention of the sequence of operations need be made, as this will be covered by the order in which the operations are listed. The data taken from the operation data sheet for incorporation in the route tag then consists only of the shop symbol or name, and the operation mark or symbol. (See Figure 19.)

The route tag, and in fact all planning work, will be simplified if shops are designated by number or letter rather than by name. A simple but effective plan is to assign a letter to each building; to number the floors, *beginning with the basement* as No. 1; and then add a letter to locate the part of the floor according to compass direction.

The Manufacturing Schedule

In tracing the steps to be taken by the planning department in order to reach a point where planning with material is possible, it now becomes necessary to work out the daily or weekly production schedule, upon which the design of the space assignments for material in process is to be based. Suppose the production schedule contemplates an output of 1,000 complete articles during each working day. This means that somewhat *more* than a thousand of most of the component parts must be produced daily, for the reason that a few will be spoiled in the assembling department, or for some other reason will cease to be available. Then in the case of each part, this quantity of $1,000+n$ pieces must be increased by the estimated losses at each operation as we trace it back through the various steps in its manufacture, so that material for perhaps 1,200 pieces of the part in question must be started into production at the first operation each day, in order to maintain the schedule with certainty.

Allowance for Losses in Process

The losses at each operation which are allowed in preplanning, should be checked in practice by comparison with reports supplied to the planning department by the inspection department. The importance of making an adequate allowance for loss of work in process should be realized and it may be noted at this place that the percentage of loss for most economical production at each important operation may be worked out quantitatively for the planning department by the inspection department as the work proceeds. The inspection department, for example, may tighten up or loosen up, on such part of the work as it is in a position to influence by its personal judgment (i.e., work that is questionably close to the limits); and then report back to the planning department the total production and totals of rejected work corresponding to the different degrees of inspection applied in the tests. It is then up to the planning department to compute the corresponding total costs, including losses, and set the standard percentage of loss to which the inspection department should hold the work in order to recover the greatest economy in production. This percentage loss may be reduced later when improvements in workmanship and equipment warrant.

The production schedule just referred to is for a uniform flow and therefore should be supplemented by a gradually increasing schedule for use in starting into production. A similar schedule should be used in tapering off production to prepare for changing models.

Determining Quantities of Work in Flow

The planner is now in a position to prepare a table showing the quantities of work to be provided in the banks of material at each stage of manufacture in order to insure a continuous flow of work. In brief but complete form this will include:

1. The maximum and minimum quantity of raw material to be carried in raw-stock stores for each part.
2. For each operation the minimum quantity of material in process waiting for the next operation.

The maximum quantity should be specified, but is not of great importance.

3. The minimum and maximum quantity of finished parts to be carried in the finished-parts stores as a bank between the producing shops and the assembling department, including similar data for subassemblies.

These assumed quantities will be adjusted later to bring them into accord with the conditions as they develop after production is under way.

There is no exact rule that can be followed in fixing upon the maximum and minimum quantities of parts to be carried in the banks of work in process. Generally speaking, it is safe to allow a day for any one piece to pass each operation, and therefore it is well to provide for a minimum supply of a half-day's work, and a maximum of from one to two days' work, depending upon the local conditions.

The Design of Space Assignments for Planning with Material

It is now proposed:

1. That the table of quantities of material required at each operation, in order to maintain uninterrupted flow, be used as a guide to compute the space required to store each maximum quantity.
2. That layout plans be made for each shop, on which a definite space is assigned to each such bank of material, in the same way as machines are shown.
3. That the space so assigned be designated in physical form, if the class of work will permit (and it usually will), e.g., by boundary lines on the floor.
4. That each space so assigned have the symbol marked thereon, and that the maximum and minimum quantities either be shown in figures or at least be readily accessible for reference.

This contemplates, it will be observed, *an extension of the best factory raw-material storeroom practice to the storage of material in process in the shop.* This is for the purpose of reaping the advantage accruing both to quality and quantity of output by keeping work in process under positive control at all times and places.

The objection most frequently advanced against such a plan is that there is not enough room in the shop. As against this view, it is submitted that there is always more room when things are systematically arranged. But to carry out an orderly arrangement of work, it should be borne in mind that it is idle to try to have everything in its proper place, unless the proper place in question is clearly indicated. This last is no difficult matter. It is a common practice to paint aisle lines on the shop floor, and what is proposed is merely an extension of this scheme.

For example, if the shop building is wide there probably is a space in the center which is not well lighted. This space can be ruled off for the orderly storage of work in process. Or the best arrangement may be to utilize spaces between machines, or next to columns, or possibly under the windows.

With the added refinement of having the quantities to be carried in these storage spaces either marked near them, or otherwise made readily accessible, it is possible to walk through the shop and observe the condition of the flow of work without the necessity of resorting to paper records to discover how things stand. It is exactly comparable, in principle, to checking up the stock of a well-arranged storeroom by a simple visual inspection. For practical purposes, it has the great merit of speed. You do not have to wait to find out what you need to know.

This is what is meant by "planning with material"—a term here used to distinguish the method from planning on paper, which process it extends and supplements. It represents indeed a culminating point in the system work of planning.

Inspection and Dispatching

Let us assume now, that we have an orderly condition of things in the shop, and that the inspection force is reasonably efficient and on the job. No very great additional burden will be placed on the inspectors if they are given the added task of the custody of work in process. The inspector will see that work is moved to the next bank (or operation storage space) as soon as it has been passed by him. Concurrently, the inspector will assist in *dispatching* work in accordance with the schedules.

When the flow gets out of balance at some point it devolves upon the inspector to direct the production department's attention to the fact if the foreman is not already aware of the situation. If the condition is a serious one, and a bad choke-point is resulting therefrom, the production department may resort to overtime work, or preferably to the use of an extra shift. There is nearly always work for such a balancing shift of all-round, or "handy," machine operators to help maintain a uniform flow in a large factory.

Doubtless there are many other methods for controlling the flow of work. At one time I visited a factory in which the flow was controlled by limiting the daily output of the fastest operators, although the superintendent did not so designate the process. He stated that on certain operations, which were indicated, the workmen were through with their day's work when they had completed a fixed number of pieces, and that this made it a very simple matter to keep the slower operations from being swamped. Surely this is a simple and direct method of insuring a balanced condition of flow, but how about its reaction on the whole matter of production? The inspection force was available, and could have been utilized, under a properly organized plan, to keep the shop in balance as well as in a far more orderly and workmanlike condition, without stopping work at any process.

CHAPTER VIII

CENTRAL INSPECTION

The Most Advanced Form of Inspection

The greatest possibilities of controlling the flow of work in process, by planning with the material itself, are realized when conditions permit that inspection be centralized and physically separated from the rest of the shop. Furthermore, the control of both production and inspection reaches its highest development under this system. While central inspection is the most highly specialized form of inspection, its use need not be so restricted as might appear. For work that is done *in large volume*, central inspection provides by far the best means for controlling manufacturing conditions. This statement holds good even if the amount of inspection to be performed is relatively small, because central inspection provides, in addition to the inspection feature, a better chance to issue work and record individual production in an orderly and accurate way.

Not Restricted to One Form

Central inspection may take many forms, and is not restricted in its application to the business of making small interchangeable parts in quantity. The basic principle of widest application is that of physically separating inspection from production. In the weave shed of a textile plant, for example, there would natually be some sort of inspection or patrolling supervision of the work on the looms. Central inspection would hardly be looked for. Yet the practice of removing the goods to a separate inspection room after weaving (where they are rerolled, measured, graded according to quality, and the defects indicated by some system of marking) is nothing if not centralized inspection. (See Figure 43.) It will be apparent from the following that the principle can be extended to embrace many different sorts of work, with all the advantages from the more special use of central inspection in strictly interchangeable manufacturing.

A natural restriction to the application of central inspection is encountered when the work is too bulky or too heavy to warrant moving except from machine to machine. Nevertheless, it should be noted that central inspection can be used for much larger and heavier work than is ordinarily supposed to be the case, provided full use is made of modern handling devices. For example, large military rifle stocks, which are heavy and bulky in the earlier stages of manufacture, have been handled in shops under central inspection, by transporting them in lots of as many as 40. In this case, they were carried in a double rack mounted on large casters. Other large and heavy parts are often carried on lifting truck platforms, designed to carry a definite number.

Value of Self-Counting Trays

The use of special carrying trays of the self-counting variety should be extended. They are inexpensively made of wood, protect the pieces from damage, and save much time in counting work. For example, suppose the problem is to provide means for handling in quantity a part approximating *T* in shape—a shape which typifies the general form of many parts. In the earliest operations of its processing, it may be handled in bulk in ordinary metal tote boxes, holding, say, 200 pieces. As the processing advances, operations are encountered that remove metal down to or near the finished surfaces. It is now an economy to keep the pieces from injuring each other. Carriers should be made, preferably of shellacked wood, of rectangular form to support 100 parts, in, say, 10 rows of 10 pieces each, and arranged to permit stacking.

The objection to open bottom containers of this type is that oily work drains onto the floor, but most of this trouble can be avoided by providing a draining pan under the tray of work at the machine. As just stated, tote boxes of this character serve a very useful purpose in assuring a finer finish by protecting parts from the little scratches, dents, and cuts that so detract from quality. Their principal value, however, flows from the self-counting feature, which simplifies the labor of securing an accurate count, and does away with arguments as to the number of pieces issued to, or received back from the machine operator. Central inspection almost necessitates something of the sort to develop its greatest possibilities.

In this connection attention is invited to Edward H. Tingley's article on "Making the Truck an Asset in Management,"[1] from which the following is quoted (see also Figures 20 to 23 inclusive from the same article):

> SPEEDING UP THE WORK OF OPERATORS, INSPECTOR, AND STOREKEEPER. The workman expects any system for handling material to help him increase his productive capacity as well as decrease his effort. The special trucks illustrated have these advantages, as they occupy a minimum of floor space and allow the work to be brought as close as possible to the machine. The trucks are easily moved by one man, and with work stacked on both sides they can be turned around to bring the other side to the machine, thus eliminating useless walking. The construction of the truck insures the separation of the pieces and so prevents damage to any finished or ground surfaces. It also suggests the idea of order and care to the workman, and it gives him the satisfaction of seeing his work progress. He unconsciously sets a goal for himself, endeavoring to complete a row or truck by noon or night. The amount on the truck is proportioned to what one man can push around and also what will make a good quantity for piecework operations.

---

[1] *Management Engineering*, Nov. 1921.

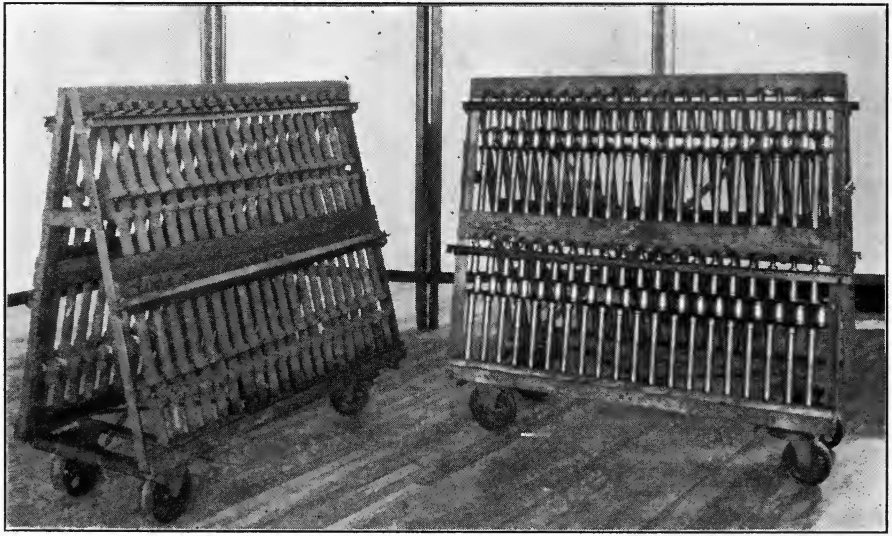


Figure 20. From Forging to Finished Crank-Shaft

The same truck is used to carry the crank-shaft through all its operations from the raw-stock room to the finished-parts stock and even to final assembly.

The work of the inspector should be as limited as possible, as his work is indirect labor, an item of overhead expense. In any well-regulated factory the foreman should be fully responsible for the quality of work produced, and the inspector should merely check the foreman. If the truck, box, or rack in which the material is handled will permit of quick and accurate counting by the inspector, easy removal and quick replacement after inspection, the time of the inspector can be reduced to the minimum. Through the use of

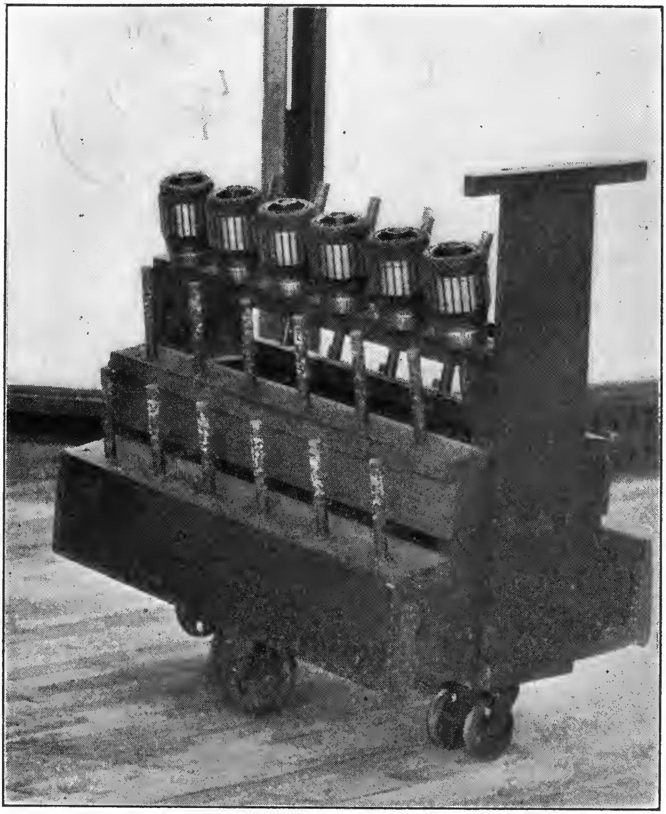


Figure 21. A Wood Frame Truck

This type is used in the armature department for handling the armatures when complete.

trucks such as shown by the illustrations in this article, counting is unnecessary, as the inspector knows from the Production Order card the total number the truck or box should contain, and only has to subtract the missing pieces from this total. This counting of the missing parts can be done at a glance.

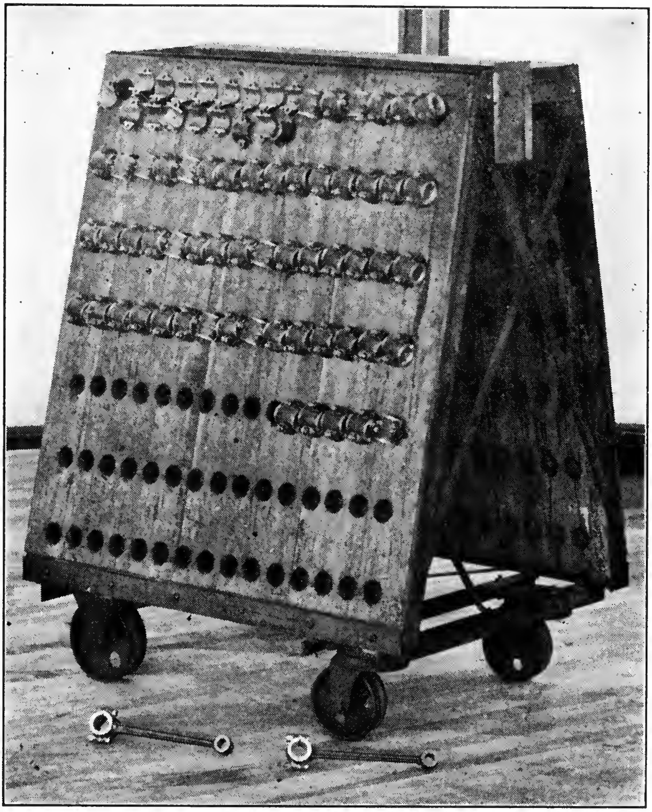


Figure 22. An "A" Frame Wood Truck for Connecting Rods
The rough forging is placed in the truck in the raw-stock room and the finished rod is taken off in the finished-stock room.

The finished parts stockroom is also benefited in several ways by the special trucks, as the counting of material as received is expedited and a visual inspection can be made in a short time. If the

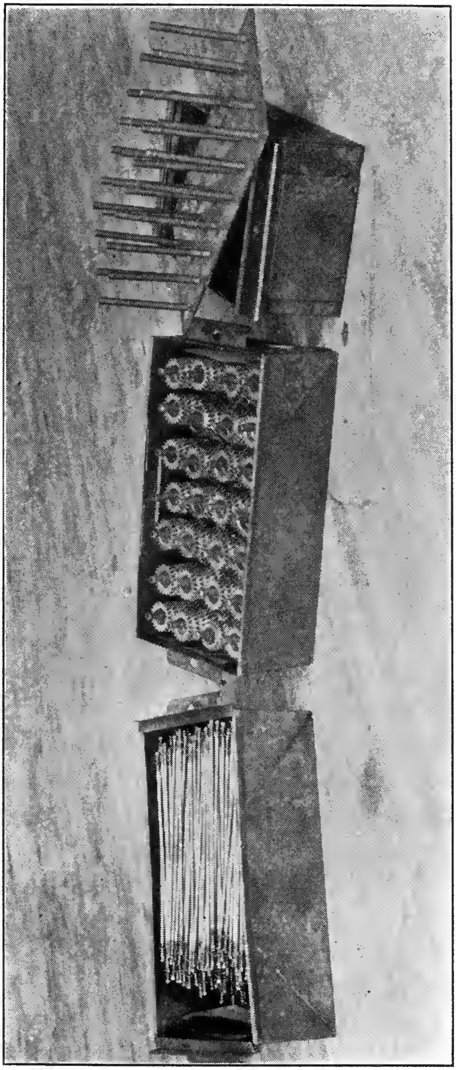


Figure 23. Standard Steel Tote Boxes

Note the rack on the right. This can be put in to make a specialized container for gears, etc.

material is to be stocked in bins, the truck can be pushed to the location and emptied as desired. Frequently the material is to be used in other assembly operations, and if allowed to remain on the truck it can be sent at once without further work to the assembly department. In preparing material for group assemblies the special trucks can be loaded in the finished parts stockroom with speed and the assurance that no damage will result while in transit, and that the count is correct as to the number of pieces sent out.

Operators working on a piecework basis will not try to claim pay for the full amount of the order if some parts are missing, as the evidence of such missing pieces is open to the time clerk and the foreman at a glance. In the matter of placing the responsibility for scrap it is very easy for a foreman to check the actual amount of material coming into his department in order to be sure that the Production Order shows the amount scrapped on previous operations. This is a factor frequently overlooked in the design of equipment to move material.

The Two-Bin System Extended

Consider an application in the shop of what Dr. Frederick W. Taylor, I believe, called the "two-bin" system. Its application in modern storehouses is generally known. For each article stored and issued with any frequency, two storage spaces are provided instead of one, as usual under the older system. Or perhaps it would be more accurate to say that the storage bin or other space is divided into two parts, *A* and *B*. Issues of stock are made from *A* until it is empty. Meanwhile new stock is accumulated in *B*, as it is received in the storehouse. As soon as *A* is empty the storekeeper begins to issue from *B*, and to accumulate new stock in *A*, and so on, alternating the issuing bin, which is indicated by a tag or movable indicator. In this way no old stock is permitted to lie in the bottom of the bin, as is almost certain to be the case when new stock is piled in on top of old stock in the single-bin system of storehousing.

Systematic Layout for Material in Process

A continuous flow of work through the shop indicates the desirability, and perhaps the necessity, of laying out the storage spaces, for banks of material in process, on the two-bin system. For example, with banks carrying a day's supply the two-bin scheme can be worked by issuing from one end of the pile today, from the other end tomorrow, and so on, alternating each day or each shift if the flow is rapid. Under a system of central inspection the storage spaces for material should be systematically arranged with this object in view. Needless to say, control of the flow is much simplified under such an application of central inspection.

As a preliminary step to taking up the arrangement of the shop under central inspection, attention is invited to the following diagram (Figure 24), which indicates the theoretical line of flow of work:

Figure 24

S_0 represents the stores of raw material for the part in question, which is daily or hourly issued to replenish the material waiting for the first manufacturing operation at the process *storage point* S_1—preferably arranged in two parts, or piles of work, on the two-bin system, and in self-counting tote boxes. From S_1 the work is issued as needed, one box at a time, to the operator at the *production point*, P_1. The production point in question may be one machine or a group of machines, under one or several operators, or it may be a bench job or some special test. After the operator at P_1 finishes the box of work, it is removed to the *inspection point* I_1, where it may be inspected in whole or in part (in whole only if 100 per cent inspection is required) or perhaps merely counted by the inspector. After the inspection, the tray of work is moved to S_2, the storage point for work waiting for the time being for the next manufacturing operation. When certain parts are rejected and a "broken" box results, the box should be filled up from the next box of parts or from a small stock kept for that purpose in the inspection room, so that only full boxes are issued from S_2 to P_2, and so on.

Layout of Central Inspection Crib

In centralizing the inspection into a central inspection system, we bring together in a central place and in accordance with some convenient arrangement all of the *storage points* (or banks of material in flow) and the *inspection points*, leaving in the shop proper nothing but the *production points,* together with such work as is actually being put through the machines at the production points in question. This means, when the system is carried to the limit, that after working hours all work in flow will be in the central inspection spaces, and therefore there will be no work at the machines, which condition insures a complete count of each day's work and tends to prevent trouble of various kinds, including the temptation to steal parts.

In concentrating the storage and inspection points at some central place or places in the shop, the greatest economy will be secured by a shop arrangement that reduces the distances between any two consecutive points in the line of flow, S_1, P_1, I_1, S_2, P_2, I_2, S_3, P_3, I_3, etc., as much as possible. For example, a good arrangement would be that shown in Figure 25.

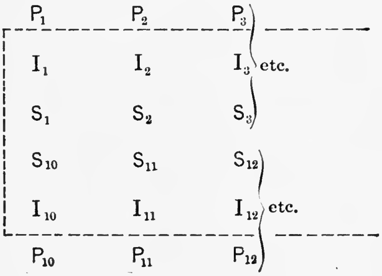


Figure 25

The dotted line indicates the separation between the shop proper, with its production points P_1, P_2, etc., and the central inspection space or crib containing the corresponding storage points and inspection points.

As a matter of fact, the diagrammatic arrangement just shown gives an erroneous conception of the quantitative space assignment required, because I and S ordinarily require much less space than P. Frequently I will represent only a counting of the work, without inspection. It is interesting to note, however, that a uniform distribution of work in flow (especially when standard sized tote boxes are stacked in piles) carries with it the condition that the spaces provided for all storage points be the same in size. The same thing can be expressed in much shorter form by saying that $S_1 = S_2 = S_3$, etc., which, incidentally, is a nice example of the saving in time from the use of symbols.

It is very likely, therefore, that the following diagram (Figure 26) more accurately shows the relative size of the space assignments for such an arrangement:

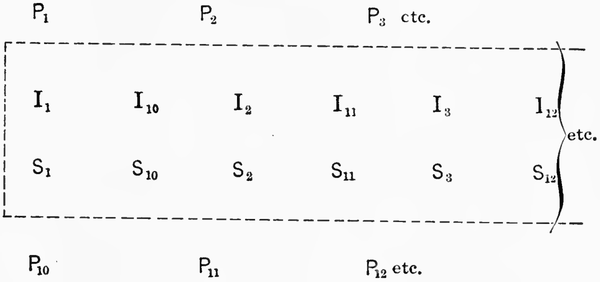


Figure 26

Construction of Central Inspection Cribs

It does not follow, by any means, that the collection of the points S and I in a central inspection space requires that this space be separated from the rest of the shop by partitions. That is a question which must be settled by the class of work involved and by the conditions attending its

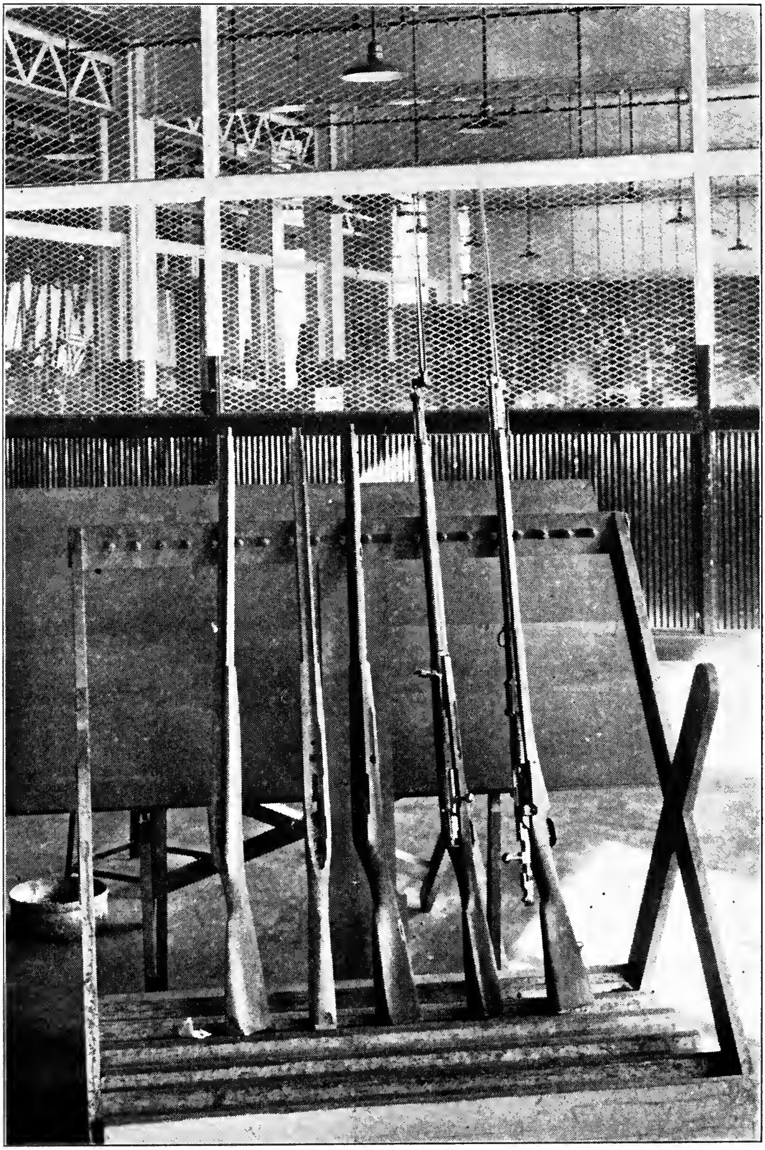


Figure 27. Transporting Rack for Rifles—Remington Armory, Bridgeport
Note especially the construction of the type inspection crib in the background.

manufacture. In many instances it is only essential that the central inspection space be indicated by lines painted on the floor, or by some other means of showing the physical separation of the principal functions that has been made. A light railing may suffice.

When the use of a partition is indicated by the local conditions, one of the best plans is to erect a light framework, supporting woven wire to a height of 6 or 8 feet. Chicken wire will do. (See Figure 28 showing a type section of a central inspection crib.)

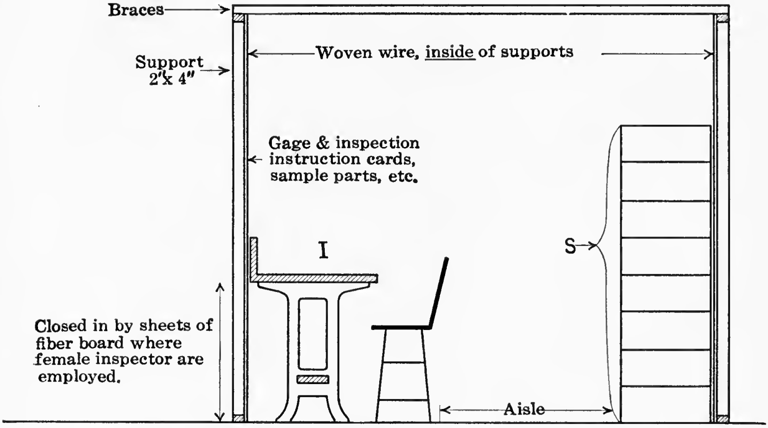


Figure 28. Type Section of Central Inspection Crib

The woven wire is preferably put up inside the line of supports. This arrangement avoids lost space and objectionable holes behind the inspection benches on the one side of the central inspection crib, and permits more orderly storage of work in process banks on the other side of the crib.

When partitions are used, it becomes necessary, of course, to provide openings through which work may be passed. If the work is bulky and each storage unit of parts is carried on wheels, for example, the opening should extend *upward from the floor* to a height just sufficient to permit the comfortable entrance of the carrying device. Smaller parts, that are handled in tote boxes or trays, usually require only a passing window with a shelf. These windows should be spaced close enough together to avoid too long distances from machines to windows. At the same time they should be spaced far enough apart to avoid interference with the inspection benches. It is not good practice in this case, nor is it ordinarily necessary, to have the machine operator deliver his work directly to the inspector who is to inspect and count it. There is far less chance of connivance between inspector and workman, together with less interference with the actual work of inspecting and counting, if the work is issued and received by the working foreman in the inspection crib, or perhaps by an assistant. Women inspectors, for example, may be employed on quite heavy work if they are relieved from having to lift tote boxes full of parts. When the flow is rapid, a worker of the common labor class will be fully employed in moving tote boxes to and from the issuing windows and the storage points.

Referring again to the typical diagram, the introduction of partitions with passing windows, or doors, brings about the arrangement shown in Figure 29.

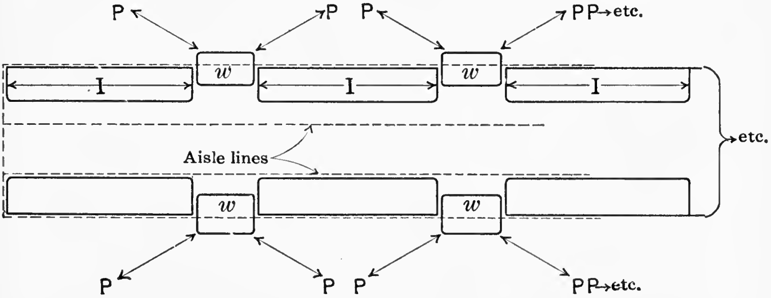


Figure 2). Floor Plan of Central Inspection Crib

An Adaptation to Rough Work

It is now proposed to show the application of central inspection in two cases, illustrating the extreme conditions that are likely to be encountered. The first example is that of a shop making a relatively small but bulky article, such as heavy canvas bags. The processing involves cutting the canvas and folding once, sewing the side seams, binding over and sewing the top seam, inserting a row of brass grommets above the latter, and finally passing a gathering cord through the grommets and attaching a fastening device to the cord. The work is counted automatically by the issue of lots of 100 pieces (on lifting platforms) from a central inspection space. Inspection, however, is by sampling at the machines, except after completion of the bags, at which stage there is a 100 per cent final inspection. In this instance it is less expensive to allow an occasional bad piece of work to slip through than to provide a closer inspection.

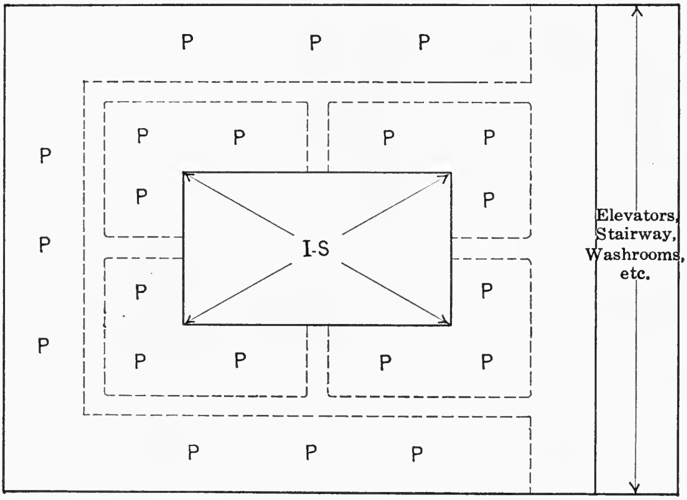


Figure 30. Floor Plan of Canvas Shop

Each shop was located in a room approximately 100 feet square, with machines, work benches, and work in process scattered throughout, but arranged in a general way in the order of operation sequence. The rearrangement is indicated in Figure 30.

One end of the shop was darkened by elevators, stairways, washrooms, and similar enclosures—a condition fixed by the building. The dark space in the middle of the shop (indicated by *I-S*) was cleared of machines, which were moved out to the light (*P*, *P*, *P*). The center aisle lines were closed, and the new aisle lines painted on the floor as indicated by the dotted lines. The new aisles were kept clear at all times. At each machine, two spaces (or platforms for lifting trucks) were located to provide one place for the lot of pieces ready for the machine and another place for work just passed through the machine.

The Resulting House Cleaning

The central inspection space *I-S* was not enclosed, but its boundaries were clearly indicated by the arrangement of benches and of work in the storage banks. As a part of the process of rearranging this shop, the foreman was instructed to clean house, and in doing so to be guided by the rule that everything not needed and *used* in the work must be discarded. After he was through, a wagon-load of junk was removed, in the form of unnecessary shop furniture, old signs, ancient records, and what-not, extending even to bench drawers that served no useful purpose. The subsequent application of a coat of white paint, and the introduction of the more orderly and systematic control of work in flow, created an obviously different working atmosphere. Incidentally the scrap value of the stuff removed paid for the direct cost of the clean-up.

This simple case has been cited for the reason that it is typical of a large class of work (often relatively rough work), to which the general principles and methods of central inspection can be applied with advantage.

An Adaptation to Close Work in Metal

Let us now proceed a very long way up the scale of application of central inspection, until we reach the other limit. In this case central inspection is to be applied to a shop making in quantity, high-grade steel parts of relatively small size—the machining is intricate, the limits are very close, the parts are strictly interchangeable, limit gages are in use, and the finish must be excellent. In short, the work is difficult, comparatively costly, and the standard of quality is almost high enough to approximate to that required for the very tools used in making the parts. Evidently, there will be need for close inspection after all important operations, sampling for practically all operations, and 100 per cent inspection of all finished parts. Since such work is ordinarily found in large factories, we may assume as well that the shop in question is only one of several such shops and that it handles the machining of but one of the parts—or at most only a few of them—that are to become components of a complex mechanism.

In a case of this kind, central inspection is a machine with a vitally important service to perform. Like any fine machine it should be designed with the greatest attention to details. It may have to be intricate, yet the design should follow the simplest and most economical line for accomplishing the desired result. Such an adaptation of central inspection is the most highly specialized form of inspection, and as such is the ideal instrument both for use in controlling quality and for insuring a uniform flow of work.

The usual type of factory floor for such work is from 60 to 80 feet wide (a greater width interferes with lighting); some 250 feet or more long; and built with sides constructed of steel and glass sash extending from the ceiling to within about 3 feet of the floor. While the glass siding is sometimes carried down to the floor, such construction is not desirable for work of this kind, as the light shining up from below the machines is trying on the eyes and therefore of deleterious effect on the work. There will be no really dark spaces in the shop, but the light may not be so good at the exit and entrance, nor at one of the corners at each end of the shop, if enclosed fire towers are built in at these points. The state laws require that clear passageways be preserved from end to end of the shop, for use in case of fire or panic. A frequent arrangement of a typical shop floor of this sort, as shown in Figure 31, provides for clear aisles at *a*, *a*, *a*, *a*, between the rows of columns.

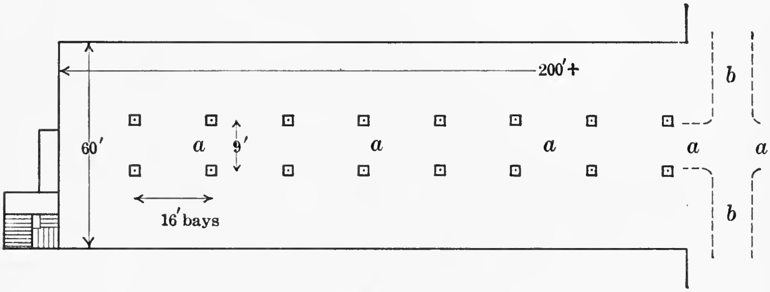


Figure 31. Typical Modern Shop Floor Plan

Aisle Arrangement

The aisles *bb*, connecting shop to shop may be found at the middle or end of the room, and since they are used for intershop traffic, must always be kept open.

Whether there are columns or not, it is usual to provide for a central aisle, which is kept clear at all times (at least in theory). Concurrently, it is necessary to have other aisles paralleling the main aisles, but out among the machines, to permit of the passage of men and material to the machines. These aisles are not so well defined, unless the machine arrangement is a simple and orderly one. It should be noted, however, that the aisles in question usually can be regulated into clear and fairly well-defined passageways, thus permitting the use of the former middle aisle for central inspection. In many cases, especially when combined with central storage of work in process, this arrangement will result in an actual economy of floor space, due chiefly to more efficient use of the space otherwise taken up by work in process. There is developed in this way the arrangement shown in Figure 32.

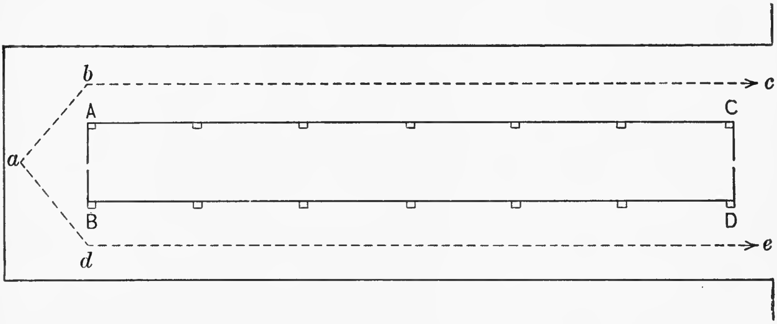


Figure 32. Modern Shop Floor Arranged for Central Inspection

The necessities of transportation and emergency exit are met, under these circumstances, in two ways:

1. At least one fairly well-defined passageway is provided among the machines at each side of the shop, along the lines *abc* and *ade*. There must be a passageway among the machines; and since the machines are in fixed locations, the principal cause of blocked passageways is eliminated when the material at each machine is limited to one standard-size lot of parts.

2. These aisles are supplemented by providing double-swing doors (if any are required) at the ends (*AB* and *CD*) of the enclosed inspection space *ABCD*. The inspection benches and material in process along the sides *AC* and *BD* decrease the effective width of the former central aisle, but not so much as to eliminate the passageway. The side aisles are therefore supplemented by a more restricted center aisle, and, all in all, ample gangway is secured.

There are many other arrangements, of course, in which a shop can be laid out to provide for central inspection, but the scheme just outlined, while of admitted uniqueness, has much to commend it in many cases. It provides a central place from which to distribute work, economizes the floor space of the whole shop, and can be used in adapting central inspection to many shops not originally arranged for this system of control. Any such location of inspection cribs carries with it a positive requirement for artificial lighting of the inspection benches, but this is not a serious objection because the more uniform light of good artificial illumination has much to commend it for inspection purposes.

Advantages of Several Centralized Inspection Spaces

Whether this or some other plan is adopted for the location of the central inspection cribs, it is well to observe that central inspection does not imply *one inspection room only*, nor even *one room only in each shop*. On the contrary, the more efficient arrangement in a large shop is to place the cribs at the locations where they give the maximum of service with the least interference to traffic. The governing conditions should be that each inspection crib be centrally placed with reference to the machines it is to serve, and that it be large enough to store its proper quota of work in process.

The least interference with traffic is secured when the crib is parallel to and near the normal line of flow of work. It will be found that there is much lost space in the ordinary shop arrangement which can be made available if the shop layout is carefully planned with reference to the space occupied by work in process as well as that taken up by machinery. Thus, if there is insufficient room for all of the inspection work in the shop itself, the next logical place to utilize is some space on the side of the passage from shop to shop. It is quite usual to find unused space going to waste in these locations. In such case it is clear that this space should be utilized for the inspection work that can best be spared from the neighborhood of the machines, i.e., the final inspection of finished parts, and the salvage or reinspection of rejected work.

Standard Arrangement Desirable

Reference already has been made to the fact that each inspection crib should be designed with great care as to the details, but, naturally, each crib should be laid out in accordance with a general unified plan for all of them. To illustrate, the outline shown in Figure 33 may be assumed to be that of a central inspection crib which is typical for a given factory.

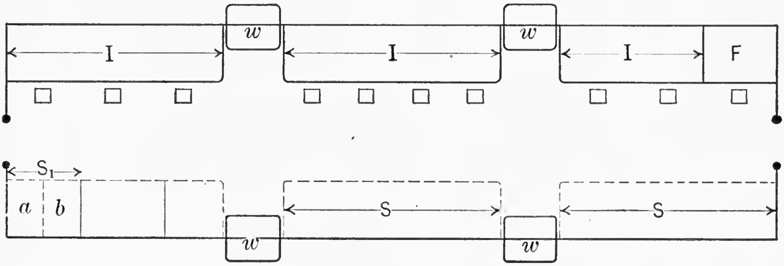


Figure 33. Type Floor Plan of Central Inspection Crib

The size of the crib will be determined in a general way by the amount of space required for storage of work in process, for the reason that if this space is provided on one side of the crib there is pretty sure to be room enough for the inspection benches on the other side. The passing windows *w*, *w*,---- will be placed at fairly uniform intervals, but this should not be a fixed rule, as the most convenient locations, with reference to the number of machines to be served, should be selected.

As the normal work bench with wooden top, back rail, foot rail, and metal frame support is satisfactory for the purpose, a number of them should be placed at *i*, *i*-- and shop stools provided. Reasonable bodily comfort is a great relief to the confining tedium of bench inspection. Bench drawers are not desirable in most instances. If it is necessary to provide against the chance of gages being tampered with outside of working hours, a cupboard, with a lock, may be provided.

On the side of the crib opposite the inspection benches, the space should be marked off for storage of work in flow. If the two-bin principle is followed, each unit storage space should have two sections, as S_1 (*a*) and (*b*). There is, of course, a natural limit in the height to which any kind of tote box can be piled with safety and this fact should be considered in laying out the storage point. Furthermore, the height that corresponds with the number of boxes of work required in each bank to maintain the flow should be indicated on the side of the crib. With these refinements in use, each storage point will be shown by a card or other mark on the side of the crib, as shown in Figure 34.

A pointer may be used to indicate the issuing pile, but is not necessary if the issuing and receiving sections are reversed automatically at given times.

The inspection benches should be marked off, or the inspection points indicated by labels showing the operation symbols on the side of the crib above the benches. It may be found very useful to supply a gage instruction card, telling in detail how the gages are to be applied, and setting forth the special points to be looked after. It is often desirable to furnish sample parts, which should be tied to the side of the crib over the bench, to prevent their becoming mixed with the regular work. (See Figure 12, page 71.)

Assuming a direction of flow from left to right in Figure 33, the inspection points will be arranged in this order, a separate bench being provided at *F* for the use of the crib boss or working foreman of the crib. Among other purposes, this bench will serve as an issuing point for working gages, which is an essential feature of quality control, as will be noted later under the subject of gage-checking.

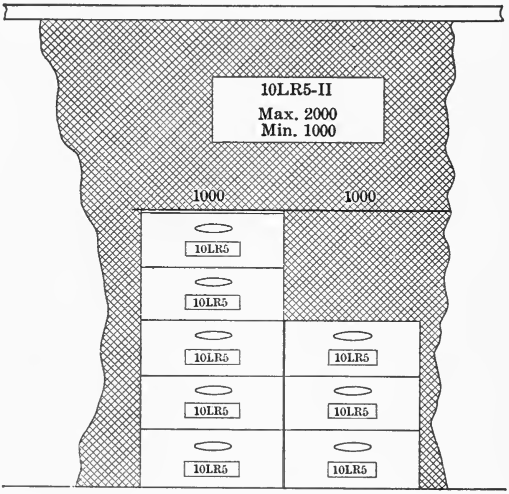


Figure 34. Type Arrangement of Material Storage Point in Central Inspection Crib

Summary of Advantages

The advantages of providing, within the producing shop, a central inspection crib combined with a storehouse for parts in process, may be summarized as follows:

1. The work can be stored in self-counting trays. A workman will come to the issuing window and obtain a box of parts, which he will machine and return. The inspector

will find that some are good and some bad, and the workman will be credited accordingly. He will be paid for what he does—and for no more nor less. This will insure, among other things, the collection of accurate data as to what is going on in the way of production and will tend to do away with losses from stolen, destroyed, or lost parts.

2. There will be nothing at the machines outside of working hours, and nothing at each machine but a box of parts at any time during working hours—result, a *clean* shop, and a *clear* one.

3. The systematic arrangement of all parts in flow makes it possible to check up the flow by quickly visualizing its condition, i.e., it is possible to *plan with the material itself* rather than with figures alone. A walk through the crib tells the story.

4. The control of quality is more certain, as the work of the inspectors can be supervised to greater advantage and the custody of work in process is well centralized. The information necessary for inspection can be so arranged in useful form by providing each inspection point with standard samples, gaging lists giving the symbol of the gage to be applied and the percentage of inspection, gage instructions, etc. All gages can be issued and controlled from this point.

5. The routing and flow of work is under sure control.

CHAPTER IX

THE ORGANIZATION OF THE INSPECTION DEPARTMENT

Designing the Instrument for Controlling Quality

Before plunging into the particulars of a subject like "organization," a term which is often confused with the related terms "administration" and "management," it would seem to be worth while to make sure at the outset of what we mean by "organization." In order to separate out the idea, let us first think of the inspection department as a machine or an instrument for use in the control of quality, together with certain secondary duties to be combined therewith as a matter of economy. The organization of the inspection department may be considered as comparable to the design of the machine, and the administration or management of the inspection department as comparable to the operation of the machine thus designed. In accordance with the foregoing analysis, questions affecting the management of the inspection department will be discussed in the succeeding chapter.

The Development of Organization

The process by which organization develops may be analyzed into three steps:

1. There is a union or grouping of individuals for a common purpose. From this fact, arises a necessity for organizing.

2. The work necessary to accomplish the purpose is divided and distributed so that each group of individuals performs the work allotted to it with undivided authority

and individual responsibility. This division of duties tends to become more complex as the number of persons involved increases or as the scope of the work broadens.

3. The interdependence resulting from the preceding steps demands a co-ordinating of the work of the separate parts or groups, in order to secure co-operative action, and thus to weld all groups into one coherent whole so that all work harmoniously toward the common objective.

Organization begins with the first of these stages, it is developed by the second, and is completed and perfected by the last. The higher the type of organization, the more intricate is the distribution and division of labor; and this fact, in turn, calls for better co-ordination, together with closer and stronger co-operation.

In the light of these general observations we may proceed to design an organization for the inspection department. As we are designing with men as our material the design must conform to the capabilities of the men that are available; furthermore it must be suited to the conditions imposed by the character of the work to be performed. The discussion that follows applies, as will be noted, to the organization of an inspection department for a large factory doing high-grade interchangeable manufacturing, but the same principles apply in simpler cases, and the organization may be readily and suitably simplified for such situations.

The Chief Inspector

It is almost begging the question to say that if the right man is at the head of the inspection department, there need be no worries about the organization and management of that department. But what type of man is called for? The position is one of trust, hence character is an indispensable. Good judgment is requisite, not only the judgment that flows from "mechanical sense" and skilled ability as an engineer, but also plain "horse sense." In addition the man must be an executive of no mean ability.

Many persons have been so accustomed to regarding inspection as one of the secondary features of manufacturing, that they fail to realize what complex and extensive organizations have been evolved for the inspection departments of large factories. It is by no means an uncommon thing nowadays to find an inspector for every 10 to 20 workmen, and the proportion may be much higher. In the Wahl Company of Chicago, which manufactures, among other things, the ubiquitous Eversharp pencil, the proportion of inspectors is 1 to 8.6 workers.[1] In the S. K. F. Ball Bearing Company's plant at Hartford, where every operation is 100 per cent inspection, 27 per cent of all the productive workers are employed in the inspection department.[2] Under difficult war conditions, the inspection department of one of the munition plants reached a total figure of 2,200 employees, and possibly there were larger inspection forces in other plants.

Even under normal conditions, it will be recognized from the above figures, the head of the inspection department has an executive job of no mean size. The duty is very greatly enlarged and complicated, moreover, by reason of the fact that the inspection department is not concentrated into one definitely bounded shop, like the various production departments. On the contrary, its work reaches into nearly every part of the factory, and in consequence its personnel is widely scattered. The character of the work is at least as diversified as the processing, which fact still further complicates the problem; for the inspection force will have one group of workers in the wood-working department, for example, while a thousand yards away it will have

---

[1] Furnished through the courtesy of C. A. Frary, General Manager.

[2] Courtesy of R. F. Runge, General Factory Manager of S. K. F. Industries, Inc.

another group engaged in the inspection of metal parts made to standards of accuracy so precise as often to split thousandths of an inch. Therefore the chief inspector should be generally familiar with all shop processes rather than a specialist in a limited number of them.

Duties of the Inspection Department

Concurrently with selecting a man to take charge of the inspection department, there arises the problem of outlining what this department is to include. Conversely, the amount of work that it is expedient to include will determine how big a man should be selected to head the work. The two things always go together, and the resulting solution is usually a compromise. Obviously, the duties of the inspection department will often comprise a number of things that, speaking strictly, are not inspection, but they will all be related to inspection, and it will be economical and wise to include them with inspection, in order to secure a more complete control of quality.

In the first place, there will be the separate inspection forces for each main group of the factory's work, as in the case of an automobile factory making both trucks and passenger cars. Each of these main groups will be subdivided into an inspection force for each shop, or smaller factory unit, including the assembling shops.

Work Related to Process Inspection

In addition to this inherent duty, we may list the following:

1. Raw material inspection, including the necessary laboratories, chemical and physical.
2. Heat treatment inspection, including the metallurgical and metallographic laboratories.

3. Tool inspection, especially if the factory maintains a tool-making shop.
4. Gage-checking and the verification of measuring standards, all in close co-operation with the chief engineer.
5. General supervision of the assembling department, in some instances, where inspection in this department is of unusual value in guiding the work of the parts-making shops.
6. General supervision of the factory salvage department, when it is specially desirable to safeguard production from the return of defective work into flow.

The inspection of machine tools and similar factory equipment, as well as of the buildings and their appurtenances, has not been included as a possible assignment of the inspection department, for the evident reason that the inspection and maintenance of all these constitute the principal duty of the works engineer. It will be carried out by the latter with due regard to the fact that every department in the plant will be "on his trail" if he overlooks anything that requires attention.

The general test for deciding whether a particular branch of factory endeavor should be included in the inspection department is simply this—"Will the chief inspector handle it to the better advantage of the entire plant or not?" The answer depends, of course, to a considerable degree upon who and what the chief inspector is.

Undoubtedly the term in widest use to designate the head of the inspection department is that of "chief inspector." It has grown up in much the same way as the title of "chief engineer," and it is possibly just as well to retain its use, although there are many organizations in which the strict following of the plan used in the general factory organization chart would result in the more definite title of "manager of inspection," or possibly that of "director of inspection." The matter of title, however, is of no great moment, for the greater one's experience in factory work the less will be the emphasis placed upon titles. But there is a matter of marked importance which should not be overlooked for an instant if the control of quality is to be assured—the chief inspector should report directly to the highest executive authority in the management, and to him only.

The Line Organization

In outlining the organization under the chief inspector's jurisdiction, it is believed that the best result will be obtained by a combination of line and staff, as in the case of the general organization of the factory itself. The line organization will consist of the usual executive heads of the different groups of workers, i.e., general foremen-inspectors, foremen-inspectors, subforemen or crib-bosses, and so on, making up the "chain of command" through whom instructions will pass from the chief inspector to the individual inspectors at the bench.

The staff of the chief inspector will consist of a few carefully selected specialists who have no executive authority over the line executives, other than that which naturally belongs to them by reason of the moral effect of their close association with the head of the department.

Arranging the type form of organization in chart form results in the arrangement shown in Figure 35.

It is generally conceded that no executive should have more than a limited number of subordinates reporting directly to him. This number varies with circumstances, but in work of this kind should not exceed ten or twelve at the outside, as there is such a volume of small questions requir-

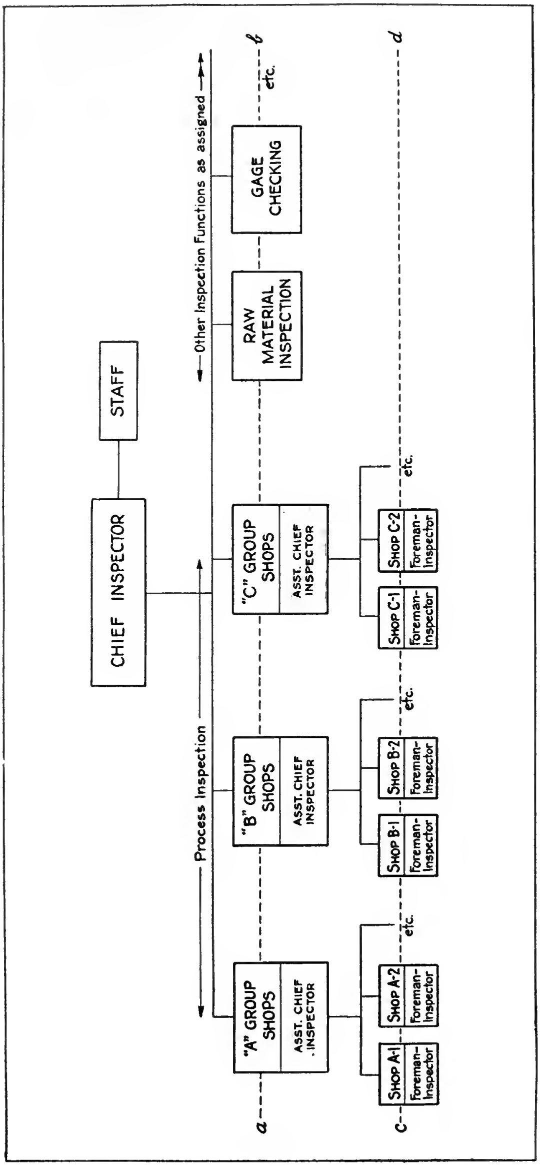


Figure 35. Organization Chart—Inspection Department

ing prompt settlement, to say nothing of the demands on the chief inspector's time for continuous constructive work. Therefore in a concern making several lines of product, there should be an inspection superintendent (or a general foreman-inspector) in general charge of each group of shops. The principal assistant to the chief inspector may very well be one of these superintendents. On the chart shown (Figure 35) any other departments that may be assigned to the care of the chief inspector (such as the laboratories for raw material inspection, the gage-checking department, etc.) should be added, as separate main divisions, on the line *a-b*.

The line *c-d* of the chart provides for a foreman-inspector in charge of each production department, and since inspection is best performed when strictly specialized according to classes or kinds of work, it is suggested that there be a separate foreman for each different kind of production department in the group, even if this results in considerable disparity in the sizes of the forces reporting to the various foremen-inspectors. Thus the foreman-inspector of the woodworking department in a small-arms factory may have several shop floors under his care, while the heat treatment department foreman-inspector has only one. In other words, the inspection organization should parallel the production organization in this respect, rather than attempt to equalize the jobs by combining different small departments under one head.

Special Value of Understudies

It is specially essential in inspection work that understudies be designated for foremen-inspectors and their more important assistants. This arises from the fact that the personnel of the inspection department's supervisory force must be relied on to a large extent to see that standards of quality do not shift; the need is great even when every care has been taken already to fix the working standards as definitely as possible. In the work of keeping standards from shifting, the inspection foremen accumulate a large body of knowledge in the form of small details, which cannot be quickly passed on from man to man, but must be absorbed from contact with the work. It is therefore very important that the organization provide for continuity in this respect, so that what might be called the "complete standard" will be carried along from shift to shift and the gaps caused by the absence of any member of the supervisory force safely bridged.

If a foreman-inspector has a department which comprises several separate floors or shops, he will need an assistant in each shop. This man's duties, in addition to maintaining discipline, will involve a continuous checking up of the inspection work going on in the shop, deciding doubtful cases—which arise principally in the reinspection of rejected work—overseeing the care of gages, and attending to the orderly storage of work in process. Each inspection crib should have a working inspection boss—that is to say, one of the ablest inspectors working in the crib should be designated to assume general charge of all the work going on in the crib. The working force in each crib will consist generally of inspectors, counters, and in addition, especially if the boxes of work are heavy and if the flow of work is rapid, a common laborer or two. The counters are, of course, engaged in the work of checking up the quantity of work performed on operations that are not inspected, and are listed separately merely to indicate that this work should be performed at a lower rate of pay from inspection proper.

Duties of Inspectors

In this connection it may be noted that a misunderstanding sometimes arises when the employment department hires men as inspectors, and the inspection department subsequently places them in central inspection cribs where they may have to do more physical handling and lifting of boxes of work than they do inspecting. The individual thinks he is going to be an inspector, but finds difficulty in distinguishing between his work and that of a shop laborer. It is suggested that this difficulty may be lessened by creating the position of assistant inspector as an intermediate step between common labor and bench inspector. If the employment department is careful to make clear to the applicant what his duties are to be, there is less chance of a misunderstanding later on.

Central inspection is usually reinforced by a small group of floor-inspectors. These men should be of a higher grade than the bench inspectors in the crib, and probably higher even than the working foreman of the crib, since their duties are performed more independently. Consequently they should report directly to the assistant foreman in charge of inspection in the shop, and not to the crib foreman.

The Chief Inspector's Staff

It was remarked on page 144 that the chief inspector's staff should have *no executive authority*, other than that which accrues to them by reason of their close association with the chief inspector. The latter fact will naturally give them all the prestige their work requires. The staff organization should be laid out along functional lines so as to provide a general service for the help and guidance of the line executives. It must secure also, for the assistance of the chief inspector, *an inspection of inspection*, without destroying the individual responsibility or dividing the authority of the chief inspector's subordinate executives. Such division of authority is one of the greatest dangers in large organizations of combined line and staff type.

Thus each staff assistant will be a carefully selected specialist, combining the work of an instructor in his line of work with that of assisting the chief inspector in checking up his assigned part of the work throughout the entire department. The staff duties to be performed may be listed as follows, with the understanding that some of them may be combined under one individual where the volume of work warrants it:

1. Personnel matters, including the investigation of questions affecting pay, promotion, discharge, assignment of new employees, etc. This work usually requires the entire time of one man.
2. Follow-up of technical instructions from the chief inspector's office to the inspection force, including checking up the adherence to prescribed standards.
3. Care, use, and custody of gages, including making sure that all gages pass through the gage-checking department as scheduled.
4. Analysis of trouble reports from the foremen-inspectors, especially those relating to technical difficulties encountered in the parts-making shops and in the assembling department. This work includes the further investigation of the reports, also seeing that the more important ones are placed before the chief inspector to bring to the attention of the proper authorities in the general factory organization.
5. Liaison duty with the production engineer to see that the inspection department is collecting production data for him in a satisfactory manner.

In addition, the chief inspector frequently has small technical matters requiring the services of a junior engineer to conduct the preliminary investigation. It is suggested

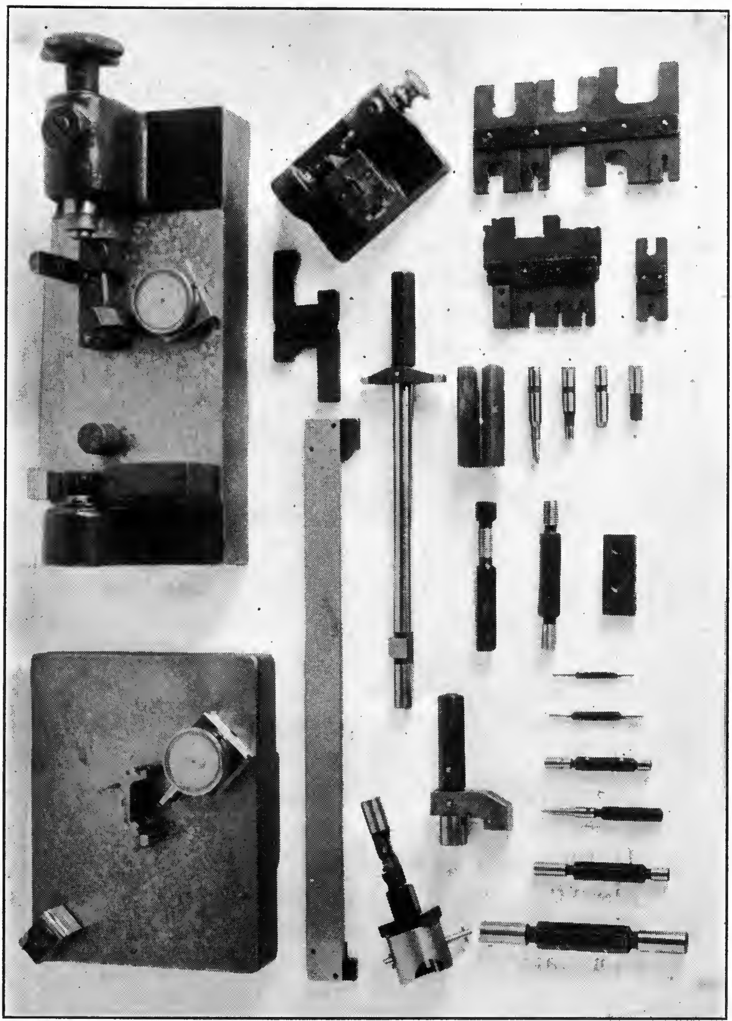


Figure 36. Various Sorts of Special Manufacturing Gages
Made by the Pratt and Whitney Company.

that such men be taken from time to time from the rank and file of the inspection force, or from the laboratories. This practice will serve to broaden the men in question, and will accomplish the specific purpose in hand quite as well as if they were permanently assigned to the staff of the chief inspector's office. Under some conditions, as a more or less temporary expedient in guiding the factory toward the best compromise required by the commercial situation, the chief inspector may be given a staff assistant taken from the sales department. In this case the sales department may be regarded as the purchaser and the sales representative as the purchaser's inspector.

The Inspection Department Personnel

Little has been said as yet about the qualities to be sought for in choosing men for the duties of foremen-inspectors, their assistants, and the working inspectors. The problem is not one of choosing the kind of men who are best qualified, but rather of making the best use of the men that are available. There is "history" in the statement, as more than one chief inspector can testify from sad experience in recent years.

Some of the men who take employment in the inspection department have had previous experience in technical work, and some have not. If the experience of the former class has resulted in a self-sufficient knowledge, they should be replaced by men of the class who have no such technical experience, and know that they do not have it, because the inspectors *must* follow the standards set, without modifying them in the light of their previous experience. In other words, obedience to orders is the prime desideratum.

In assigning duties in the inspection department organization, therefore, it is necessary to place the personnel so as to grade the amount of discretion to be allowed in matters requiring the exercise of judgment. It might be said that the amount or quantity of judgment to be applied by any individual member of the inspection force should be decreased as we go down the line from foreman-inspector to the inspector working in the crib.

The Bench Inspector

The inspector applying gages at the bench, or inspecting finish as to sample, should be the kind of person who has reasonably good eyesight and tactile sense; but more than this he must be temperamentally suited to doing exactly what he is told to do. This will consist in sorting the work he is inspecting into work that is clearly according to standard, work that is clearly *not* according to standard, and work about which he is doubtful, leaving the decision as to the latter class of work to his immediate superior. As stated before, this process implies reasonably definite standards of quality in the first place.

The Floor-Inspector

The floor-inspector should be of entirely different character. He has the important duty of first-piece inspection before he authorizes a machine to begin a run of work. In addition he may be given the right to order a machine stopped if the work is not to his satisfaction. This calls for good judgment backed up by practical experience, hence the floor-inspector is usually a first-class machinist, to whom the title and duties of inspector may make an appeal, or who views this work as a step in the direction of a foremanship of some sort—which it certainly should be.

Salvaging Native Ability

Practically every large inspection department possesses a unique characteristic, and a very happy one. It is a veritable "gold mine" of men possessing unusual native ability and good character, but lacking experience in factory work. Every once in a while, and for various reasons which do not matter, some man decides to make a radical change in his work. His very lack of acquaintance with factory life may be the source of his desire to try it, and he presently appears at the factory employment office. Having no knowledge of machinery, he hesitates to attempt machine operation, even if the way is made easy for him to acquire the necessary skill; but the title of inspector may make a special appeal, both as a dignified occupation and as an opportunity to learn more about manufacturing methods at close range.

This is one explanation of the presence of such men in the inspection department. As to where they are to be discovered, the answer is, obviously, at the bench, usually working quietly but nevertheless with their eyes open to what is going on around them in the shop. Unless the foreman is an unusually human sort of executive, he will fail to see the possibilities in these subordinates. Someone higher up must keep an eye out for such men, and see that they are given the chance they hoped for when they entered the establishment.

A Case in Point

The circumstances just referred to came to my attention for the first time a few years ago, in the course of reorganizing an inspection service of some 2,000 employees, where an excessive labor turnover in this department was considered to be one of the primary reasons for defective control of quality. The problem of reducing the turnover was attacked by direct action—the chief inspector had a personal talk with every man entering or leaving the department. The experience was somewhat arduous, but this was more than offset by the results, which were felt almost immediately.

A certain foreman-inspector complained regularly and frequently that the men supplied him were " no good." The foreman himself was a man of long experience in the business, and by reason of this fact seemed unable to adjust himself to the necessity of training the men supplied him rather than expecting to find men already skilled in their work—a situation resulting from the war time labor condition. Most of the men leaving his department gave every reason but the right one for quitting, probably in the factory spirit of being good losers. Presently, however, a man appeared in the chief inspector's office on his way out. Character and personality were written plainly on his face. Under pressure he told his story, and in a detail that showed a keen grasp of conditions.

Briefly, the story was this. After completing a semi-technical college course, he had taken a political job, and by an unlucky swing of the political pendulum about fifteen years later found himself under the necessity of seeking other means of supporting his family. So he turned to this particular factory because he had heard of possible opportunities there. It looked to him like a fresh start with good chances for a satisfactory career. After three months at the bench as an inspector he confessed that he knew little more about the intricacies of the business than when he started. What he did know, he had been forced to dig out by himself without encouragement from above. On the other hand, he knew what was basically wrong in that shop better than the foreman-inspector himself.

This experience was the cause of starting a school for such men under an old foreman who possessed a heart as well as a head, and who passed on enough of his practical knowledge to enable his pupils to qualify as tool-setters and gang bosses. After this, promotion was up to the individual, but he was always encouraged to bring his problems back to his old instructor for helpful advice. The man whose case was just referred to became assistant superintendent of a large production department in about six months from the time when he was ready to give up in disgust and discouragement. Several other men, discovered in the same way, were developed into excellent foremen instead of being lost to the organization.

Study the Individual

All of which suggests that while the individual unit of an organization may be, in one sense, part of a machine, he nevertheless is a man, with all of the perfectly natural limitations and variable potentialities of a human being. I venture to say that there is nothing in the entire work of organizing and running the inspection department (not to mention the rest of the factory) that will yield so large a return, both in actual accomplishment and in personal satisfaction, as the study of the men themselves.

CHAPTER X

MANAGEMENT OF THE INSPECTION DEPARTMENT

The Task

The chief end to be sought in the management of the inspection department is to obtain a firm control of quality by holding the work to definite predetermined standards; and to accomplish this with the maximum of economy. The task presents at least two essential differences from the management of a production department of commensurate size:

1. The working force is widely scattered and the work unusually varied. Co-ordination is difficult.

2. The pay of inspectors is nearly always low in proportion to their responsibilities, with attendant difficulty in attracting and keeping the right kind of labor.

Co-ordination

The first step in co-ordinating the work of the inspection department is to see that the chief inspector's office is located as nearly as may be in the center of the plant.[1] The inspection force is concerned with every manufacturing process going on in the factory and with many of the general service departments. It reaches into every part of the plant. Questions arise every hour of the day that call for settlement by personal conference with the chief inspector or some member of his staff. Much time and effort will be saved by lessening the average distance to the point of trouble. Furthermore it is greatly to be desired that both production and inspection department executives feel that the chief

---

[1] In the author's opinion, the same statement is true for all executive and managerial departments. See "Production as Affected by Size of Plant," by G. S. Radford, *Management Engineering*, Aug. 1921.

inspector is in as close contact with the work as they are themselves. The chief inspector's job is not in the front office, but rather in the very heart of the works. Moreover it is in every way a more sociable arrangement, and that is desirable.

The Use of Conferences

In co-ordinating the efforts of his own executives, the chief inspector will find use for all of the ordinary devices of good management. He will find conferences with his superintendents and foremen of special value.

Incidentally the main purpose of the conferences will be obtained more surely if the chief inspector does not do all the talking. The men in the room will be brought together better if they come to accept the conference as an opportunity to obtain the help of several minds in working out their immediate and most baffling problems. The chief can soon develop good fellowship and a common interest in the work of the entire inspection department, by a little adroit steering.

A conference of his immediate subordinates once a week will be sufficient under ordinary circumstances, but it is suggested that this practice be supplemented by an occasional conference with the inspection executives of each inspection group, for the principal purpose of developing a closer personal contact and acquaintance between the subordinate executives and the chief of their department. For the entire department should be in harmony with the chief's policies and therefore quick to react to his instructions as they are passed down the line. Such flexibility of control will be strengthened more certainly by personal acquaintance and through frequent contact the personality of the head of the department will be reflected in the department as a whole.

Letters of Instruction and Advice

It will be found to be an excellent plan, in co-ordinating the various units, if each foreman and staff employee is supplied with a simple letter-size binder for keeping a file of department bulletins. These bulletins should be issued from time to time from the chief inspector's office as a quick means of conveying his executive instructions to the entire organization, defining his policies and supplying technical information. The book should be kept on the foreman's desk for the subforemen to read, and it should be the duty of one of the staff assistants to question the subforemen occasionally about the messages in the bulletins which specially concern their work, so as to encourage them to keep in touch with the plans and policies of the department. The scheme will not work unless it is closely followed up, but it can be made a most potent force in keeping men "on their toes" and working harmoniously, especially if the bulletins or instruction notices are explained and discussed in conference.

Finally, it is in the general work of helping to keep the entire department pulling together smoothly, that the members of the chief inspector's staff will justify their employment. To make their work most effective, the chief should encourage them to confer with him. Whenever practicable they should make their headquarters in the chief's office.

Reduction of Turnover of Inspection Force

No matter how thoroughly standards of quality are specified, there will be a certain amount of incompleteness in the statement of them that can be filled out only from the accumulated experience of the inspector. Again, it requires a varying length of time for any inspector to acquire the technique necessary to apply a given gage with the desired accuracy and skill, or to conduct satisfactorily any given inspection operation. Because of these reasons it is important that the personnel of the inspection force be as permanent as that of other departments, or even more permanent, if standards of quality are to be prevented from fluctuating. This is in addition to the usual loss in quantity of work performed, due to excessive labor turnover in any class of work. The disparity in pay already referred to is a disturbing element and the turnover in a large inspection department is likely to be unduly high in consequence.

Obviously, the primary action to take in order to stabilize conditions is to employ people for inspection work who are most likely to take to it kindly. For example, the inspection work is usually less strenuous than the operation of manufacturing machines, which indicates the employment of people (frequently women) who cannot stand the physical strain of the heavier production work, and know it.

Provision for Promotion

When a relatively high degree of experience and skill are requisite, as in the case of floor-inspectors, there should be assurance that the inspection force will share in promotions to assistant foremanships in the production departments, so that the inspectors have something to look forward to when higher vacancies are to be filled.

Since the easier way of the direct financial incentive is mostly barred, resort must be had to every possible non-financial incentive. That is to say, in brief, that the inspection department must be handled so that it will come to be recognized as an excellent place in which to work—and more important yet, a force that a man should be proud to belong to. The work can be made pleasant if the inspector is treated by his executives with just a little more friendliness and courtesy than is customary in shops. I do not mean to imply that his job should be made a soft one. On the contrary, the spirit of the organization, and hence the dignity of the work, will be greatly enhanced by stressing the value of character, by cultivating a pride of achievement in terms of accuracy, and by a rigorous demand for personal responsibility. But all of this should be tempered by a very obvious interest, on the part of the chief inspector and his assistants, in the personal welfare and interest of everyone in the department. If this takes only the form of an evident willingness to help the other fellow to help himself, the object sought will be attained. All parties gain—the executive by having a more contented and efficient force, and the subordinate by having a conscious increase in satisfaction in his work, through the knowledge that his value to himself and to others is growing all the time.

Wages

Owing to the fact that it rarely is practicable to measure the work performed by inspectors, it is the general practice to pay them on the day-wage, or hourly wage basis. It frequently occurs that the inspection work must be performed in a shop where the machine operators are paid on a piece work or similar system based upon the quantity of work performed. Hence it is not unusual to find a situation arising where ordinary machine operators are paid at rates considerably in excess of those paid the men who inspect their work, and under such circumstances, there is more than the usual difficulty in keeping the inspection force in a contented frame of mind.

The easiest apparent cure is to raise the wage scale for inspectors, but that way is rarely open, in spite of the fact that the inspectors perform work in many cases that is worth enough to warrant a higher scale. An economy in total cost might conceivably be attained thereby, but in nearly every plant, inspection is regarded as a necessary but regrettable and non-productive expense. Consequently the chief inspector is faced with the problem of doing the best he can with a strictly limited pay-roll, and therefore is forced to use the lowest rate of wages that will keep him supplied with a grade of labor that will do.

As a result the chief inspector and his foremen will be besieged with requests for raises in pay, and a relative degree of contentment can be obtained only by having a definite rate of promotion with graded rates of pay based upon length of service in combination with efficient work. This, I believe, has been found to be the best solution under the day-wage system for all kinds of work. I have seen the labor turnover actually decreased by the flat announcement that no increase in pay would be considered for sixty days, and this in the face of insistent demands for raises. In this instance, however, there had been no systematic arrangement for graded increases, so that the practice of asking for raises had grown up, with the net result that the granting of one request only served to encourage others.

Piece Work in Inspection

It is believed that inspectors working on small pieces can be paid piece work to advantage in many more cases than would ordinarily be supposed; but this system, obviously, can only be used to advantage when the work warrants a check inspection, or inspection of inspection by sampling all work after the piece working inspectors have gone over it. When this can be done without sacrificing quality, the usual economy inherent in the piece work system will be experienced, although the individual worker makes more money. Inspectors employed on piece work, however, must be penalized strictly by non-payment for any boxes of work found to contain defective parts, and less heavily for the rejection of good parts.

Working Hours

Another potential source of discontent arises from the fact that at least a part of the inspection force will need to be on hand both before and after the regular working hours. It is especially important that the inspection cribs be ready to issue work before the beginning of work in the shop—sufficiently early, indeed, to make sure that all machine operators are supplied with work well ahead of time. Otherwise the production force have a valid cause for complaining that they are delayed in getting to work promptly. Then again, it is often desirable that work turned in at quitting time should be inspected at once. When choke-points occur this may be imperative. The suggestion is offered that much unnecessary hard feeling can be stopped by a definite understanding, at the time of employment, that the working hours of inspectors will be staggered a little out of phase with the regular shop working hours. The total time can be adjusted by allowing a longer time for lunch and by a reasonable leniency in days off. The time outside of regular hours need not exceed 15 minutes in most cases, so that adjustments of total time are not difficult. Needless to say, overtime should be avoided with care, as both costly and conducive to the creation of additional and needless overtime.

The Cost of Inspection

Most chief inspectors will agree that the average foreman-inspector, by reason of his being a foreman-inspector and concurrently with his assumption of that duty, at once develops an unusual ability to ask for more inspectors, and for better inspectors, and for more gages. Now as all of these things cost money, which is a relatively rare commodity in so far as the chief inspector's disbursements are permitted to go, some other way out must be found. For example, the foreman may be shown that more men does not necessarily mean a corresponding increase in the amount of work performed. Thus in the curve shown in Figure 37—in which the abscissae represent the total number of men in the working force, and the ordinates represent the total amount of work performed—it is not unnatural to assume that output will increase in direct proportion to the number of people engaged in the work, as shown by the line *OA*—the more men, the greater the total output.

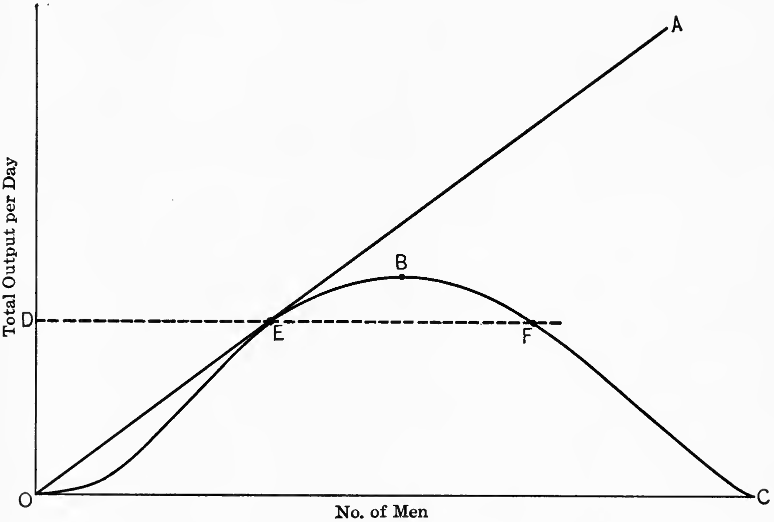


Figure 37. Curve of Output and Number of Men

As a matter of fact, a little consideration will show that the curve *OBC* is more nearly true for any given job, for the reason that a point, *B*, is soon reached where additional help only interferes with the people already at work, until at *C* the shop is so crowded that no one can move, and the output returns to zero again. Hence it follows that for any given output, *OD*, there are two limiting numbers of men, *DE* and *DF*. It is the painful lot of the inspection department to work a little inside of the number of men indicated by the point *E*. This may not be entirely convincing to your foreman, but it at least shows them what they are up against in asking for more men.

Teaching Inspectors

Rather than engaging more men, therefore, it is a matter of increasing the efficiency of the allowable force and here it may be noted as a fortunate circumstance that inspection work lends itself readily to very marked economies in the way of greater output per man, through the application of many of the devices of modern methods of management. This is especially true of bench inspection, under the conditions of central inspection. The device of greatest utility is a carefully planned use of sampling, insuring that no more work is done than is necessary. Next comes the matter of instruction in the work of inspection, to see that each inspector knows just what he is trying to do, and the quickest and easiest way to do it. There are so many operations in inspection work which appear very simple, that there is a strong tendency to show a new employee what he has to do in a very casual and general sort of way and then leave him to his own devices. The application of a gage or two, or a viewing for surface finish, appears to be transparently easy, but the mental attitude that regards any piece of work as simple is a danger signal. It should be borne constantly in mind that time and motion study began with handling pig iron and shoveling earth. It is not unlikely, in fact, that the most striking economies are to be realized in the most simple operations.

The instruction of inspectors is a staff job—that is, it should be a staff job if the best results are to be obtained. Perhaps this conclusion flows from the proverbial truth that work which is left to everybody is rarely done right.

Combine Instruction with Staff Supervision

The instruction should be combined with the work of one of the technical men on the chief inspector's staff, as it fits in well with a critical examination of each inspection point taken seriatim and somewhat as follows:

1. Is the measuring device, gage, or what-not, such that true results can be obtained?
2. Is the gage being applied so as to obtain true results?
3. Is the work being done in a way to secure the greatest economy of inspection?

The first two questions are vital, naturally, since money spent upon inspection is worse than wasted if the results are not close to the truth. The third question opens up the whole field of possible increase of efficiency. Frequently, in fact, the most cursory use of motion study reveals large possibilities for saving time in inspection, especially if the inspector considers himself under the necessity of hurrying. The most frequent loss arises from improper placing of the boxes of work, so that unnecessary and overcrossing motions are made. Then there are the losses that arise from awkward posture and clumsy holding of the gage. It sometimes happens that a separate support for the gage will help matters by leaving free both of the inspector's hands. In this case attention should be given to seeing that the support is flexible enough to permit automatic adjustment of a close limit gage to the work.

A large saving can be secured through spreading the message of careful handling of both work and gages. Precision instruments and fine work call for a certain amount of gentleness, of the sort that the late A. J. Corbesier, the honored fencing master at Annapolis, referred to when he said, "Hold your foil as you would a bird—firmly, so it will not escape; gently, so it will not be hurt."

I recall an experience in a munition plant, where a room full of foreign help was engaged in the inspection of high-grade work. The gages were applied with such enthusiasm, and highly finished parts were thrown into tote boxes with such vigor that the anvil chorus would not have had a chance to be heard. The ordinary bench inspector or machine operator in our larger factories will easily fall into almost as bad habits unless he is cautioned continually.

Unskilled Help in Inspection

Turning now to one of the greatest economies in inspection, especially in central inspection as previously stated; it is not necessary (except in certain kinds of floor-inspection) to have a personnel already skilled in the work of inspecting. In fact it is quite inadvisable to employ such people when the object is to limit the use of judgment and to hold to a close standard. But the employment of unskilled help again indicates the necessity of providing adequate instruction, not alone by teaching, which always should be a large factor in management, but also by providing accessible reference data, such as samples, large-scale drawings with gaging points distinctly marked, gage instruction cards, and so on. It should not be necessary to mention, except for completeness, how important it is to begin this educational work as soon as the new inspector is employed. There are obvious advantages in "catching them young." The work will be done more certainly, and probably better and quicker, if it is followed up by a staff assistant.

Female Labor for Inspection Work

In speaking of the use of unskilled labor as a measure of economy in inspection, the question of using female labor deserves serious consideration. In fact, if female labor is carefully selected with reference to the adaptability of the

Figure 38. Prestwich Fluid Gage as Used to Inspect Piston Pins
Diameter held to within 0.0002 inch—Packard Motor Car Company.

individual to the class of work involved, it will be found that women are able to do many more kinds of inspection work than might be supposed, also that they almost invariably perform it better than men. A higher grade of tactile sense and skill can be secured for the same investment, together with a stricter compliance with instructions in the matter of holding to standard. The advantage to be gained in greater contentment of the inspection force alone, makes the employment of women highly desirable whenever possible.

It is realized that many factory executives hesitate to introduce women into the inspection department in shops where none but men are employed at the machines, and this for reasons quite apart from their suitability for such inspection work. It may be stated as a fact, however, that the feeling is not warranted if proper measures are taken at the start to maintain discipline; for the presence of women may be made to secure an elevation of the entire tone of the shop. To do this requires that the subordinate inspection bosses be chosen from among the most dignified inspectors and that they be duly impressed with the importance of their work. It should be made a fixed rule also, that questions affecting inspection be taken up by the production bosses with the male foreman only.

In a large factory employing at the time none but men in the shops, female help to the number of several hundred were introduced into the inspection department in the endeavor to stabilize labor turnover in the department, as well as to secure better control of the technique of inspection. Because of the class of labor in the plant, the management realized that matters might arise which would be reported to them more certainly, and perhaps more easily and gracefully, if the women could carry their troubles to a woman rather than to a man. It was recognized, besides, that a high standard of character in the inspection department was worth a great deal in controlling the quality of the factory output. With this in mind, one of the secretaries in the main office, who had been a working girl and who combined rare judgment with a very human sympathy for her associates, was asked to take the time to become acquainted with at least one or two girls in each inspection group. The plan proved to be an unqualified success, although it resulted in the dismissal of a foreman or two, and a few of the inspection force, very shortly after the facts began to come in and investigations were made. It was not long, however, before that particular plant achieved the reputation among working people of being the safest factory in the state to which to send their daughters for employment.

Women as inspectors will be found to work faster than men, especially if their strength is conserved by providing men to do the heavier work of lifting and moving tote boxes. The amount saved is sufficient to pay for the greater comforts in the way of chairs, recreation and rest rooms, and other conveniences, that must be provided for women. It should be remembered, however, that women inspectors should be required to adapt their dress to secure personal safety, by wearing caps and suitably protected sleeves, as in the case of female machine operators; for even women inspectors are occasionally passing near machinery in motion.

Women Inspectors on Heavy Work

From the technical standpoint, there are many kinds of work not ordinarily inspected by women which could be so handled to advantage, even in the case of comparatively heavy pieces. This requires that the individual be chosen for the job and given a preliminary course of training. The inspection of the interior of rifle barrels has been performed by women to great advantage, although it is technically difficult and the physical work of holding them up to the light is tedious, to say the least. In the case I have in mind, the inspectors were chosen from among a number of obviously robust and sturdy individuals, whose eyesight measured very nearly perfect. They were then instructed in the art by an expert foreman *who believed that women could be taught to do the work.* It took ten days to graduate them, and it only remains to be stated that they developed a proficiency that at first set too high a standard. It would, in fact, have tied up production, if prompt measures had not been taken to reinspect their rejects, until they could be taught to hold to a more reasonably commercial standard. And in spite of this experience the scheme was nearly wrecked by their inspection foreman (a man of long experience and great skill in the business), who stubbornly refused to believe that women could learn, in so short a time, work requiring such skill. From this fact the reason may be deduced for emphasizing certain words in this paragraph. It may possibly suggest in addition, that there is more than a modicum of "bunk" about many skilled operations, so-called, as is rapidly discovered when the problem of controlling them is approached in a truly scientific manner.

Morale

No treatment of the management of the inspection department should close without stressing the special value of a high morale. Just as the precision of measuring instruments is fundamental in determining the degree of mechanical accuracy that may be attained, so must fidelity to truth be developed in the inspection force, to secure the predetermined standard of quality that is desired. Thus character is the first desideratum, and as a necessary element of it, impartiality, thoroughness, and accuracy in developing the real facts, and courage in bringing them to light. The chief inspector must train his people to secure this result; and then, lest he lose the advantage, he must support them when they are right, and must in his turn be supported by his superiors in the management. Concurrently, the inspection force should be disciplined to a strict obedience in carrying out the chief's instructions, if for no other reason than to secure a quick flexibility and certainty of control in developing the standards of quality, with freedom from disturbing influences arising outside of the inspection department.

The presence of this same discipline, administered always with personal courtesy, will build up the individual's sense of the value of his work to the entire organization; and with the resulting realization of personal dignity and knowledge of trust, there will come a feeling of responsibility and pride in the work of the whole department—that is to say, an esprit de corps.

CHAPTER XI

INSPECTION IN PRACTICE

Type Varies with Individual Factory

The development of a philosophy of inspection requires that its principles be stated somewhat in the form of abstract generalizations. It is believed, as has been stated, that these principles are of much wider application than is generally appreciated and that industry would benefit greatly if they were followed much more closely in practice. It is equally true, however, that the translation of these principles into action, as has been pointed out in several instances, requires that they be interpreted with a leaven of common sense, and applied in the form of whatever adaptation is economically most suitable for the particular case involved.

Each manufacturing enterprise has its own peculiar conditions to meet, and the arbitrary introduction of a fixed system of any sort, without careful and intelligent modification, is fraught with grave dangers. "What is one man's meat is another's poison."

If the management is critically introspective, so to speak, the way in which inspection is organized and applied is likely to be well suited to the needs of the factory. Hence the value of studying the inspection methods of well-established industries, whose successful operation may be taken for granted. Such study is the purpose of the present chapter. As an introduction thereto the various modifying considerations which are involved in special cases may now be assembled.

When to Use Extensive Inspection

Briefly stated, the most extensive and complex use of inspection is desirable when:

1. The product demands frequent and thorough inspection, as when great accuracy is required.
2. When models are changed with frequency, as in a swiftly advancing art.
3. When labor is unskilled or rapidly changing.
4. When quality standards are being raised.
5. When considerable judgment must be used because standards are being shifted or have not been reduced to a definitely measurable basis.

Each of these cases may apply separately but when they are cumulative, as in the case of unskilled labor working in an industry that is advancing swiftly, the use of a much more intensive form of inspection is indicated.

On the other hand, if the product is highly standardized and if the workers are skilled mechanics well acquainted with the requirements of the work, then inspection may be greatly reduced. In fact, if the work is performed under these conditions and on so small a scale that the management is able to devote considerable attention to the details of the business, the need for inspection almost disappears. Cases of the latter sort are very rare, however, and are not worth considering except as exemplifying the extreme or limiting situation.

The following examples have been chosen from a number of industries with the idea of presenting in brief form certain general features of inspection methods which are typical.

Inspection in Automobile Plants

In looking for a good example of inspection as practiced in its highest development, there is no better place to turn than to the automobile factories. The evolution of automobile design and manufacture is one of the great romances of modern industry. For reasons that need no mention, it has made tremendous demands upon every department of engineering science and the technical arts, in order that ways and means for meeting its requirements might be devised. It has made it necessary to create a new school of machine tool design, to carry tool-room precision into the ordinary fabricating shops, and to install every reasonable safeguard for controlling quality.

The Packard Inspection Service

Inspection in the factory of the Packard Motor Car Company[1] has been developed to a point that is best illustrated by the organization chart shown in Figure 39. The chief inspector is responsible to the factory executive staff, composed of the vice-president of manufacturing, the factory manager, the assistant factory manager, and the general

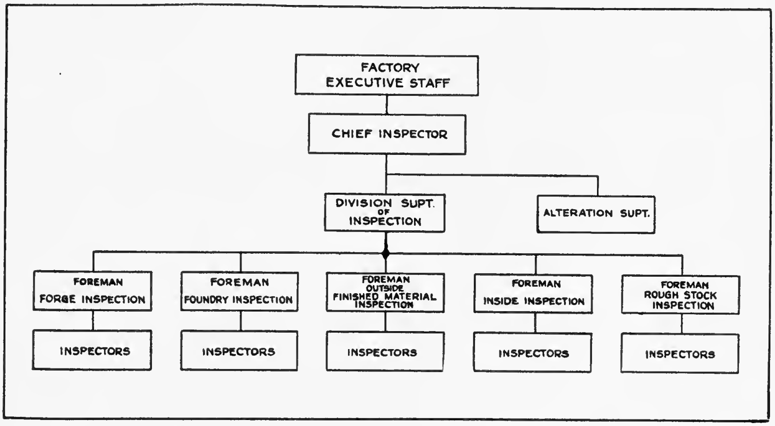


Figure 39. Inspection Organization Chart—Packard Motor Car Company

---

[1] The author is indebted to D. G. Stanbrough, General Superintendent of the Packard Motor Car Company, for his courtesy in furnishing information relative to Packard inspection practice and precision methods.

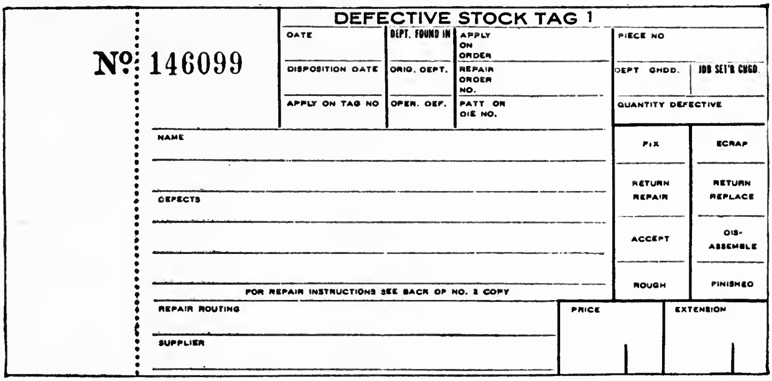
superintendent. The chief inspector is responsible for proper and efficient inspection throughout the inspection organization, in accordance with standards set by the factory management.

Directly under the chief inspector is an inspection superintendent for each of the main divisions of the business, namely, carriage, truck, and service. Each of these divisions is further subdivided into three departments: outside finished material inspection, inside inspection, and rough stock inspection, with a foreman in charge of each department to whom the individual inspectors report. In addition, there is an alteration superintendent, also responsible to the chief inspector, whose duty is to see that alterations in the dimensions or in the design of parts are properly put through in the factory with the minimum of interference.

Both floor-inspection and centralized inspection are in use. Large parts, such as cylinders, crank cases, etc., are inspected on the floor near the machines, since manufacturing facilities are so arranged as to permit it conveniently. Small parts, however, are removed to the department inspection cribs for inspection. When a workman machines the first piece on a job, he is required to submit it to the foreman or the job-setter. If the piece is done correctly, the foreman or job-setter OK's the workman's time slip and he goes ahead with the job. If the operation is not done correctly, the foreman shows the workman how to do the operation, and the time slip is not signed until the piece is finished correctly.

Final inspection of each individual piece is maintained on the following parts: heat treated parts and parts that are held to close limits, such as cylinders, pistons, piston-pins, crank cases, transmission parts, gears, steering knuckles, etc. Ordinary small parts such as screws, nuts, bolts, washers, etc., are subjected to a percentage inspection.

The disposition of rejected parts is rigorously controlled. Reference to Figure 40 shows this in detail. While the production department may be consulted by the chief inspector, the fact remains that no piece once rejected can be disposed of except in accordance with instructions issued by the chief inspector in person.



DEFECTIVE STOCK TAG 1

Nº 146099

DATE	DEPT. FOUND IN	APPLY ON ORDER	PIECE NO
DISPOSITION DATE	ORIG. DEPT.	REPAIR ORDER NO.	DEPT CHGD. JOB SET'R CHGD.
APPLY ON TAG NO	OPER. DEF.	PATT OR DIE NO.	QUANTITY DEFECTIVE

NAME

DEFECTS

FIX	SCRAP
RETURN REPAIR	RETURN REPLACE
ACCEPT	DIS-ASSEMBLE
ROUGH	FINISHED

FOR REPAIR INSTRUCTIONS SEE BACK OF NO. 2 COPY

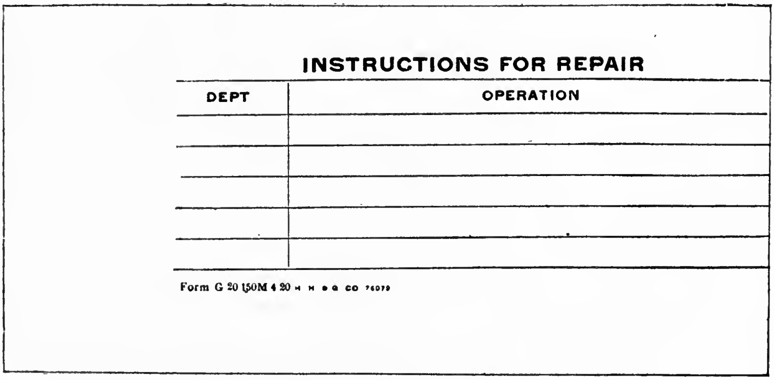
REPAIR ROUTING

SUPPLIER

PRICE

EXTENSION

Figure 40. (a) Inspector's Tag Disposing of Work (face)—Packard Motor Car Company



INSTRUCTIONS FOR REPAIR

DEPT	OPERATION

Form G 20 150M 4 20 H H B Co 76079

Figure 40. (b) Inspector's Tag Disposing of Work (reverse)

The foregoing pertains to the methods of handling inspection on forgings, castings, semifinished and finished pieces. In addition to this, there is a metallurgical and chemical department for the usual analyses of iron and steel. This department, however, is separate from the regular inspection organization and is in charge of the chief metallurgist, who is responsible to the factory executive staff. The chief metallurgist also prescribes the requisite characteristics for heat treated parts, although the actual work of inspection of these parts is carried out through the regular inspection organization.

Operating inspection on finished vehicles is also a separate function in charge of the operating manager who is responsible directly to the president.

In addition to all of the above, the quality of the product is further insured by a supervisor of quality (reporting to the factory executive staff) whose function is to check the work of the inspection organization. The method of the supervisor of quality is to have his men take a complete unit at random, which is then disassembled and checked up in detail by his men.

Inspectors are paid day work, which is the almost universal practice. With a working force of 9,000 men, 500 inspectors were employed. It should be noted, however, in connection with any data of this sort, that the proportion of workers must vary considerably from time to time, depending upon the situation of the work and the number of workmen employed. Consequently, the figures that are given relative to the number of inspectors for any given working force must be considered as applying merely to a particular situation.

In its general features the above outline is believed to be typical of the best automobile inspection practice, although there are naturally a number of variations from factory to factory. The proportion of workers to inspectors, for example, varies all the way from 1 inspector to 10 workers, up to 1 inspector to 30 workers.

An Example of Former Practice

By way of contrast with the above, it may be of interest to compare the inspection methods in use several years ago in a plant which at that time was fairly prominent as the maker of a high-grade car. In this factory the chief inspector reported to the chief engineer in matters affecting material organization and the holding of the work to drawing dimensions. He was responsible to the superintendent for the routing and movement of all work in process.

The inspection department organization consisted of a chief inspector, an assistant chief inspector, department-inspectors, floor-inspectors, and inspectors. The department-inspector had charge of all inspection in his department and was responsible for the quality of the work and the discipline of his force. There were in general 2 floor-inspectors for every 150 operators and their duty was to inspect all work in process at least four or five times a day. They were required to check each new set-up before work could start, after which the machine operator was held responsible for all defective work.

The floor-inspectors inspected and had moved to the various operations, all large pieces of work, such as crank-shafts, axles, radius-rods, drive-shafts, and fly-wheels. These parts were moved into the central inspection room only when finished or at the time of being moved from one department to another, in order to fix departmental responsibilities.

Work requiring skilled mechanics, such as grinding crank-shafts, cam-shafts, cylinders, pistons, piston-rings, gear-cutting and grinding, boring of crank cases and transmission cases, was not considered to require floor-inspection.

Figure 41. Piston Ring Inspection—Packard Motor Car Company

The floor-inspectors were usually expert machinists receiving (prior to 1914) about 70 cents an hour, and as an incentive were usually next in line for promotion to assistant foreman and foreman.

The amount of inspection given to each lot of pieces depended upon the quality of the lot as determined by the first few pieces inspected. That is to say, if the first few pieces were good, the inspector examined about 25 per cent of the lot. If any were bad he would then inspect the entire lot. In each case he then counted the work and credited the operator with the number of pieces passed.

For a force of 1,500 operators there were 40 bench-inspectors, 8 floor-inspectors, 2 inspectors for commercial work, 1 inspector for forgings and castings, and 1 inspector on the scleroscope test. All of these men were paid on the hourly basis, bench inspectors receiving from 50 to 65 cents per hour. The drawing was the only standard allowed, close dimensions being stated with the limits given in detail. Limits of plus or minus 0.010 inch were allowed on all dimensions which were stated in fractions. The standard of finish was marked on the drawing to denote the points to be finished, the allowance for grinding (say 0.010 inch), and the surfaces to be disc-ground or spot-faced, and no departure was allowed from the above without the written authority of the chief inspector. It is of interest to note that the company, being responsible only to themselves for their standards, had permitted it to become the accepted practice in the shops to shift the standards of workmanship and material to suit the urgency of the demand for parts, keeping in mind the ability of the assembling department to use them without increasing the cost too much—this from the statement of the chief inspector to the writer.

In the routing of work, in accordance with operation sheets furnished to the inspector, the work was accompanied by a route card, or traveler, which stated the part number, order number, and quantity. This card moved with the work from raw material to finished stock. When an operator finished his operation, he took the card to his foreman, who then gave it to the time-keeper. The time-keeper then made out an inspection ticket in triplicate, keeping one copy himself. The remaining two went to the inspection department where the inspector filled out the quantity accepted or rejected. Of these two copies one was sent to the pay department and the other returned to the workman. The inspector then made out a card, ordering the material out of the inspection department and delivered by the trucker to the next operation.

Machine Tool Industry

In the manufacture of machine tools, the organization and methods of inspection do not differ widely from those employed in the best run automobile factories. As might be expected, however, the same degree of refinement has not been reached, although there is evidence that inspection methods are being overhauled rather carefully in several of the machine tool making factories, as a result of their experience in the war. The ratio of inspectors to workers varies all the way from 1 to 30 for ordinary machine tool work, up to 1 to 15 in the case of small tools. Inspectors are paid on an hourly basis. In many plants central inspection, floor-inspection, and first-piece inspection are all in use together.

The most marked deviation in inspection organization is in the relation of the inspection department to the rest of the organization. In the Pratt and Whitney Company, for example, the chief inspector reports directly to the works manager, but this is by no means the general practice elsewhere in the industry. In some factories the chief inspector reports to the engineering department. In others he reports to the factory superintendent. These latter practices are of interest as indicating the results of an inherited system.

Small Precision Work

Inspection methods have reached a high development in many plants which are engaged in the manufacture of small high-grade articles. For example, in the Elgin National Watch Company's [2] plant the inspection work is performed in a central inspection room or space, generally set off at the end of each department. Each piece produced is submitted to 100 per cent inspection. Out of a total working force of 3,500 the ratio of inspectors to workers averages 1 to 10. All inspectors are paid by the day. Each main factory division has its own inspection department with a chief inspector in general charge.

At the Weston Electrical Instrument Company's [3] plant at Waverly Park, Newark, central inspection is in use, but is reinforced for certain classes of work by so-called "floating inspectors" who move through the various departments where inspection at the machine or at the completion of the process seems to be advisable. In general, first-piece inspection is held to be a part of the responsibility of the department in which the work is done, and is not covered by the inspection department except in special cases. Most of the work is arranged in departments—the milling department, the drilling department, etc., but no work is allowed to pass from one department to another without first passing through the hands of the inspection department.

The ratio of inspectors to workers averages about 1 to 10, and inspectors are paid on an hourly basis.

Every piece of the completed product, that is to say

---

[2] From data furnished by DeForest Hulburd, second Vice-President.

[3] Courtesy of Edw. F. Weston, second Vice-President.

Figure 42. Inspection of Time Fuse Parts
War work of American Locomotive Company.

every instrument, undergoes several final inspections. The subassemblies and parts used in the production of Weston instruments are subject to individual inspection. The only exception is in the matter of unimportant parts (such as ordinary screws) which are inspected by sampling.

The chief inspector is responsible directly to the general superintendent, and is assisted by a foreman and subforemen, each subforeman controlling from 3 to 10 inspectors, according to the nature of the work.

General Machine Shop and Foundry Practice

In industries whose work requires medium and heavy foundry work, forgings and their machining, the inspection department usually is more loosely organized, although in highly standardized businesses of this sort, such as the manufacture of power transmission machinery, it is usual to find greater refinements in use, with a chief inspector reporting directly to the management. Most of the work is inspected on the floor, as a matter of necessity, but final inspection is not infrequently performed in a separate department. Inspectors are paid universally on an hourly rate. The ratio of inspectors to producers is as low as 1 to 50.

Special Cases

The inspection methods in use in the manufacture of a continuous product, such as paper or textiles, requires individual treatment, depending considerably on the grade of the product. The general principles, as set forth for interchangeable manufacturing, are the same, but different methods are necessary. All such work should be regarded as an assembling proposition, with various preparatory operations for the raw material and with appropriate finishing operations after the materials have been brought together in the goods. Errors are bound to occur and are almost always worked into the product in such a way as to defy their correction. Consequently, inspection at the sources of greatest error has an added value in checking undue loss. Inspectors of high caliber are required, moreover, because apparently insignificant matters in the earlier stages of manufacture are likely to have a serious effect upon later processes. The inspector thus requires a wide knowledge of the technicalities of the business as a whole.

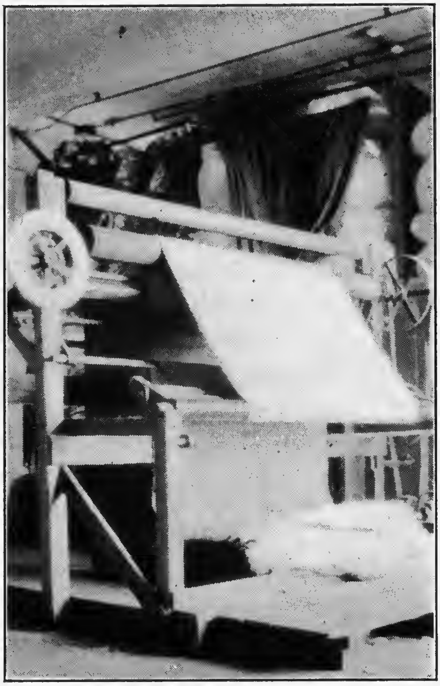


Figure 43. Perch for Inspecting Textile Fabrics—The Shelton Looms

An interesting variation in the method of inspection is occasionally desirable for continuous processing—if the workman is paid a bonus for quality (and consequently knows that the defective work will cost him money), he automatically becomes an inspector of work performed on the material before it reaches him. In fact, it may be a desirable feature in any such scheme of quality control to require each operator to make a list of the defects he finds in the work as it reaches him, and, where practicable, to report the same before starting his own machine.

There is another class of inspection work which has not been touched upon heretofore because of its very special nature. It is to be found in places where a volume of mail orders are packed, and in similar operations which are more in the nature of checking. For example, in the Charles-William Stores [4] at a time when a force of about 500 girls was employed in packing orders for shipment, the orders ran in about the general proportion of 300 freight, 3,000 express, and 30,000 parcels post. Obviously, it was necessary to have some sort of check on the packing, although it was equally true that the inspection of this packing could not be carried very far without duplicating the work of the packers. Satisfactory results were obtained by the employment of 30 girls as inspectors, with a manager or chief inspector. Arrangements were made to carry the parcels through the inspection department on two 36-inch belt conveyors. The inspection operation was performed by sampling; that is to say, an inspector would take a package from the belt, get the papers in the case, and check the order as filled and packed.

Ratio of Inspectors to Workers

As has been stated before, any figures giving the number of inspectors required, in proportion to the working force, must be accepted with reservations based upon conditions surrounding the work at the time. Consequently, such figures can be used only as a general guide. As a matter of convenience, the following table summarizes the data assembled from a number of industries:

Industry	Ratio of Inspectors to Workers
Ball bearings	1 to 4 or 5
Small and very precise interchangeable parts	1 to 8 or 10
Automobiles, high-grade close work	1 to 10, up to 1 to 20
Simpler automobile work	1 to 20, up to 1 to 40
Machine tools	1 to 15, up to 1 to 40
Foundry and general machine shop	1 to 50

---

[4] Under the organization and methods developed by its president, G. H. Eiswald.

CHAPTER XII

QUALITY CONTROL IN PRACTICE

Complexity of the Quality Problem

Inspection is only a part, although a very important part, of the wide and important subject of the control of quality. As has already been pointed out, an analysis of successful industries will show that these manufacturing activities comprise three essential branches or stages:

1. *Planning or Engineering*—the determination in considerable detail, of what is to be made and how it is to be made, before work is begun.
2. *Production*—the economical application of suitable manufacturing processes whose output is controllable to uniform standards of quality.
3. *Inspection*—the comparison of the work as produced with the predetermined standards of quality, and the filtering of unsatisfactory work out of the line of flow of work in process.

The determination of what makes an enterprise successful is a difficult matter in any case. Some things help, others hinder, and some are merely carried along without affecting the issue either way. Not infrequently success results from a combination of circumstances which are merely opportune, and vice versa. The resulting mixture of causes is so complex that it is hard to analyze. If, however, we approach the matter from the negative viewpoint, it is simpler to determine what the basic causes of success really are. The test in this case is: What are the things whose *non*-observance will result in failure? As indicated above, it is believed that a very small oversight in any one of the three essential branches of planning, production, and inspection may be disastrous; while the same thing cannot be said with equal truth of the other branches of factory endeavor.

By the above test then, we should expect to find unusually successful industrial enterprises accompanied by a close attention to planning, production, and inspection. The war furnished a number of examples which illustrate the above in a conspicuous way, both by direct and by negative proof. Unfortunately, however, everybody was so busy at the time that the most valuable lessons to be gained from war time experience were missed, except by the people who came in actual contact with the industries in question. This is doubly unfortunate because the conditions were especially good for proving in a very intensive way the truth or untruth of the methods used.

It is, of course, difficult to choose typical examples from such a quantity as are available, but the war work of the American Locomotive Company, the Lincoln Motor Company, and the Remington Arms of Delaware may be selected as illustrating strikingly the points made throughout this book.

The Shell Contracts of the American Locomotive Company

Early in 1915, the American Locomotive Company undertook the manufacture of shrapnel and high explosive shells for the British government. The work was carried on under the direction of Vice-President C. K. Lassiter (in charge of manufacturing). The excellence and importance of this accomplishment are not generally known. Such results, however, might have been expected of one who already had an enviable record as a designer of highly efficient machine tools, and as a production executive. As will be observed from the accompanying illustrations, Mr. Lassiter's methods are characterized by directness, simplicity, and effectiveness—in short, by that absence of frills which denotes a genius for making things.

In order that the magnitude of the undertaking may be appreciated (for it shortly grew to huge proportions), the following summary of the work done by the American Locomotive Company and its associated shops is of interest:

Manufactured complete, loaded	3.3-in.	Shrapnel	2,500,000
" " "	3.3 "	H. E.	2,500,000
" " not loaded	4.5 "	H. E.	1,468,000
" " " "	6 "	H. E.	1,468,000
" " " "	8 "	H. E.	300,000
" " " "	9.2 "	H. E.	125,000
Extra cartridge cases, complete	3.3 "		3,886,000
" " " "	4.5 "		1,147,000
" time fuses, complete, loaded			3,200,000
" shell forgings—various sizes			2,733,700

During the last nine months of the undertaking this tidy little job reached an *average total daily output of 25,000 tons*, and employed 40,000 men. The average daily output of cartridge cases alone was 58,000; while of 3.3-inch shrapnel and H. E. shells it was 40,000. To accomplish these results with an organization unacquainted with the work, however skilled it might be in other lines, certainly would indicate a thorough grasp of the fundamentals of manufacturing.

Beginning the Work

The first order undertaken was for 1,250,000 3.3-inch 18 pdr. shrapnel, and a like number of 3.3-inch high explosive shell. *Not one of these was rejected after delivery.* Let us now see how the thing was done, beginning with the cartridge case, which is the same for both shrapnel and H. E. shell.

At the outset it should be noted that the contract provided only an outline plan without tolerances or limits. The first step took the form of a visit to the Quebec Arsenal, where inquiries were made as to what these cases should be like. In other words, Mr. Lassiter first endeavored to determine what was wanted, in detail; in fact, he frankly stated that he and his associates approached the work as novices. As a special result of this visit, two sample cartridge cases which were satisfactory were obtained and brought back to New York. These samples were then sawed in two, and the hardness determined by careful and extended measurements with the scleroscope. Dies were designed and a set of tools made to produce the case from blank to finish, special attention being paid to see that the drawing processes were developed to secure the necessary coining at the points where extra hardness was required. Tolerances and limits were then worked out.

As an example of the processing, the annealing furnaces were of the oil, overfired, perforated roof type. In order to avoid scale, superheated steam was introduced, at a sufficiently high temperature to permit *uniform control.*

Limit gages and 100 per cent inspection were provided for all operations from rough blanks to finished cases. All work rejected by either the company or the purchaser's inspection was forthwith removed from the line of flow and sent to a hospital. Needless to say, the latter was pretty large at times; but this practice permitted an unbroken flow of work from operation to operation. The value of this practice was enhanced by the excellent handling devices and conveyors, which were provided everywhere throughout the shops.

No Rejections After Delivery

The plant for this work was laid out for an output of 9,000 per day of 20 hours, but the actual output reached was 24,000. The quality of the first series submitted to the purchaser was highly commended, even after firing some of the cases three times. *Not one series nor one single case out of the 2,500,000 was rejected after delivery;* and the same statement holds for the complete and loaded shells.

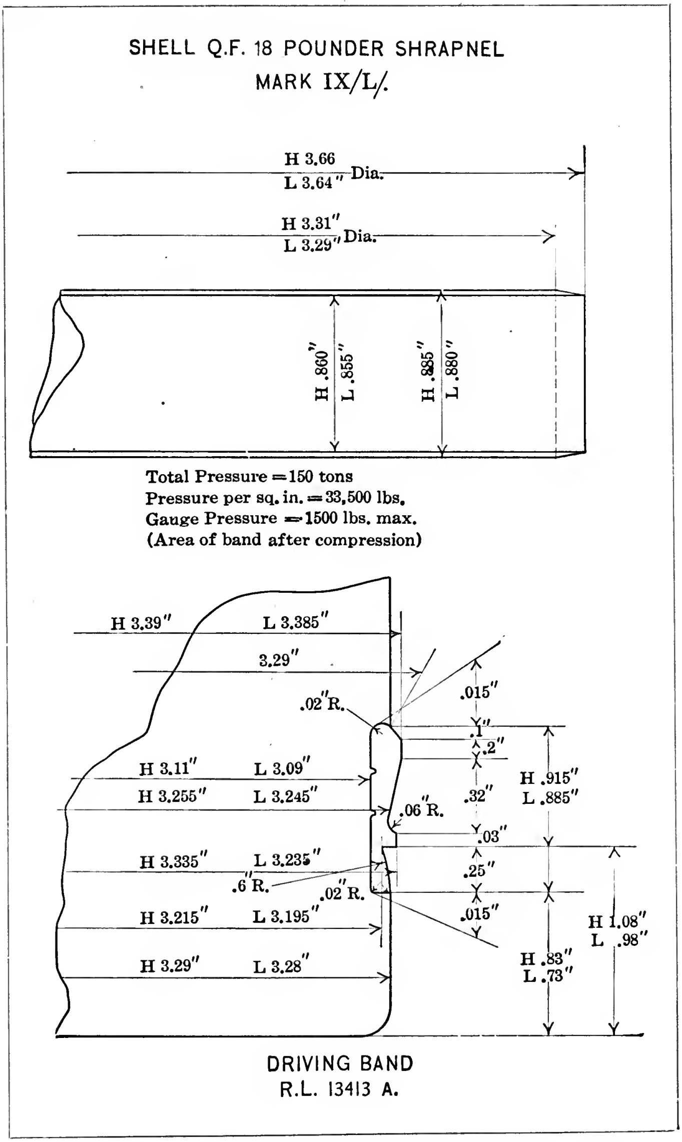
Mr. Lassiter, in speaking of this part of the work, recently said, "We were novices, so the first thing we had to do was to find out what we had to make, then we had to make all our processes alike, and finally we had to inspect everything."

To what extent the first thing was done, is shown very clearly by the little 7½ by 3¾ inch booklets which were supplied to the shops. Each booklet contains an index and about 40 pages of blue prints, which give all the necessary information as to the product, the tools for making it, the shop arrangement, and so on. Sample pages are shown in Figure 44. In connection with the simple but complete way in which similar information was developed, attention is invited to Figures 45 and 46. They contain no unnecessary information, yet everything needed is there.

Shells

The importance of getting processes under uniform control is illustrated even better by some of the difficulties encountered in making the shrapnel and H. E. shells. In general terms, the usual processing in the early stages is to forge, rough turn, harden, and grind to finish. It was desired to substitute finish turning for grinding, in order to get greater production. The problem was to get them soft enough to turn, but hard enough to meet the ballistic requirements without the walls of the shell upsetting in firing. This, of course, involves very uniform heat treatment.

A furnace was built 24 feet long, with six pyrometers spaced along the sides. The shells were placed in special triple pocket cradles, and were pushed into one end of the furnace by a pneumatic pusher. The pyrometer at the entrance fluctuated, but the sixth pyrometer was steady,


SHELL Q.F. 18 POUNDER SHRAPNEL
MARK IX/L/.

Total Pressure = 150 tons
Pressure per sq. in. = 33,500 lbs.
Gauge Pressure = 1500 lbs. max.
(Area of band after compression)

DRIVING BAND
R.L. 13413 A.

Figure 44. (a) Typical Page from Shop Instruction Book
American Locomotive Company practice.

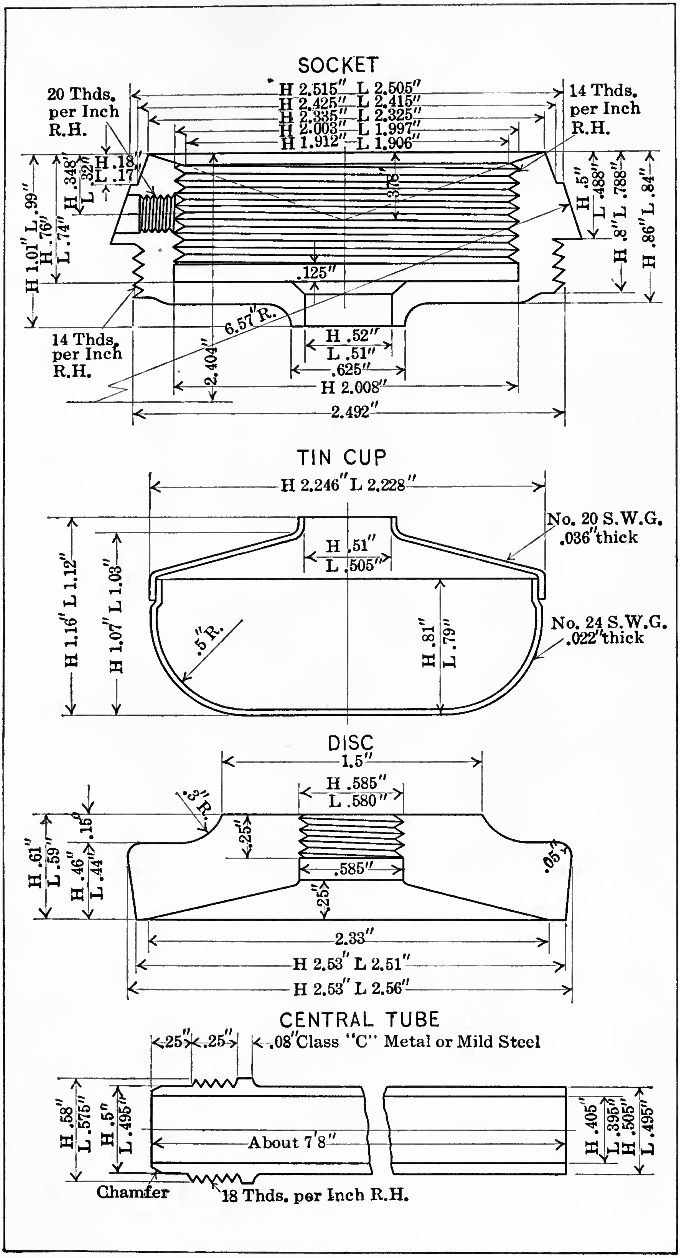


Figure 44. (b) Typical Page from Shop Instruction Book

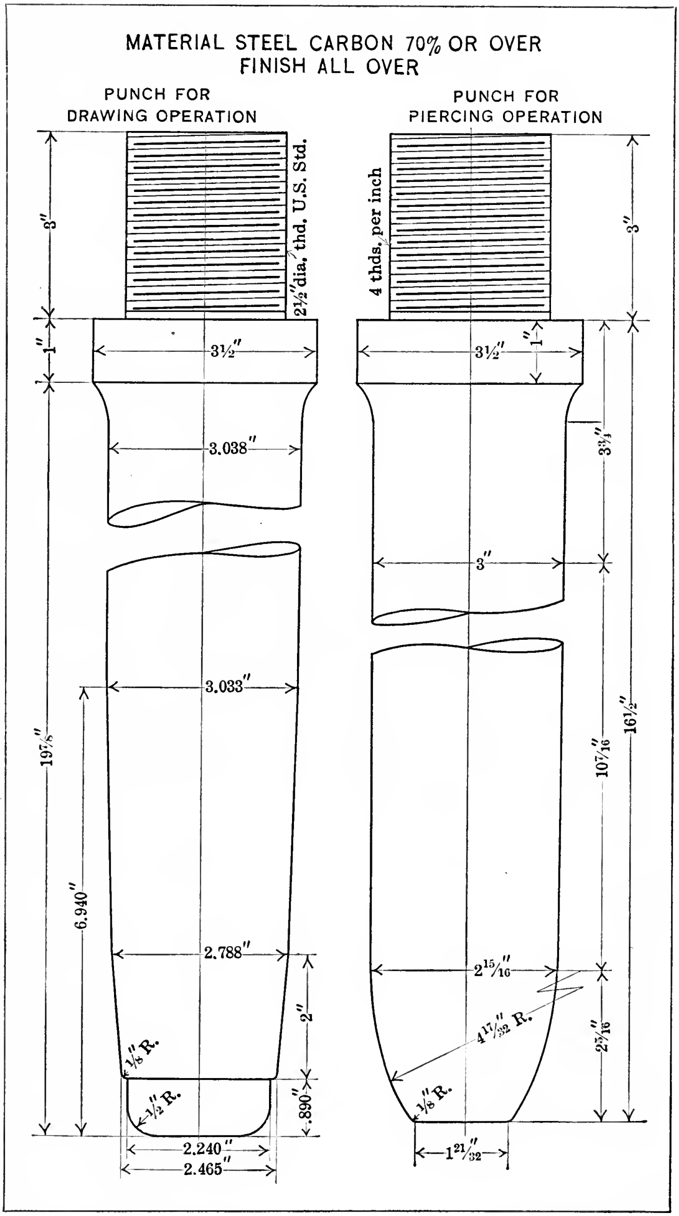


Figure 44. (c) Typical Page from Shop Instruction Book

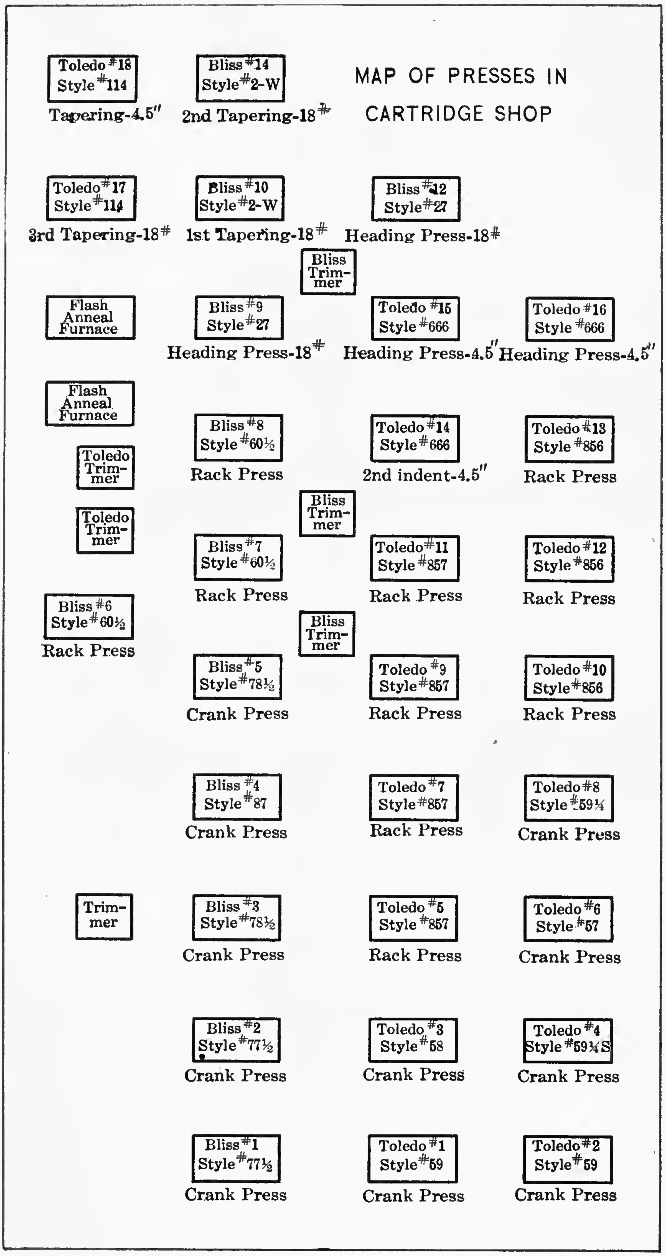
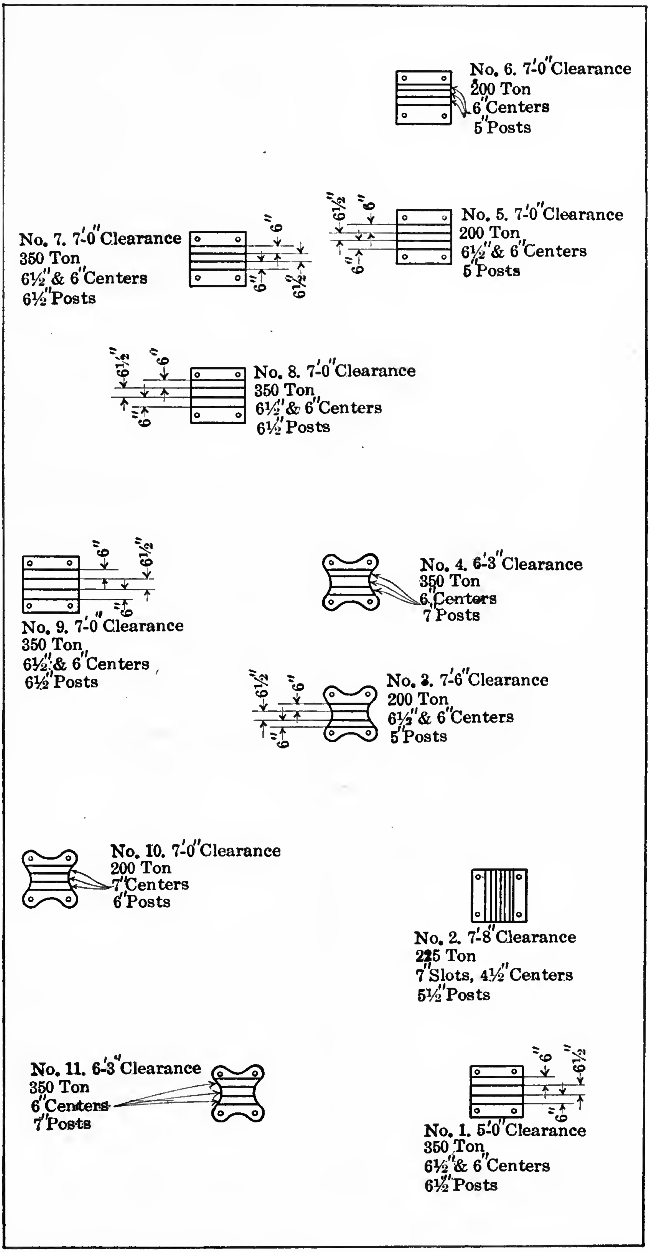


Figure 44. (d) Typical Page from Shop Instruction Book



No. 6. 7'-0" Clearance
200 Ton
6" Centers
5" Posts

No. 7. 7'-0" Clearance
350 Ton
6½" & 6" Centers
6½" Posts

No. 5. 7'-0" Clearance
200 Ton
6½" & 6" Centers
5" Posts

No. 8. 7'-0" Clearance
350 Ton
6½" & 6" Centers
6½" Posts

No. 9. 7'-0" Clearance
350 Ton
6½" & 6" Centers
6½" Posts

No. 4. 6'-3" Clearance
350 Ton
6" Centers
7" Posts

No. 3. 7'-6" Clearance
200 Ton
6½" & 6" Centers
5" Posts

No. 10. 7'-0" Clearance
200 Ton
7" Centers
6" Posts

No. 2. 7'-8" Clearance
225 Ton
7" Slots, 4½" Centers
5½" Posts

No. 11. 6'-3" Clearance
350 Ton
6" Centers
7" Posts

No. 1. 5'-0" Clearance
350 Ton
6½" & 6" Centers
6½" Posts

Figure 44. (e) Typical Page from Shop Instruction Book

showing that the furnace was long enough to permit equilibrium to be reached. Presently it became possible to adjust the temperature to suit the various "heats" of steel.

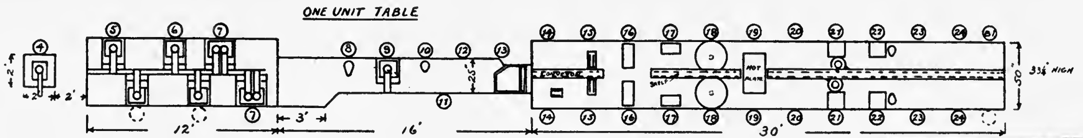
The furnace unloaded automatically through a low door and into a cooling oil tank, which was equipped with an elevator. As it soon developed that this cooling tank did not provide constant conditions, a 10-ton refrigerating plant was installed; also two circulating pumps to keep the oil bath uniformly mixed. A similar furnace equipment was used to draw out the hard spots, which were found to occur from time to time if only the heat treating furnace was used. After heat treatment and annealing, all shells were scleroscoped.

As a result of this process it was possible to substitute finish turning with a very fine feed, instead of grinding, with a resultant saving of 50 per cent in cost, no loss ballistically, and no loss from failure to clean up in turning. The loss from the latter cause, by the method previously used, had run as high as 20 per cent at times.

Bullets

The first difficulty encountered was to get the required amount of antimony into the lead, and in a uniform mixture. This was met by adding the antimony in progressive steps, one-fourth being put into the lead at each melting. The metal was then extruded into ½-inch wire and wound on reels. Each bullet press used 16 reels, and operated at 90 strokes per minute.

The little fins left by the press were tumbled off in slat rumblers. Naturally some bullets got too much tumbling and ran out of round. As the elimination of the latter by means of the usual bean-sorting belt was deemed to be too slow and costly, a simple, inclined, gravity, separation table was provided. The bullets were allowed to roll down this



POWER FROM OVER-HEAD LINE SHAFT

TABLE DRAWINGS 3-F-20 3-F-103 3-F-104

GRADUATE TIME TRAIN RINGS
WORK TABLE AND OPERATIONS
-F-
WALCO MANUF'G CORPORATION
PROVIDENCE, R. I.
DATE JANY 1917
R.E.C.

RINGS TRUCKED FROM LOADING ROOM

OPERATION Nº.	LIST OF OPERATIONS	OPERATORS REQUIRED	POWER MACHINES	JIGS & FIXTURES	DRAWINGS	HAND TOOLS
4	REAM WORK HOLE & BROACH	1	EA BOAMS JEWELERS FOOT PRESS	BROACHING COLLAR & BROACH	1-F-29	YANKEE SCREW DRIVER AND COUNTERBORE
5	DRILL FOR BOTTOM PELLET VENT	1	AVEY SINGLE SPINDLE DRILL #½	DRILLING JIG	2-F-27 2-F-28	
6	DRILL TOP PELLET VENT	1	" " " " "	" "	4-F-19	
7	DRILL FOR INTERIOR PELLET VENT & COUNTERBORE	2	" DOUBLE " " "	" "	3-F-29 3-F-30	
8	PRESS IN ROTATING PIN	1		HAND PRESS & PUNCH " " FIXTURE	3-F-44 2-F-26 1-F-46	
9	DRILL FOR DOWEL PIN IN ROTATING PIN	1	" SINGLE " " "	DRILL JIG	1-F-225	
10	PRESS IN DOWEL PIN	1		PRESS, JIG & PUNCH	3-F-18 2-F-43 2-F-26	
11	CLEAN	1				
12	INSPECT	1				
13	MILL ROTATING PIN	½	[illegible] ROTATING PIN MILLER — CONVEYOR		4-F-44 4-F-69	
14	INSERT INTERIOR PELLET "Z"	2		SHELLAC CAN RING RACK	1-F-66 -F-	BRUSH BENT PUNCH
15	PRICK PUNCH & SEAL DISC - SHELLAC	2		SEALING FIXTURE PUNCH	2-F-167	HAMMER
16	APPLY SHELLAC FOR PAPER WASHER	2		SHELLAC CAN	1-F-66	PAD FOR WASHERS 8" × 18"
17	APPLY PAPER WASHER	2		WASHER RACK WASHER HOLDER & WEIGHTS	1-F-31 1-F-33 1-F-203	" " " 8" × 14"
18	FILING EDGE RING & PAPER WASHER	2				2' ROUND REVOLVING TABLE
19	PARAFFINE PAPER WASHER	2		ELECTRIC PLATE 16" × 30"		
20	PRIME, INSERT POWDER & PELLET "A"	2				SMALL POWDER TRAY 2" × 2" SMALL BRASS SPATULA BRASS PICK & BRUSH
21	APPLY GLUE FOR FELT WASHER	2				3½" GLUE POT ELECTRIC HEATED 10" DIA. WOOD BLOCK 12 × 12 × 3 BRUSHES
22	APPLY FELT WASHER & WEIGHT OR PRESS	2		FELT WASHER WEIGHT " " PRESS	1-F-28 3-F-44	BRUSH POT BOTTLE VINEGAR
23	CLEAN WITH FILE & BRUSH	2				FILE KNIFE BRASS PUNCH BRUSH
24	CLEAN & INSPECT	2		GAUGE	1-F-120	" " SCISSORS BRUSH FELT WASHER GAUGE
	ONE FLOOR LADY FOR 3 UNITS FOR OPRS 4 TO 12	⅓				
	ONE OPERATOR ACTS AS FLOOR LADY OPRS 13 TO 24	—				
	ONE UNIT TOTAL OPERATORS	32⅓				

OUTPUT 4000 = 10 HRS.

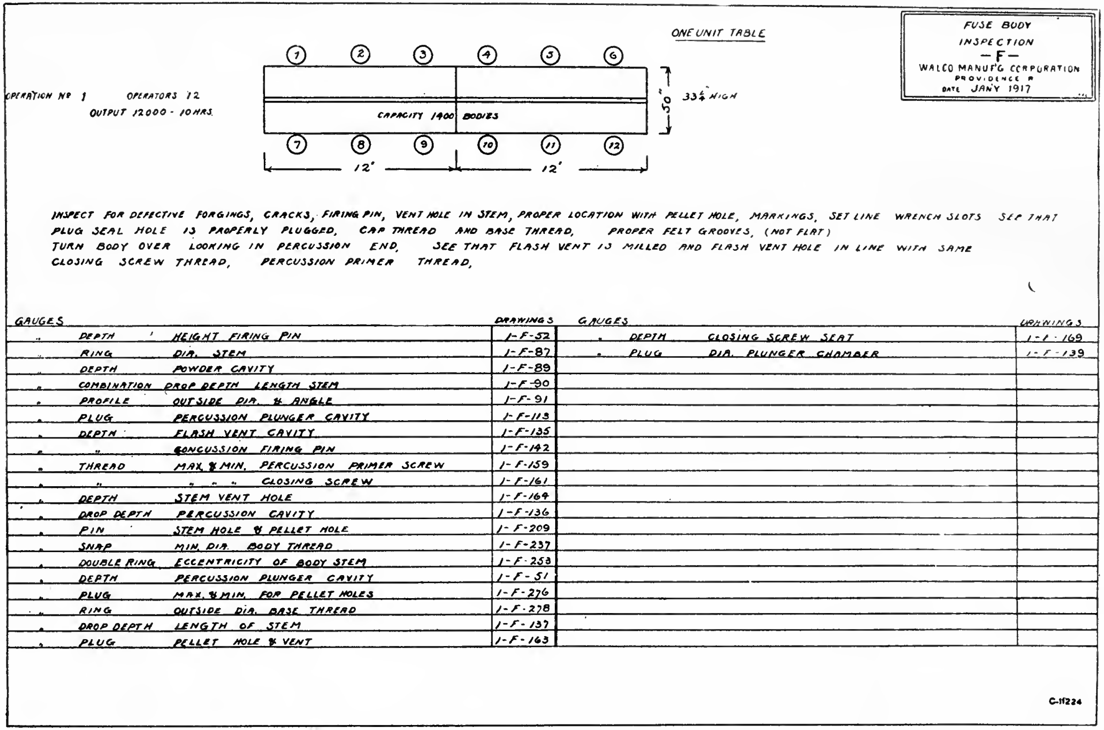
BRITISH INSPECTION

THEN TO TRUCKS - HELD HERE (OR IN RACKS) FOR 24 HRS THEN TO ASSEMBLY TABLE

C-11232

Figure 45. Work Table Layout and Operation List for Time Fuses

War work of American Locomotive Company.



FUSE BODY
INSPECTION
—F—
WALCO MANUF'G CORPORATION
PROVIDENCE R
DATE JAN'Y 1917

OPERATION Nº 1 OPERATORS 12
OUTPUT 12000 - 10 HRS.

INSPECT FOR DEFECTIVE FORGINGS, CRACKS, FIRING PIN, VENT HOLE IN STEM, PROPER LOCATION WITH PELLET HOLE, MARKINGS, SET LINE WRENCH SLOTS SEE THAT PLUG SEAL HOLE IS PROPERLY PLUGGED, CAP THREAD AND BASE THREAD, PROPER FELT GROOVES, (NOT FLAT)
TURN BODY OVER LOOKING IN PERCUSSION END, SEE THAT FLASH VENT IS MILLED AND FLASH VENT HOLE IN LINE WITH SAME CLOSING SCREW THREAD, PERCUSSION PRIMER THREAD,

GAUGES		DRAWINGS	GAUGES		DRAWINGS
DEPTH	HEIGHT FIRING PIN	1-F-52	DEPTH	CLOSING SCREW SEAT	1-F-169
RING	DIA. STEM	1-F-87	PLUG	DIA. PLUNGER CHAMBER	1-F-139
DEPTH	POWDER CAVITY	1-F-89			
COMBINATION	DROP DEPTH LENGTH STEM	1-F-90			
PROFILE	OUTSIDE DIA. & ANGLE	1-F-91			
PLUG	PERCUSSION PLUNGER CAVITY	1-F-113			
DEPTH	FLASH VENT CAVITY	1-F-135			
"	CONCUSSION FIRING PIN	1-F-142			
THREAD	MAX & MIN. PERCUSSION PRIMER SCREW	1-F-159			
"	" " " CLOSING SCREW	1-F-161			
DEPTH	STEM VENT HOLE	1-F-164			
DROP DEPTH	PERCUSSION CAVITY	1-F-136			
PIN	STEM HOLE & PELLET HOLE	1-F-209			
SNAP	MIN. DIA. BODY THREAD	1-F-237			
DOUBLE RING	ECCENTRICITY OF BODY STEM	1-F-253			
DEPTH	PERCUSSION PLUNGER CAVITY	1-F-51			
PLUG	MAX. & MIN. FOR PELLET HOLES	1-F-276			
RING	OUTSIDE DIA. BASE THREAD	1-F-278			
DROP DEPTH	LENGTH OF STEM	1-F-137			
PLUG	PELLET HOLE & VENT	1-F-163			

C-11224

Figure 46. Fuse Body Inspection Layout
War work of American Locomotive Company.

table and thus classify themselves automatically, as regards their lack of sphericity.

By such methods as those just related a supply of bullets of the required hardness and roundness was soon obtained. The plant requirements were 60 tons per day, but they were soon able to supply other plants which had encountered trouble in making bullets.

Time Fuses

Everyone knows of the grief encountered in making and loading time fuses, so that a mere statement that the American Locomotive Company produced millions of them successfully, with no explosions or injuries to employees, should be indicative of the care that was taken. They had to find out that no two lots of powder are sufficiently alike to permit loading for a uniform burning time of 21 seconds + or − 0.2 second. They started without any knowledge of the business and had to feel their way. But they did know the principles which must be followed in making anything.

They developed a simple type of powder blender and created a larger supply of uniform powder. Then they learned that powder will not pack to burn accurately unless the humidity of the air is constant, so the air for the loading rooms was first dried by freezing, and then conditioned to a standard humidity. In order to make sure of the ±0.2-second limits in burning time, they paralleled the commercial type of chronographic instrument with a time-measuring instrument of their own design.

The following item is significant: The second lot of fuses went wrong in burning time, and the trouble was located promptly as occurring in one of the 17 separate loading stations. There were seven men in that room instead of the usual five. In the hot weather this caused sufficient variations in humidity to affect the firing time. Would it have been possible to locate such a difficulty promptly without an efficiently handled inspection service?

Quality First—Then Quantity Follows

Mr. Lassiter believes in inspection, just as he knows that the first move toward quantity production is to make things right. In this work the ratio of inspectors was 1 to every 4 workmen.

The percentage of work rejected in process inspection varied widely from time to time, as must always be the case. When the estimates were made for submitting proposals for the contracts, a 5 per cent loss in manufacture was allowed for. When starting on production, the inspectors were very rigid and the temporary rejections amounted to about 19 per cent. These rejections were held in suspense, however, until a hospital could be organized for reclaiming some of the product. This was done, as already stated, so that rejections could not stop the progress of the flow of work through the machines. As the work progressed and the organization learned more about the business, rejections began gradually to decrease, so that upon the completion of the job it was found that the total losses from every cause in the process of manufacturing was only 6 per cent. The total loss therefore exceeded the estimated loss by 1 per cent, but the reduction in cost below the estimated cost greatly exceeded the 1 per cent excess of loss.

Mr. Lassiter states:

> If we had not provided our enormous staff of inspectors, who checked each operation on the work as it progressed through the shops, with limit gages with very close tolerances our loss would have run into an enormous sum of money. Therefore, one of the causes of our great success in the economical manufacture of shells was our large staff of inspectors, the tolerances which we established on the limit gages and the system which we installed.

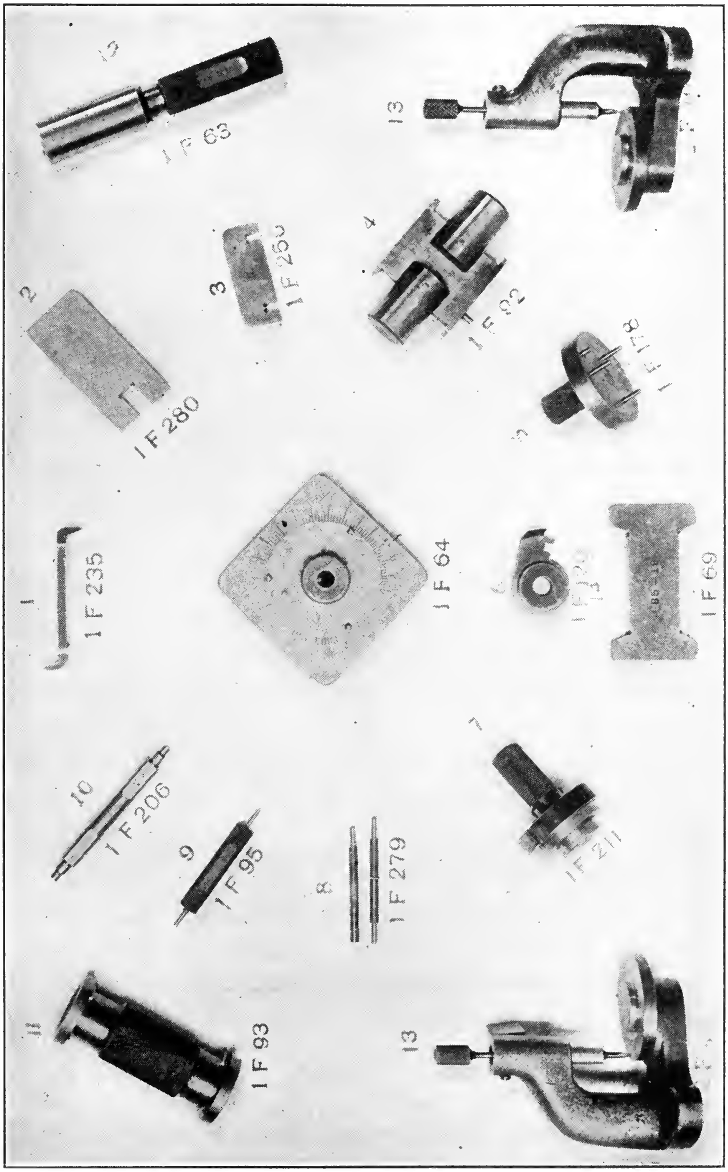


Figure 47. Special Gages for Bottom Rings of Time Fuses
War work of American Locomotive Company.

It is to be regretted that the very many other interesting features of this work cannot be presented here. The methods pursued, as shown by the salient features already mentioned, strikingly illustrate the premises laid down at the beginning of the chapter.

Liberty Motors at the Lincoln Motor Company[1]

The name of Leland has long been associated with the idea of precision and fine workmanship carried to the *n*th degree. Henry M. Leland began his career in the Springfield Arsenal, and later extended his experience from firearms into the field of manufacturing sewing machines and machine tools. With his son, Wilfred C. Leland, he was one of the pioneers of the motor car industry. Together they carried the Cadillac factory to a point where hundreds of machine operations were held within 0.0005 inch of the absolute dimensions.

In 1917, they established the Lincoln Motor Company to build Liberty engines for the United States Air Service. The first contract, dated August 31, 1917, was for 6,000 engines, and contemplated an ultimate output of 70 12-cylinder engines a day. Henry M. Leland, then 74 years old, made this pledge to General Squier:

> It's true that we have no factory now. But we have the know-how. We will guarantee to build within a specified time as many motors and of at least as good quality as will be produced in any existing plant.

The land was acquired and an $8,000,000 plant built and equipped. This called for over 90,000 special tools, among which were 6,522 separate designs. Mr. Leland told the writer that the large number of tools and gages as well as the time required to get started was questioned by some of the

---

[1] The statements made are taken from "A Pledge Made Good by Deeds," published in the *Detroit Free Press*, and are supplemented by data obtained by the author in conversation with Henry M. Leland during a visit to the Lincoln Motor Company's factory.

9-17-20 4 Sheets,
Sheet No. 1

LINCOLN MOTOR COMPANY
OPERATION SHEET

PART NAME: HOUSING FOR TRANS. CONTROL LEVER PART NO. 2002

Oper. No.	Name of Operation	Dept. No.	No. Req'd	Kind of Machine, Machine Size, & Special Tools Per Set Up L. M. Co. Mach. No.	Tool No.	No. Req'd	Commercial Tools Per Set Up
5	Inspect	M-19		Bench			
			1	Gauge for checking depth of core from unfinished face of boss 5 1/2 dia.	11948		
10	Snag	K-16					
12	Inspect	M-36		Bench			
13	Sand blast	K-17					
15	Rough and finish bore, rough tap large hole and rough and finish face base	K-23		#6 W & S Screw Machine	1965	1	10" Face plate (Std. W & S) #196-A
			1	Face plate fixture and layout	4128	1	1 3/4-16 Go thd. gage Go & No Go
			1	Tool block for rough and finish facing base	4135	1	1.686 Go plug gage with handle
						1	1.690 No Go plug gage handle
			2	Bar for roughing and finishing inside dia. and thread dia.	4136	1	1.654 Go plug gage with
						1	1.656 No Go plug gage handle
			1	Gauge for setting cutters on finish boring bar	4138	3	#641 Warner & Swasey flanged tool holder
						1	Shell reamer 1.655 dia.
			1	Alignment bar for 1 1/4-1-3/8-1.654 and 1.686 holes with stop collar for testing squareness of base	4506	1	Holder for shell reamer #8 Std. Tool Co.
						1	Floating tool holder W & S
						1	#M-652

Figure 48. Typical Operation Sheet—Lincoln Motor Company

M-16 Part 2002

HOUSING FOR TRANSMISSION CONTROL LEVER

1. Observe for burrs, cracks, sandholes and other casting defects, also that radii, chamfers and countersinks are as per Blue Print.
2. Observe four 13/32 drilled holes and 3/4 dia. counterbore.
3. Check 8″ over all height with Template Tool #4512.
4. Check 10–24 threaded hole with Go and No Go Plug Thread Guages. The "Go" end of guage must enter to the depth as shown on drawing. Threads may be passed as O.K. if they are a snug fit on "No Go" end of gauge.
5. Check 1-3/4–16 threaded hole with Plug Thread Gauges. The Go end of gauge must enter to a depth of 1/2″ as shown on drawing. Threads may be passed as O.K. if they are a snug fit on No Go gauge.
6. Check .999–1.001 reamed hole with Plug Gauge.
7. Check 1.654–1.656 diameter bore with Plug Gauges.
8. Check .1865/.875 diameter reamed hole with Plug Gauge.
9. Check .248/.250 hole with Plug Gauge Tool #4514.
10. Check .748/.750 diameter reamed hole with "Go" and alignment Plug Tool #4915, also with "No Go" Plug Gauge.
11. Check alignment of .248/.250 and .999–1.001 holes with Tool #4508.
12. Check 1-5/64 counterbore depth and diameter with Template Tool #4511.
13. Check depth of 3/8 diameter of counterbore with Tool #4920.
14. Check 3/8″ thickness of bosses with Tool Snap Gauge .365–.385.
15. Check 7/8″ dimension faces of bosses with Snap Gauge Tool #4509.
16. Check angle and radius on top with Tool #4707.
17. Check .307–.317 dimension with Tool #4919.
18. Check 1-5/8 dimension with Tool #4921.
19. Check 1.810/1.820 dimension with Bar Gauge, Tool #4513.
20. Check 1.624/1.630 dimension face of bosses with Bar Gauge Tool #5440.
21. Check 7-1/2 dimension, 6-9/16 dimension and 5-7/8 dimension for location in relation to 1-1/4 bore with Tools #10540–10541 & 10542.
22. Check 7-11/16 dimension depth of bore to base with Tool #4510.
23. Check alignment of 1.654/1.656 bore with threaded hole and squareness with base, the 1.990/2.010 dimension, the .905/.910 dimension and 1.148/1.154 dimension, with fixture Tool #4507.
24. Check the 13/32 depth of .248–.250 hole with Tool #10775.

Figure 49. Typical Instructions for Inspection—Lincoln Motor Company

government inspectors, but that he considered it absolutely necessary to get things right before beginning production.

The company built up an organization of 6,000 people and produced 2,000 Liberty motors within one year of its formation. Before the close of 1918, it produced the largest number of motors in a single day, the largest number in a single month, and the largest total rolled up by any manufacturer. It completed its final contract 16 days ahead of schedule, and received the highest commendation for its motors.

It is stated that the leading English manufacturer, with *3* years of aircraft engine experience and *10,000* employees, was producing at the rate of *50 motors per week.* With this for a background, it is easier to measure the achievement of the Lelands, for the Lincoln Motor Company, with 6,000 employees and after only *1* year's development, was producing at the rate of *50 motors per day.*

Mr. Leland has always been guided by a desire to do things right. Quality is his hobby and he carries it to the point of gathering his men together in little groups in the shops and talking quality to them. Furthermore, he knows the precision that is necessary for such work and how to get it, as is evident to anyone who has the privilege of going through the shops of the Lincoln Motor Company. The shops show it in their equipment and management. What is more important, the work in process shows it. Several illustrations which bear this out are to be found throughout this book, where they have been placed to exemplify certain methods. In particular, attention is invited to Figures 6, 8, 12, 15, 48, 49, and 64.

Remington Arms Company—Springfield-Enfield Rifle Production

Our armies in the field never lacked American-made small-arms and small-arms ammunition, a statement that hardly holds for any other of their arms equipment. More than to any other one man, the credit for this fact is due to the war time Director of Arsenals, Brigadier-General John T. Thompson, U. S. A. (Retired), D. S. M. He developed the war plans of the Army Ordnance Department as a result of personal experience in the Spanish-American War, and had charge of developing the Springfield rifle, thus gaining recognition internationally as a small-arms expert. More recently, in association with his son, Colonel M. H. Thompson, he has brought out that remarkable arm known as the Thompson sub-machine gun.

In September of 1914, he told the writer one afternoon, on the front steps of the State, War and Navy Department building in Washington:

> We are going to be forced into this war sooner or later. I am going into civil life (he had just retired as a colonel) to help teach our people how to make military rifles and rifle-making machinery. There are not nearly enough military rifles in the world. This country will be flooded with foreign orders, and these orders can be used to get the private armories ready to meet our own needs later on. All our military rifles have been made heretofore at Springfield or Rock Island in government plants only: and making sporting rifles is not the same thing as making millions of military small-arms exactly alike.

So General Thompson joined the staff of the Remington Arms Company, where he laid the plans for the huge armories at Bridgeport and Eddystone. Subsequently he went to the Eddystone plant (the Remington Arms Company of Delaware) and acted as consulting engineer during the manufacture of Enfield rifles for the British government. When the United States entered the war he was recalled to Washington to take charge of the production of small-arms and their ammunition.

Some time later came the so-called "broomstick" investigation by Congress, following the tardy discovery that this country did not have rifles enough to arm our troops. Of course we did not. Congress had never given us a chance to have them. To those most interested technically, the outstanding feature of the investigation was the discussion of tolerances. Many of the private manufacturers wanted tolerances and limits increased—"to get greater production." General Thompson insisted that the contrary was true, and that even closer limits would result in greater production as well as in better arms. Not only that, but he had the courage to insist on converting the Enfield rifle to use the better Springfield cartridge; hence the Springfield-Enfield. This meant that 14 parts had to be changed, and the necessary delay in changing tools and gages had to be accepted. As a further step toward greater precision, also at the expense of time at the start, the gages of the different armories and arms factories were brought into accurate agreement. Was the General correct in his contention that quality preceded quantity production? Let the facts speak for themselves.

In the first place, rifles were ready for all troops at least by the time they sailed for Europe; and they never lacked them in the field. Several plants were engaged in making these arms, but the greatest output was delivered by the Eddystone armory, where the daily output reached the remarkable total of 5,000. More interesting still, the number of rifles finally assembled per man per day started at 40 (which according to the best data available, was formerly considered a good figure for this rifle), then increased to 120, and finally reached a figure of 160. As to the quality of the American rifles thus produced, for this was undoubtedly a factor in the fine shooting of our troops in the field, let the Germans before Chateau-Thierry (and elsewhere) tell the story. According to report, they repeatedly mistook rifle fire for machine guns and shrapnel.

Quality Is the Road to Production

To summarize: Mr. Lassiter developed an organization of 40,000 men and produced 25,000 tons of munitions per day with only 6 per cent of spoilage; Mr. Leland started with not even the land for a factory, built a plant, gathered 6,000 workers and produced 2,000 Liberty motors to meet rigid requirements—all in one year; General Thompson directed the planning which resulted in our enormous war time rifle production. At the basis of each of these difficult manufacturing achievements is the guiding principle of quality control.

CHAPTER XIII

MEASUREMENT AND ERRORS

The Evolution of Measuring

Measurement is the foundation upon which the exact sciences rest. Since the manufacturing arts are—or should be—but the application of the laws of science in practical form to meet our daily needs, it follows also that measurement is the proper starting point in the arts just as it is in the work of pure science. In fact, it has long been recognized that the degree of accuracy with which measurements are made is the best criterion of progress in the arts. The process of measuring permits comparisons to be made and recorded in form for use. By it we may note the differences and likenesses of similar things, also the degree of such likeness or dissimilarity; and it is by such comparison that progress can be recognized. Some changes show retrogression and others indicate improvement, but without the ability to measure them it would be quite impossible to advance either science or art in a way sufficiently systematic for practical usefulness.

When the attempt is made to manufacture a number of like things, some sort of measuring process is absolutely indispensable. Hence the importance of understanding what the process involves.

The history of the development of the standards of measuring (used here in its widest sense to include weighing or similar operations) presents a specially interesting and fascinating picture of man's material progress.[1] It does

---

[1] See further "The Progress of Science as Exemplified in the Art of Weighing and Measuring," by Professor William Harkness, U. S. Naval Observatory—presidential address before the Philosophical Society of Washington, 1887. (Smithsonian Report, 1888.)

not serve the present purpose, however, to digress in that direction, other than to note the rise of accuracy that has accompanied the evolution of our present standards. It is relatively only a short time ago that the most precise and scientific laboratory methods were quite incapable of realizing the accuracy that is commonly attained in modern shop practice, with much less effort and care. Furthermore we are able to measure many things today that our forebears never thought of measuring—and the end is not yet.

There are some features of the evolution of measuring, nevertheless, which must be considered in connection with what follows. They are illustrative of the procedure which must be observed in order to develop in a logical way the processes of measuring necessary for controlling quality in manufacturing.

The Selection of Characteristic Qualities for Measurement

Suppose we assume that we have to make a quantity of articles—bricks perhaps. They are to be as nearly alike as may be consistent with the commercial restriction of economy. Let it be assumed also that we have no means or scheme of measurement. The first step necessarily must be in the direction of selecting the characteristics in which the articles are to agree. These characteristics, which determine the quality of the article, are, of course, sensed and evaluated by us through the physical means with which we perceive them. Thus if we were concerned with bricks, the essentials would be shape or form, size, strength, weight, surface finish, color, and so on. For practical purposes, we could get along very nicely without paying any attention to any of these points except shape, size, and strength, but as the art of brick-making progresses, the demand increases for greater uniformity in the less utilitarian and more aesthetic characteristics.

The economist says that manufacturing, as a process, inhibits making beautiful things.

> Individuality is the essence of art; to be beautiful it would seem that a thing must bear the impress of its maker's personality. There is little room then for specialization in the making of beautiful things. If we want the material apparatus of life to be beautiful, we must be content with less of it; we must choose between a great many ugly and ordinary things and a few beautiful and unique things.[2]

This statement is true only if we are content to permit it to be true. It should be a pleasant duty for the manufacturer to dispel this somewhat common, although fallacious belief, and the way to do it is by the first step just indicated. Keen and searching analysis of a product will show its characteristic qualities, some of which contribute to its usefulness while others make it pleasing to the senses. Economy of manufacture reaches its greatest efficiency when every characteristic is controlled to uniformity with deadly accuracy, but its product need not be ugly or lifeless, unless we choose to ignore all but the most utilitarian qualities. If the model is beautiful, its beauty can be repeated indefinitely with proper care and attention to the pertinent details—a business in which little things become paramount. Is not the modern automotive engine an article of beauty? It is made so by precision manufacturing, which also makes it an article of commerce. If it could be made, and were made by the "individualistic" methods of the artist, no ordinary man could afford to own one; nor would the automotive art have made such rapid strides.

Standard Samples

Having selected the characteristic qualities which we wish to have alike in all the articles we are to manufacture,

---

[2] Henry Clay, Economics for the General Reader.

the next step involves the selection of a standard of comparison, and this standard must always be some tangible physical thing. To return to the case of the brick, we probably should select a brick and say, "This is of the shape and size wanted. We will call this our standard sample for shape and size." Then perhaps we might select another as the standard sample to show the desired color.

As a matter of fact, the method of comparison by using standard samples is the accepted practice in more than one industry. In many cases it has to be. Take the matter of making cigars. The tobacco must be graded in several ways, as well as by odor (and possibly taste), to secure the desired bouquet. There is no instrument as yet, to measure such qualities—nor is there even a classification of them. Any uniformity that is secured must be by comparison with some sample or samples arbitrarily selected as standard as regards both raw material and finished product. Even if samples are not at hand, they exist in the memory of the expert whose judgment is relied upon for the grading — and the statement still holds in principle.

Color is measurable, but the methods and apparatus find little application as yet outside of the physics laboratory. The principal industries in which color is a dominating quality, such as the textile industries and those of similar type, have made the first important step toward standardizing by the adoption of the so-called "standard color card" (see Chapter XXI), which shows the colors adopted as standards in the form of classified standard samples.

The selection of a standard sample can hardly be called measurement. It is rather the first crude step toward measuring, as we understand the term "measuring" when speaking of weight or dimension. But it is a very necessary link in the chain of development. Perhaps it may be asked, Why carry the process further if such samples will serve the purpose? The answer is best found by considering what must be assumed when comparison is by standard samples.

Dangers of Standard Samples

The first assumption is that several samples are sufficiently alike for practical purposes. If a number of samples are available to choose from, this may reasonably be assumed to be true, *but only up to a certain degree of likeness.* Further progress toward general uniformity is blocked when that stage is reached.

The most dangerous assumption which must be made, however, is that the standard sample will not change with time. It is bound to change. That is one of the few great laws of nature we are sure of. Everything changes all the time, and very few samples indeed could be found that would not alter perceptibly—if we had anything to use as a measure for detecting the change. What is more to the point, the oftener we use our standard sample in practice, the sooner does it alter in the very characteristic for which it was chosen as a standard of comparison. Our old friend, the brick, would soon wear, and abrade away from its original size and shape, if we used it to compare with new lots of bricks. Also, the one we selected as a sample of the desired color would be quite sure to fade with exposure to light, or to grow darker from handling. At best, any system of uniform manufacturing which is based on standard samples alone requires that the most unusual precautions be taken to safeguard the standards. The use of master gages and the care required in gage-checking may be instanced in illustration.

Measurement by Comparison with a Standard Scale

The next move toward a more efficient means of making comparisons in order to secure uniformity of product, is in the direction of greater general usefulness, simplicity, and permanence of results. Convenience, if nothing else, requires that we obtain a standard of more general applicability. Suppose we take dimension as the quality to illustrate this. Once we assume an arbitrary standard of length with a suitable scale of divisions, we can dispense with the business of comparing brick with brick, so far as dimension is concerned. In fact, with such a means of measurement, we are in shape to compare dimensions by themselves, without regard to the particular articles whose size is involved. Thus the idea of true measurement appears, because we are able to reduce our comparisons to the abstract form of figures. Any dimension is then expressed in the form:

$$\text{The measured length} = \frac{\text{the given length}}{\text{the standard of length}}$$

The point to be borne in mind is that when it becomes desirable to carry the control of quality beyond the standard sample stage, the first step is to develop a graded scale which will permit us to express the measure of the quality in figures. The latter makes us reasonably independent of the dangers of standard samples. Needless to say, such a scale itself is always, in the last analysis, based on some tangible and arbitrarily selected object which is taken as the common standard. But the general usefulness and wide application of the selected object warrant the precautions necessary to insure permanence. Thus dimension and weight, the evolution of which has been carried to the practical limit, may be taken as amply safeguarded. The standards in this country are represented by certain weights, bars, etc., which are kept in the vaults of the Bureau of Standards in Washington. (See Figure 50.) That is to say, all our measures refer back to certain objects which are arbitrarily selected as the standards. The standard of length is now reproducible for any reasonable requirement of accuracy, because its measure is known in terms of light waves.

Figure 50. The Standards of Weight and Length for the United States

Kept in the vaults of the Bureau of Standards at Washington, D. C.

Nevertheless it is still true that we cannot get away from an arbitrarily chosen standard even then, because we must use a given light wave, such as sodium, and the light must be made or taken from sources selected as standard, and measured with a certain definitely selected and calibrated equipment.

The choice of the fundamental units for measurement should be made with care. They should be convenient, should permit accurate comparisons with other quantities of the same kind (see Professor Harkness as referred to above), and should permit of accurate comparisons regardless of time and place. Scientists ordinarily use as fundamental units for physical measurements a definite length, a definite mass, and a definite unit of time. Most of our ordinary measurements are based on these units or some combination of them, e.g., electrical measurements, etc. Characteristic qualities which are not measured outside of the laboratory as yet, usually will be found to be measurable in terms of three constants. The fact that sound is measurable in terms of tone or pitch, amplitude, and timbre indicates a line of attack when the problem arises of measuring noise due to vibration. The color constants are hue, purity or saturation, and luminosity or brightness (see Chapter XXI).

The Measuring Instrument

The final step in the evolution of measurement is the development of instrumental means for making comparisons. Their need springs from the desire for greater accuracy, which requires the use of something that is less subject to personal error and differences from individual to individual. This impersonal quality of the instrument flows from the fact that it is more positive in action than any unaided comparison by means of our senses can possibly be—a result that is accomplished ordinarily by enlarging or magnifying differences in reading, so that errors may be detected with greater ease.

In using a finely calibrated scale, for example, the point is soon reached where finer readings are impossible, and further progress toward greater accuracy is blocked. Suppose the scale is a high-grade flat steel scale 6 inches long, marked off in fiftieths and hundredths of an inch. If this is applied in the attempt to measure a block of steel, say, about 4 inches long, there will be considerable doubt as to which of two of the hundredths marks is the closest to the block's size. If the block is longer, the difficulty becomes greater; and if it is longer than the scale, an accurate reading is much harder to obtain. The use of a magnifying glass permits closer reading, but the use of an end measuring instrument, which makes positive contacts in place of

Figure 51. Method of Using Hub Micrometer Caliper #241—Brown and Sharpe Manufacturing Company

side-by-side comparison, renders easily possible a much greater precision of measurement.

The use of instruments permits the application of means for enhancing errors and thus permits closer reading. As most of the means ordinarily employed for accomplishing this are illustrated in the following chapters, we may note meanwhile only some of the features which such instruments should possess.

No instrument is worth using in the factory unless it is sure to measure more accurately than can be done without the instrument. At first thought this may seem a commonplace, but it seems so only at first thought, for the reason that some instruments are apparently more accurate merely because they are sensitive. An instrument has great sensitivity when it answers (or shows a change in reading) for a very slight change in the thing being measured or in the conditions under which the measurement is made. It is desirable to note this difference between sensitivity and accuracy, because the two are sometimes confused. A balance whose indicating pointer answers to a very slight change in weight, may still be quite inaccurate.

The converse is true also, because an accurate instrument may lack sensitivity. In the latter instance the fact should be known, because it sometimes happens that the lack of sensitivity results in a lag. It is therefore important to know how long it takes a sluggish instrument to show a correct reading. But in order to know what degree of accuracy an instrument is capable of showing it must be possible to check its precision, and this requires a more exact standard for checking purposes. It is for this reason that emphasis is laid on the necessity for control centers or laboratories for the control of the quality concerned. Thus a later chapter (XVII) deals with an ideal control center for dimension, as typical of any such control centers.

In this discussion of instruments it will be noted that no attention is being paid to certain general requirements for measuring apparatus with which everyone is familiar, such as ruggedness, precision, facility for making direct measurements without corrections, general suitability to the requirements of the work, and so on.

Danger of Overgraduation

It is desired, however, to direct attention to some of the qualities in such instruments which are frequently overlooked, and thus make accurate measurements out of the question. One of these oversights, as a case in point, is what may be termed an "overgraduation" of the instrument. One of the great dangers faced by the technician, as by everyone else, is that of fooling one's self. It is vitally necessary in manufacturing to be sure of the facts—especially as to measurement. Therefore an instrument which is calibrated to permit closer readings than it is capable of making is to be avoided with care, or at least used with a knowledge of its probable errors.

To illustrate—the chief engineer of a large concern was criticized because his plans said that certain dimensions, on tools, should be held within .0002 inch, the specific charge being that such precision was uncalled for and would lead to unnecessary cost in the tool-making shops. He answered by asking "What do you think that requirement for .0002 inch means?" Of course, he was told that everyone assumed it to mean .0002 inch, as stated. Much to their surprise he replied—"It does not. I intended it to mean what our tool-makers think is .0002 inch. In other words, what I am after is the degree of accuracy in workmanship which our tool-makers produce when they think they are working to within .0002 inch of the stated dimension. If you think that is the same as .0002 inch, suppose you check their work with our Pratt and Whitney measuring machine. If you do, you will find that what the tool-room thinks is a precision of .0002 inch is actually over twice that, although they are perfectly sincere in their belief. They are doing the best they can with the instruments provided, which happen to be calibrated in ten-thousandths. These instruments may be capable of such accuracy, but as used in our shops, no such result is obtained."

Every once in a while a factory is found whose drawings call for exceedingly close adherence to the absolute dimension, although the shop is not equipped, *except by the markings on the instruments*, to work to any such degree of accuracy as is prescribed. Usually all hands are quite sincere in believing that they attain the requirements stated on the drawings, but they merely fool themselves. Why do so, however, when it is so easy to possess the truth?

The Need of a Final Check

Not very long ago the chief inspector of a factory whose work required a high order of accuracy for a very special sort of work was asked to produce his final standard of dimension. He pointed out the usual standards supplied with micrometer calipers. His questioner said, "But I asked you to show me your final standard—your 'court of last appeal.'" The chief inspector blushed and said, "We haven't any!" Later he added in self-justification, "I've asked for gage blocks several times, but they never gave them to me." Does your chief inspector, by any chance, happen to be in the same fix?

By the same token it is equally erroneous practice to expect accuracy when the instruments provided do not permit of close enough reading. A pressure gage with a 2-inch dial, calibrated by 5-pound intervals, will hardly permit the process to be held to closer than 5 pounds. Yet just such a case came to light during the recent overhauling of a process in which a close adherence to a given standardized pressure was vitally important for securing a uniform product from that process. It is questionable as to which is worse—a mechanic who thinks he is doing accurate work because an inaccurate instrument says so, or one who is trying to do accurate work without a clear reading instrument to guide him. Neither condition need exist, which makes their occurrence all the more lamentable.

Figure 52. Setting a Johansson Adjustable Limit Snap Gage by Means of Johansson Gage Blocks

The Choice of Instruments

In step with the preceding is the failure to realize that practically all instruments are less precise over a part of their range than they are for the greater part of their range. Furthermore, at the part of the range where greater errors occur the measurements are likely to be subject to greater variations under different conditions of use. This is true in marked degree for the smaller readings of instruments which are inherently afflicted with an initial friction. It is true also for instruments whose design and construction involve backlash; and, naturally, the maximum errors may occur where the backlash may develop to the greatest degree. As an example of error resulting from initial friction, consider a balance. It may be extremely accurate for large weighings, but will show very large errors indeed for weighings made at the threshold of its scale. Accordingly the smaller weighings should be made on a balance of smaller total capacity as the smaller readings are thus expanded to a size that is perceptible. The conclusion is inevitable, that the instrument should be chosen with reference to its capability to meet the requirements of a given situation. It must not be expected to meet all requirements. You cannot weigh everything with one huge pair of scales. But the way to determine the suitability of the instrument, or to select a suitable instrument for a given purpose, is to be prepared to check the work of that instrument—by some superior method of measurement, which is *many times more accurate than the instrument* which is being checked. Otherwise you cannot be sure of your facts.

The Precision of Measurement

In developing a method or process of measuring it was observed that the first step involves the use of an arbitrarily selected standard for comparison. Presently a point is reached where observations fail to agree, and this point fixes the limit of precision obtainable by such method. Further improvement is to be sought through devising a scale of more general applicability which permits not only of stating measurements impersonally in the form of abstract figures, but also securing an additional degree of accuracy in most cases. This method also soon reaches its limit of precision, and further progress toward more exact measurement must make use of still more impersonal methods by means of instruments. While this last step usually gains much greater fidelity to the absolute measurement, nevertheless it too reaches an ultimate limit of precision beyond which measurements of the same thing under like conditions are not in agreement. This situation follows an earlier stage where measurements by different observers, working under the same or slightly different circumstances, do not check.

Thus Langley, in the discussion of small irregularities of his bolometer records of the solar spectrum, said:[3]

> When we approach the limits of vision or audition, or of perception by any other of the human senses, no matter how these may be fortified by instrumental aid, we finally perceive, and always must perceive a condition, a condition still beyond, where certitude becomes incertitude, although we may not be able to designate precisely where one ceases and the other begins. This is always the case, it would seem, on the boundaries of our knowledge in every department, and it is so here.

Inevitably, then, a certain critical point is reached for any given set of conditions, where errors enter, and this is entirely apart from the ever-present assurance of occasional accidental errors. Of course we know that errors are bound to occur—the theme of our study has been throughout that quality is varying continually—consequently the readings of our measurements of quality will vary.

The term "precision" is a confession that absolutely correct measurement is impossible of realization. Accuracy means exact conformity to the absolutely true standard.

---

[3] Joel Stebbins, "Observation vs. Experimentation," *Science*, January 13, 1922.

Absolute accuracy implies freedom from error, hence for practical purposes we are forced to speak of the degree of accuracy rather than of accuracy itself. "Precision" is a shorter term than "degree" or "rate of accuracy," and means the same thing. Consequently precision is a percentage of the measurement. Thus, the precision of Swedish gage blocks is stated as, say, one hundred thousandth of an inch *per inch* of length; and, strictly speaking, we should always state precision in that form. The attitude of the physicist toward these terms is:

> When the true value is known the "Accuracy" may be expressed as the difference between the experimental quantity obtained and this true value. Since, however, the exact or true value is seldom known, the accuracy of the result cannot be stated, and it becomes the more imperative to have methods of estimating the precision measure or reliability of the result of a series of observations.[4]

Precision of Workmanship

Now, just as there is a limit to the precision of measurement for any given situation, so is there a limit to the precision of workmanship that is possible for any given process or operation. And this limiting precision in manufacture follows after and is dependent upon the attainable precision of measurement of the work produced by said process, whether the measurement be made by a highly developed instrument or by mere visual comparison with a standard. What is true of the *possible* precision is equally true of the precision that it is sensible to use commercially, for cost will enter as the determining factor in the selection of the degree of accuracy best suited to a particular case. It is usually true, however, that a decidedly higher precision can be obtained with little effort, if the effort is properly made.

Whether the attempt to increase precision should be

---

[4] "Precision of Measurements," by Professors George V. Wendell and W. L. Severinghaus of Columbia University.

made is a matter of business judgment, and calls for a sensible decision. A military gun stock demands much closer fidelity to accurate dimension than does wooden furniture, but it would save a deal of profanity if desk drawers did not stick. The stores are full of all kinds of goods that indicate the same situation. It is a mistake to say that anything is good enough, for there must be some one dimension, for example, that is best suited to any special case. If the article, as designed, is best suited to the job, the manufacturer's constant endeavor should be to obtain a closer and closer adherence to this ideal standard. This means the refinement of manufacturing through the reduction of errors —an undertaking that should be inaugurated by a study of errors themselves.

The Theory of Errors

The most valuable thing to realize about errors, so it would seem, is that they always have a tendency to occur. They follow the general rule that it is easier to be bad than it is to be good. Their number can be reduced only by the vigilant use of foresight, care, and thoroughness. Moreover, like a snowball rolling downhill, they tend to accumulate others of their own kind; so that an ounce of prevention is worth many pounds of cure.

A knowledge of the theory of errors is so important in accurate physical measurements that considerable attention has been given to it, and several substantial literary contributions have been made. The application of their conclusions are too much confined to the physics laboratory, however, and should be more generally understood by manufacturers. The physicist starts off by making a distinction at once between mistakes—that is, mere blunders—and errors. In the factory, mistakes are the order of the day, and their best prevention lies in the direction of checks by independent methods of one sort or another, as has been indicated early in this work.

> Individual vigilance and the habit of doing everything in a careful and orderly manner are the only means of reducing such inaccuracies to a minimum. It is often highly advisable to run some rough independent check experiment or to test the final results with common sense to see that no gross blunder has been committed.[5]

Professor H. M. Goodwin, in his "Precision of Measurements and Graphical Methods," classifies errors as *determinate errors*, whose value can be determined and their effects eliminated, and *indeterminate errors*. He classifies determinate errors as:

1. Instrumental errors, due to faulty adjustment or construction of the measuring instrument.
2. Personal errors, due to the "personal equation" of the observer.
3. Errors of method or theoretical errors, due ordinarily to using an instrument under conditions for which its graduations are not standard or correct.

It will be observed that some errors lead to incorrect conclusions, in spite of the fact that several measurements may be in agreement. Thus if the instrument is out of adjustment, or if the observer is, by nature, generous in his readings, so that he constantly errs on the high side of the measurement, or if the instrument is standard at 68° F. but is used at 90° F., the measurements may in all cases agree and still all be in error.

As to indeterminate errors—accidental or residual—Goodwin says:

> Experience shows that, when a measurement is repeated a number of times with the same instrument and by the same observer

---

[5] "Precision of Measurements," by Professors George V. Wendell and W. L. Severinghaus of Columbia University.

under apparently the same conditions, the results usually differ in the last place or sometimes last two places of figures. Thus in so simple a measurement as the determination of the distance between two lines with a scale graduated in millimeters, successive measurements will not agree to one-tenth millimeter if fractions of a millimeter are estimated by the eye.

Such errors have been found to follow the law of chance, which may be plotted graphically, as shown in Figure 53, from the equation:

$$y = \frac{h}{\sqrt{\pi}} e^{-h^2x^2}$$

in which y is the frequency of occurrence of an error of magnitude x, h is a constant related to the reliability of the observations and called the "precision index," e is the Naperian logarithmic base (2.7183), and π is the constant, 3.1416.

It will be observed from the curve that:

First—Small errors occur more frequently than large ones;

Second—Very large errors are unlikely to occur;

Third—Positive and negative errors of the same numerical magnitude are equally likely to occur.

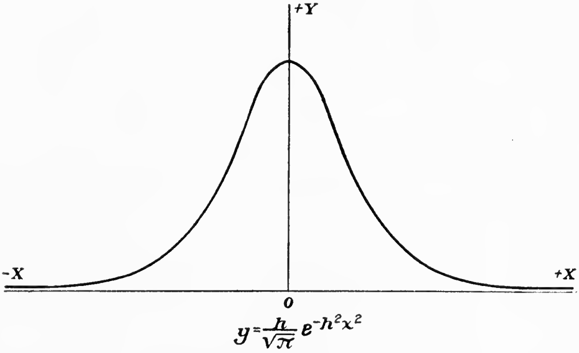


Figure 53. Probability Curve, Showing the Frequency of Occurrence of an Error

When Theory and Practice Differ

This law assumes an infinite number of observations, but is reasonably true in most cases for a comparatively small number—hence its value as a guide. It presupposes, however, that the observer is trying to attain absolute accuracy as nearly as may be; and, in the case of factory workmanship, this is where practice frequently departs from theory. Being sane, the workman will do what he believes to be to his own best interest. Consequently if there is a penalty attached to spoilage of work, he will deliberately keep on the safe side, since in that way he has a chance to repair his errors.

Consider for a moment the case of a 2-inch shaft which has a tolerance of .0004 inch. If the limits are set $\frac{.0004}{0}$ inch (i.e., allowed .0004 inch over and 0 under dimension) the greater part of the work will hug 2.0004 inch, because the operator will stay on the safe side and work toward the full dimension. If that is what is desired, well and good; otherwise the tolerance should be split up to allow for this tendency. In closer work especially, it would be better practice to set the limits as $\frac{0}{.0002}$ inch instead of $\frac{.0002}{0}$ inch, or ± .0001 inch. The probability and chance would thus favor securing more work to the desired ideal of 2.0000 inch.

If all errors were equally distributed as to size and occurrence, plus or minus, they would cancel each other to a large extent. In the factory they do *not* do so, but accumulate too rapidly for comfort. There are several ways in which this occurs, and happily there are several ways to meet the situation.

The Chain of Inaccuracy

First, there is what may be termed a "chain of inaccuracy" due to slip in the transfer of measurements. The master or reference gage is not quite like the model, the reference gage template is not quite like the gage, and so on. This error is negligible when a very precise method of measurement is available for checking purposes.

The Chain of Wear

Then there is a chain of wear, resulting in *systematic* and progressively increasing error. Granting the availability of more precise control apparatus, the remedy for such errors also is checking with sufficient *frequency*. As to the mechanical side of intentionally lessening wear, there is room for considerable discussion and the resulting conclusions are widely applicable—to tools, to measuring devices, and to the product itself. Professor John E. Sweet was the great apostle in this field as in many other practical problems. In 1876 or before, he advocated the use, and pointed out the advantages of equal length wearing surfaces; viz., the first "straight-line" engine had a cross-head and guides of equal length, which, after years of use, showed practically no wear. In 1903, he stated, "*Things that do not tend to wear out of true do not wear much.*" This principle is worthy of much consideration. In connection with it the present tendency toward the use of gages with wider and larger anvils—or gaging points—may be noted although it is true the use of such gages is to be attributed in part to other causes than minimum wear, inasmuch as they tend to give more accurate results, by lessening the chance of applying the gage at an angle.

Incidentally, it may be noted that we may profitably extend the above principle to include the idea of *even wear* for a number of like parts. Thus if everything wore at the same rate, progressive errors would accrue, but their effect would be less, due to the averaging process going on, and thus tending to hold to uniformity. Take a multicylinder automotive engine—if one of the several piston gudgeon pins is a poor fit, all will tend to wear out of adjustment. Suppose, even, that all the pins are fitted with beautiful exactness by hand-reaming, but that some are larger than others. Will they wear evenly? Will they continue to remain in adjustment as perfectly as if all were almost exactly alike? Furthermore, not only does the idea of even wear bear upon this matter of uniform dimension, but also upon the question of uniform hardness, uniformity of material, quality of finish, and so on.

The Cure for Errors

The cures for most errors will suggest themselves as soon as a systematic effort is made to locate and determine their causes. Whenever possible they must be hunted down and stamped out at the source. Some errors may be reduced by putting processes under uniform control, and in particular by averaging the errors through spreading them out evenly. The experience of Whitworth in creating the first accurate surface plate reveals a valuable lesson. Taking three plates, alternately comparing them by contact, and then scraping off the high spots, he used the errors to destroy each other and thus created the basis of all our machine shop precision—a true plane surface, relatively speaking.

The concluding observation to be drawn from the study of measurement and of errors, beside the very obvious necessity for care and thoroughness as to every detail, is the need of providing control apparatus for the qualities with which we are concerned. To be effective, such apparatus must be safeguarded, and even then it is useful only in so far as its use and the conditions surrounding its application are freed from possible causes of error. The ideal dimensional control center or dimensional laboratory to be described in Chapter XVII, is to be considered as a guide to what, in principle, any such control laboratory should be, regardless of the quality concerned. Dimension has been chosen as the type merely because dimensional control has been carried to a higher degree of precision and its apparatus is more highly developed than is the case with most other qualities —such as color, for example. This condition, it seems probable, will be modified as time goes on, and more and more qualities are brought to the same state of accurate control.[6]

The fact that means do not exist at the moment for measuring some of the characteristic qualities with which industry is concerned, merely serves to indicate the direction in which the start should be made toward conscious improvement of these qualities. If industry makes the demand on science to develop principles, practices, and equipment to meet its requirements, the needful things that are lacking at present will be supplied.

---

[6] The principle of measurement, in fact, is being extended to evaluate the functions of management. See an editorial by L. P. Alford in *Management Engineering*, Nov. 1921.

CHAPTER XIV

QUALITY DEFINED—THE IDEAL STANDARD

Characteristic Qualities of Product Must Be Known

Thus far we have considered the subject of quality in its various relationships and have traced the basic influence of measurement in order to prepare the way for a better understanding of quality itself. We are now in a position to ask —"What is it that constitutes quality?"

The first answer is that each attribute or characteristic—shape, dimension, strength, finish, color, and so forth—which defines one kind of article is a quality of that article. The more definite and specific we make the descriptions of the dominating qualities, the more accurately do we understand just what the product is intended to be, and, incidentally, wherein it is to differ from other articles of the same general class of goods. To state a quality at all accurately, it must be compared with some arbitrarily selected standard. For example, we might say a rod is to have length, but we have not described the rod as regards dimension until we state the relationship between its length and that of something else. We can secure a more exact definition of the dimensional quality of the rod if we say that its length is to be the same as that of a sample rod which has been selected as standard. But, as a matter of fact, in this case the comparison would be made with the well-accepted standard of dimension and the length stated in standard units of feet, inches, or both, depending on convenience.

This well-known and seemingly elementary example is simple only because we have a thoroughly established and well-known method of comparison or measurement for dimensional quality; but what about some of the other qualities? With respect to color, for instance, there is, as yet, no accepted method of analysis and comparison with a standard. To say an article is to be painted red is nearly as loose a definition of color quality as to describe dimensional quality by saying that a rod had length—because there can be an enormous number of tints and shades of red. In the absence of a color scale for numerical comparison, we are reduced to saying that the color will be like a given standard sample. We must also take precautions to see that the color of the sample itself does not change in the course of time, and thereby carry the product away from the standard as originally set.

The question of whether such qualities as color can be reduced to a basis of definite measurement with the same ease of treatment as dimension must be deferred at this time. Meanwhile, dimension will be used chiefly to illustrate the discussion as it proceeds. It should be borne in mind, however, that the general principle applies to the treatment of all qualities, that no quality can be described without comparing it to some standard—which process is *measurement*—and that the application of the idea of measurement must not be confined to dimension alone. This is one excellent reason why every industrial executive who is interested in the subject under discussion should be familiar, in a general way at least, with the principles underlying the precision of measurement and the theory of errors —to secure an important attitude of mind and a necessary sense of discrimination, of proportion and perspective.

Quality Varies Continually

One of the first things that this knowledge will reveal is that there is no such thing as an absolutely accurate measurment. No matter how carefully the unknown is compared with an accepted standard, errors are bound to creep in; and very shortly a certain critical point is reached beyond which these errors can be reduced only through the use of extreme precautions, if at all.

This thought leads at once to one of the most important conceptions of what constitutes quality, an idea that must be kept in mind throughout the subsequent study of the control of quality, namely, that *quality is a variable.* Quantity relates to the product en masse, and in this sense is abstract and impersonal. Quality, however, is different for each separate article produced. Hence the quality of the factory product varies from piece to piece. This fact must be clearly appreciated before an attempt is made to fix

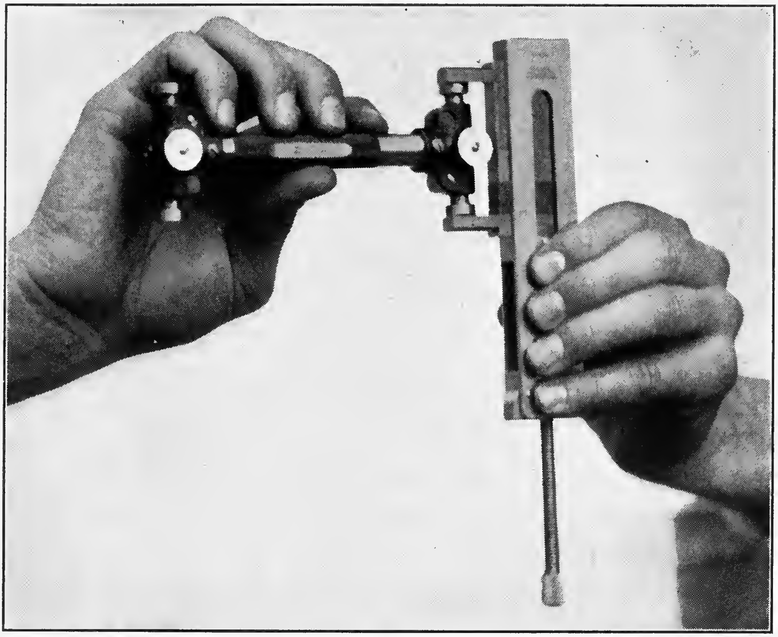


Figure 54. Checking Johansson Adjustable Limit Plug Gage with Gage Blocks Mounted in Holder

upon the standards of quality desired, or to take up the consideration of the organization and arrangement of manufacturing equipment and methods most suitable for securing these desired standards with greatest economy. In practice, the degree of quality varies continually from the standard desired. Further, the degree of quality varies with respect to time, in the sense that the attempt to make many things alike results inevitably in quality gradually slipping away from this desired standard as the work proceeds. This tendency of quality in all its forms to vary and change is always present as a potential force, and acts except in so far as it is held in check by external means provided for control purposes.

Development of the Design

With the preceding in mind, it should be apparent that the study of the control of quality must begin with an intensive study of the product, from which should result what is ordinarily called the "design." Now the production of almost anything, let alone making accurately uniform articles, presupposes a definite standard, usually represented by drawings, specifications, or a model; but preferably by all three. This standard is purely ideal and cannot be replicated exactly in quantity, because the absolute is unattainable. Nothing ever was made in *exact* accordance with the ideal design, or ever will be.

Under given conditions, the time and cost of production in quantity varies with the degree of accuracy to the ideal standard that is required. Hence the art of the designing engineer and of the production engineer is called into play to fix upon *manufacturing standards*, which vary from the ideal by certain differences or allowed errors. This process sets limits which constitute a tolerance for the actual fabrication of the work. Returning to the example of the rod, the complete design would state its length as so many inches plus or minus certain stated limits, or allowable errors.

By way of summary, suppose now that we reverse the preceding order for the purpose of more clearly developing the following definitions:

1. The complete design (which will be referred to simply as the "design") is the exact description of the product, and therefore sets forth in detail (with allowed variations from exact measurements) the characteristics of all essential qualities, i.e., the manufacturing standards. This presupposes, of course, that the product has been thoroughly analyzed and that a list of the desired quality characteristics has been made.

2. The "ideal standard" is the bare design without the allowed variations, and consequently is merely the outline or shell of what the ideal product would be if quality were *not* a variable.

3. The "theoretical standard" is what the ideal standard would be if it were designed with a view solely to obtaining the best article for the purpose for which the product is intended without regard to cost; i.e., it is the 100 per cent standard for the class of articles to which the product belongs.

It is hardly proper to call these concepts by the formal name of "definitions," as they have no special significance except as a means of avoiding misunderstanding of the following consideration of some ideas about design that are essential to our purpose.

The Theoretical Standard

The principal value of the theoretical or 100 per cent standard, to which attention was directed in Chapter II, is to provide something to which we can refer in improving the product, as time goes on and such improvements are commercially practicable. The latter are always desirable, if the selling price is not increased thereby. The manufacturer who has a well-rounded out idea of what his product would be if it were the 100 per cent article of its class, is better able to guide future progress, also to know in what directions such progress should take place. Incidentally he may avoid the predicament of the modest advertiser who illustrates a "perfect" product, only to announce inconsistently with each new season, an improvement of an already perfect thing—and this to a purchasing public which is becoming increasingly critical and whose discrimination is ever more intelligently applied.

No mention has yet been made of one of the greatest advantages in having a theoretically perfect standard to guide the development of a design—namely it will help to counteract the danger of copying the errors of the past, by blindly doing things as they have been done before.

Professor John E. Sweet[1] expressed the idea as follows:

> Whoever designs a new machine or an improvement on an old one conceives of some feature or ruling object of his design or some feature that is an improvement on present practice and neglects the other features—simply follows common practice without considering whether the other features may not be as open to improvement as the special feature he is working out. . . . And it all comes from following habit, without reason . . . it is only those who come to think of the best way who are likely to do the best; and those also who think that the "best way is bad enough."

It happens too often that betterment of the product is blocked by prohibitive cost, simply because the designer either was not informed as to the probable direction such improvement would follow, or failed to take it into consideration in designing earlier models. With a wider and farther-seeing perspective, he would have been able to shape

---

[1] John E. Sweet, "Things That Are Usually Wrong."

his design and make his factory arrangements so as both to meet the present needs and to be adapted readily for an improved product when the time is ripe for such refinement.

The Ideal Standard

The outline or skeleton design, without statement of the permissible variations, is here called the "ideal standard" —it is ideal in the sense that it cannot be realized *exactly* in practice in spite of the fact that it is the *desired* standard. As a matter of fact, one article might be made so very nearly like the ideal that the errors could not be detected by the available means of measurement, but its cost would

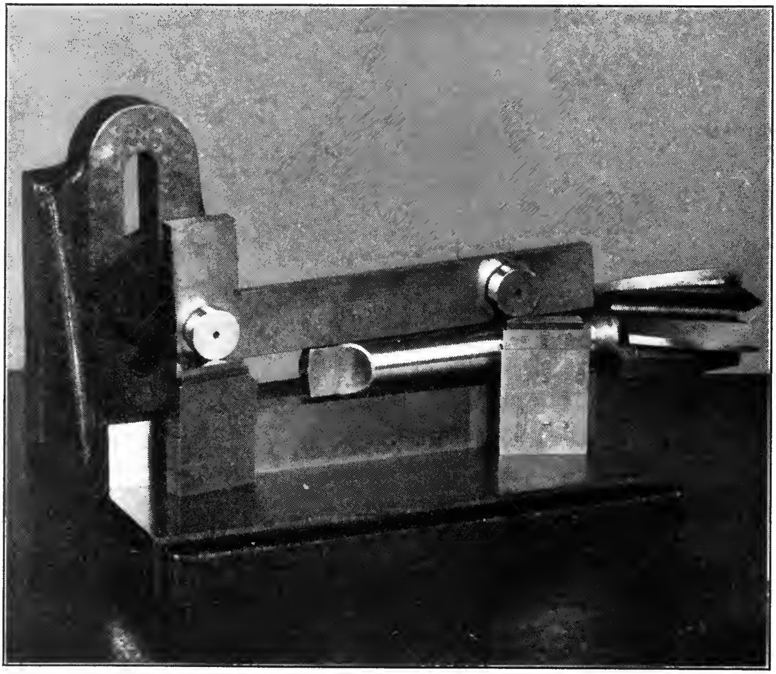


Figure 55. Use of Johansson Gage Blocks and Sine Bar to Check Taper of a Milling Cutter Shank

place it beyond the pale of commercial possibilities. A great telescope is an example of the sort. But the construction of two such articles alike to the same degree of exactness would markedly increase the effort required, even if it were possible. The *manufacture* of many such articles would increase the problem enormously, and any attempt to avoid errors wholly would certainly fail. On the other hand, a relatively slight releasing of the requirements for accuracy renders the task much simpler, so that it becomes a true manufacturing proposition. In fact it is possible to set a very high standard, provided the conditions of the problem are appreciated and proper precautions taken at the start to meet them.

To admit that the ideal or desired standard cannot possibly be realized, may at first appear like an attitude of hopelessness, but that is not the fact. All progress requires that we have in mind some rather definite ideals, which we are trying to realize. It detracts in no degree from the importance of the effort to realize these ideals, if it is admitted that at best it will result only in approximation to them. The fact remains that before we attempt to make anything, we should know what we are trying to make; and however thoroughly we may know this ourselves, it is equally important that we describe it so clearly that all concerned in the work may know what we wish done. The more definite, exact, and complete this preliminary description which makes up the skeleton design, the greater will be the economy of effort, materials, and time in the work of construction.

Progress Toward More Exact Designs

The increasing tendency toward the more specific and complete definition of qualities is easily traced. It is not necessary to hark back very far in the development of engineering to reach a point where the design was developed in large part as the work progressed. There is a quite credible story to the effect that early wooden shipbuilding was carried on in two stages of hull construction. The shipbuilder first erected the parallel middle body, after which the construction of the bow and stern was taken up by a "bow-and-stern gang." Such a gang traveled from yard to yard, sized up the job as it stood, perhaps made a rough sketch on a piece of plank, and with this general understanding proceeded to erect a bow and a stern to suit the work already in place. This method certainly

Figure 56. Set-Up of Johansson Blocks for Checking Taper of a Special Plug Gage

had the advantage of simplicity, to say nothing of reducing overhead expense.

An examination of the early designs and construction plans in any of our oldest machine shops, shows nearly the same degree of rough-and-ready methods. There is much sad experience to be read between the lines in following up the evolution of the present-day drawing from its crude start, through the later addition of more and greater refinements, until we arrive at the finished plans of the modern highly organized drafting-room. Notice that the tendency is toward an ever-increasing exactness and completeness in showing the details of what is wanted. We have learned, in short, that it is cheaper to make our mistakes on paper than to have to correct them in the materials of construction as the work progresses.

The same development is to be noted in the specifications or written descriptions that supplement the drawings, although not to the same extent, for even today most specifications contain ambiguous language. The wise manufacturer, while preparing his estimates, will be careful to iron out as far as possible, before starting work, such expensive little pitfalls as "small surface scratches on this part will be permitted in the judgment of the inspector," or "variations in other dimensions will be allowed, but the work must be to the purchaser's satisfaction."

Changes in Design Must Be Avoided

This lesson of past experience in design and manufacture has been paid for dearly. It teaches quite clearly that the time to make up our minds, as well as to do a lot of thinking, is before commencing to make chips. But even with the full knowledge of this principle before us, is it rigorously applied? In the majority of enterprises it is not so applied, and the particular way in which it is violated most seriously may be summed up by the word "changes" —the great killer of economy in manufacturing, whether it be of ships, automobiles, firearms, or what-not.

The design should be made with an open mind and the designer given the widest latitude *while he is designing.* Further, a method of attack has been indicated that should make future changes in the details of the design a matter of orderly development and progressive improvement. Curiously enough, however, this freedom of action must later give way to its exact opposite. Once the design is completed and manufacturing started, *the designer must "sit tight."*

Usually the production man himself is alive to the serious delays and losses caused by changes in design made after production has begun; but ordinarily the changes originate from a source outside of the shops. Improvements in design are rapid, and the temptation is great to make changes that better, or seem to better, the product. Consequently after all the trouble of getting out carefully detailed plans, after making manufacturing arrangements to carry them out, and even after material is in process, a rumor comes into the shop that such and such a thing is to be changed. The result is uncertainty and the beginning of confusion. Then comes the order for the change, which is usually made without the degree of care that was used in presenting the original design, for as soon as the making of changes begins, many ill-considered changes are suggested. The general effect, then, is to mix experimental work with production, instead of separating it out of the routine manufacturing shops as is done in any well-regulated factory.

When Improvement Changes Should Be Made

Some years ago in a large plant making a high-grade car, changes in design were being made with such frequency that the effect on production finally demanded the installation of a special system for handling these changes. It is true that the art was moving forward with rapid strides. Without doubt business considerations warranted the prompt adoption of some of the new improvements. On the other hand, the model was changed formally each year, and most of the improvements should have been collected systematically and saved for incorporation in the next season's car. The chief engineer, however, was busy improving the car from day to day, while the factory output was unnecessarily slowed down and the work made much more costly to the purchasing public.

It is frequently a matter of considerable doubt whether a radical change in appearance is advisable, even when the change is made for the ostensible purpose of modernizing the design. A "quality" article, for example, has been developed in accordance with an ideal—otherwise it would not be high grade. In the course of time, it acquires in the eyes of its friends a distinctive but often intangible something which makes it different and gives it a distinctive character. The time inevitably comes when there is a temptation to bring the design up to date, but long before the attempt is made, the necessary changes should be mapped out along lines consistent with the basic ideal of the design. Then the product can be modernized gradually without losing the resemblance to the original which is associated with a reputation for satisfaction. The ideal on which the design was made and on which the success of the business is founded should never be destroyed.

Every Cause Has Several Effects

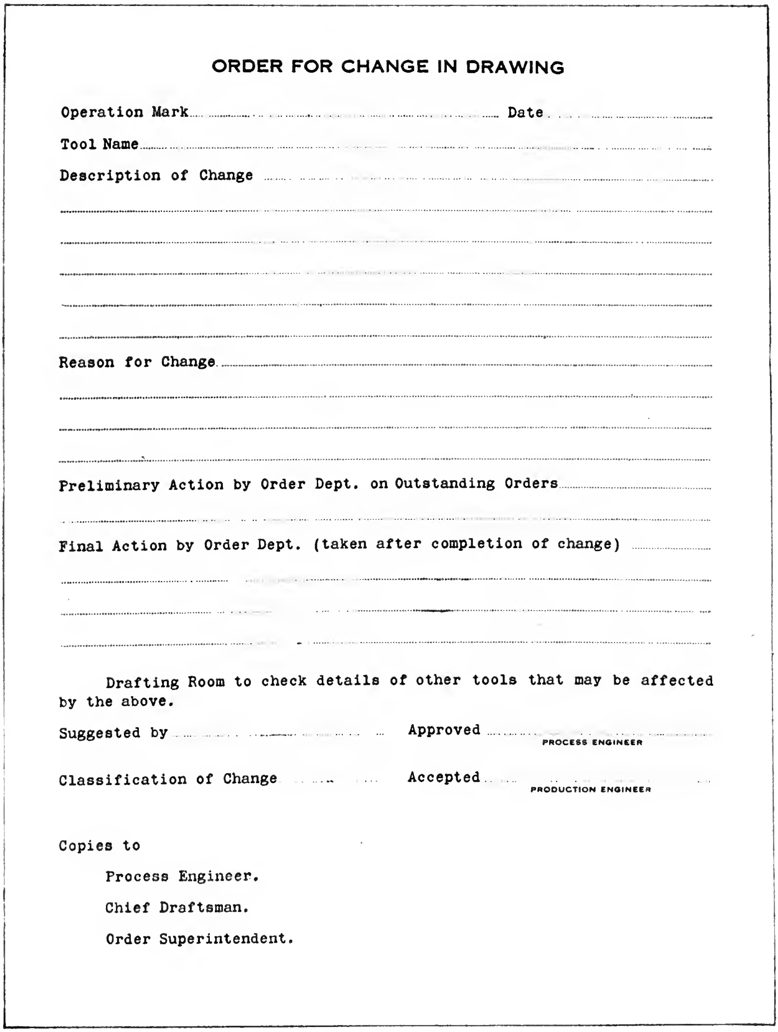
Some changes must be made. In such cases the greatest care and attention should be applied to see that they are put into effect so gradually as not to interfere with efficient production any more than is absolutely necessary. It becomes the duty of the production man to impress that fact strongly upon the designer. Very often the fact alone must be accepted, because the sources of loss are so intimately interwoven with the processes of production that separating them out is too difficult to be worth while. It is a perfectly safe statement that any change costs money in an amount entirely out of all proportion to the direct work involved.

Finally, there comes to mind the principle laid down by Herbert Spencer—"Every cause has more than one effect." You may accomplish a slight local improvement, but you should not forget that you have altered other conditions as well. The very thing that improves one part of the design may affect other parts adversely.

Precautions to Avoid Changes

Changes in work due to errors in design are almost bound to occur, but every effort should be made to minimize them. Careful work in the drafting-room will decrease such errors. In small accurate work it is often helpful to make drawings to a magnified scale, or even to make a large-scale model. Many engineers hold that our drafting-room practice has reached such a degree of perfection that the making of a model is unnecessary. There are some cases, however, in which a model would seem to be advisable, if for no other reason than to assist the draftsman's eye to a more readily comprehended picture of the relations of the component parts in a complicated assembly.

Further, in every sort of work which permits of making a model or sample, it should be noted that every practicable effort should be made to avoid changes occasioned by mistakes in the designs, by the obvious process of eliminating the necessity for such changes before beginning manufacturing operations. The way to discover and eliminate the



ORDER FOR CHANGE IN DRAWING

Operation Mark Date

Tool Name

Description of Change

Reason for Change

Preliminary Action by Order Dept. on Outstanding Orders

Final Action by Order Dept. (taken after completion of change)

Drafting Room to check details of other tools that may be affected by the above.

Suggested by Approved PROCESS ENGINEER

Classification of Change Accepted PRODUCTION ENGINEER

Copies to

Process Engineer.
Chief Draftsman.
Order Superintendent.

Figure 57. Order for Change in Drawing
Form used at Remington armory, Bridgeport.

"bugs" in a new design of product is by careful and thorough work in the experimental and research department. The latter department will pay for itself many times over by providing a smooth path of development and co-ordination between the engineering department and the producing shops. Without this procedure, experimental work, which has to be done somewhere by someone in any case, is mixed with production, and the resulting great waste is quite likely to be lost sight of because no ordinary cost or production system will reveal it.

CHAPTER XV

THE WORKING STANDARDS

The Compromise in Setting Tolerances

Granted that the ideal standard cannot be realized in practice because quality varies continually, practical manufacturing or *working standards* must be determined. These vary from the ideal standard by certain differences or allowed errors, and by adding them to the outline design or ideal standard, a complete design is obtained.

The use of the plural in referring to the working standards is intentional, since *many* differences from the ideal design will occur in the shops, and from these must be selected the variations that are to be allowed in the finished article. This process of selection will fix the working standards. Needless to say, the determination of permissible errors or variations is not always a simple matter, but rather a task calling for the exercise of unusual discrimination and good judgment. The designer, especially when freed from responsibility for costs, will endeavor to have these variations as small as possible. He will insist on a close approximation to the ideal. On the other hand, the man who is responsible for production will reason that the time and cost of manufacturing under certain conditions will increase with the degree of accuracy required; so he naturally will seek to obtain the largest possible allowed errors.

If the situation is dominated by either of the above-mentioned views, trouble is very likely to ensue. The unrestricted designer usually demands unnecessarily high standards, government work sometimes furnishing an extreme example. Contrariwise, the unrestricted production man usually tends too strongly in the opposite direction. As is usual in such cases, the truth lies somewhere between the two extremes; hence the necessity for someone to apply good common sense in the selection of the working standards. The best compromise is to be had, usually, when the standards are selected by a well-balanced committee on which engineering, production, and inspection are represented.

Raw Material Standards

The design states the kind of material from which a part is to be made, and specifies the required conditioning of the material (such, for instance, as heat treatment), also the dimensions and form desired, the finish of the surface, and frequently the requirements to be met in assembling and functioning in service.

The selection of suitable raw material is a matter of the utmost importance, in which the governing considerations are uniformity, ability to meet service requirements, and ease of working in the manufacturing process. First cost is a subordinate consideration in nearly every case, in comparison with uniform behavior in manufacturing and uniform performance under working loads. A typical instance is furnished by the motor industry, where a very low-priced car has been built of the highest percentage of alloy steels. There are better places for economy than in the raw materials.

The determination of working standards for raw material has received a great deal of attention in recent years and need not be dwelt upon here. The preparation of standard specifications for various kinds of material (and for the different grades of each kind) by some of the great railroads and manufacturing plants, by various governmental departments, and by the American Society for Testing

Materials, has made available a large body of technical data arranged in systematic form. It is only necessary to select the specifications of a suitable material in order to have the limiting conditions known.

In the case of metals, especially, the data are quite complete. The permissible variations in the chemical constituents are set forth, together with the limiting conditions for pertinent physical characteristics. In the case of other kinds of material, the essential characteristics are mentioned and limits frequently stated. It would seem, however, that much progress remains to be made in specifications for many of the usual non-metallic materials, such as wood and fibrous materials, principally in the way of information to be collected and systematized through the application of the microscope and the binocular microscope and other scientific apparatus not applied as yet to any great extent in such work. The use of micro-photography in the metallographic study of metals has developed a wide and fruitful field. A similar development will follow the application of these methods to many of the non-metals.

Conditioning Standards

The determination of working standards for what, for lack of a better term, may be called the "conditioning of material" is not so simple a matter. A part made from soft or untreated steel in order to permit economical machining or working, subsequently may require some form of hardening or tempering in order to suit it to the duty it must perform in the assembled mechanism. In fixing the limiting conditions the scleroscope or Brinnell test is available, or perhaps a file test may answer. Another element is introduced, however, if appreciable distortion occurs in individual parts to such an extent as to require straightening. If straightening is necessary and the function of the component part is an important one, some sort of special test should be specified, of a kind to demonstrate that the part will pass the maximum demands that are likely to be encountered in service.

Important springs should have maximum and minimum weighing tests to be made in a special fixture, and should be set up for a specified period of time and to a given displacement without more than an allowed set.

The time and order or the particular stage of manufacture at which any such special tests should be applied may possibly be of importance, hence the value of listing these tests on operation sheets and route cards, just as if they were ordinary manufacturing operations. Special tests should be provided for important non-metallic materials requiring special treatment or conditioning prior to or during manufacture. The kiln drying of high-grade lumber is a case in point, where the binocular microscope may sometimes be used to advantage.

Standards of Finish

There is considerable laxity in determining standards for exterior finish. Probably the fact that more attention is not devoted to setting standards of finish is due as much to commercial considerations as to the difficulty of reducing the degree of finish to measurable and tangible terms. The manufacturer selects a finishing process sufficiently economical for the purpose, and then strives to get as good a finish with that process as is reasonably possible, on the general assumption that the shinier or prettier an article looks the more it will appeal to the customer's eye. Unfortunately there often is good reason for this attitude, many purchasers prefering a polished surface where a good coat of paint over a rough surface would be more durable and less expensive to maintain. In competitive businesses, however, it is often wise to give the purchaser what he thinks he wants, even if it may not be the best thing for him. Note, for example, the face of a pressure valve flange. It has been faced off in the lathe with a roughing cut, followed by at least one finishing cut. Then one or two small circular grooves are cut for the gasket to be squeezed into, in order to secure tightness. And yet one rough turned facing would accomplish the purpose better by providing a multitude of grooves. This is only another instance of perpetuating the errors of the past by thoughtless imitation.

Oftentimes the allowable gradations in the hue, shade, or tint desired for a colored surface are left to the judgment of the production man or the inspector. Sometimes a sample is furnished which is to be approximated as nearly as possible commercially. In such cases, it is well to obtain the advantage of manufacturing to limits by providing samples showing all extremes that will be allowed. When standards for smoothness of finish are to be set, the same practice should be followed, i.e., the use of standard samples. Preferably a few sample parts should be used for small work, some showing acceptable work, and others showing work not quite good enough to be passed. In other words, the samples should be selected close to the limiting conditions desired. This general process is the best that can be adopted until more and more of such qualities are reduced to a basis of numerical measurement—a result that is sure to come as the qualitative refinement of our industries progresses.

Standards of Dimension and Form

In its ultimate effect the establishment of practical or working standards for dimension and form covers the most important and far-reaching subject of all. It is of the essence of that great branch of repetition work which is known

Figure 58. Measuring Diameter of Automobile Piston

Illustrating the correct use of micrometer calipers—Brown and Sharpe Manufacturing Company.

as "interchangeable manufacturing," which will be considered in greater detail in the following chapter.

In determining the working standards for dimension and form or shape, the relation of each part to the other component parts of the mechanism must first be considered. The ideal standard, as described in the preceding discussion, fixes one size and shape, and it may be assumed that the designer in articulating the mechanical movements involved provided for the necessary strength and other physical qualities required. These qualities have to do with what might be termed the "main body" or "interior" of the parts, whereas for present purposes we are concerned with variations in the outer surfaces or exterior of a given part, with special reference to the similar surfaces of the other parts of the mechanism with which the given part works. We know that these outer ends of the dimensions, so to speak, are going to vary, and therefore we must determine the limiting variations in the *fit* of the one part to the other parts that will still secure a proper functioning of the entire mechanism. In this way we can settle upon the greatest distance from edge to edge of related parts, as well as the smallest separation or play that is permissible, thus determining the maximum and the minimum allowance for fit.

With the figures just referred to as a guide, the next step involves the determination of the permissible variations in the dimensions of each part, considered separately, and these maximum permissible variations fix the *limits* of the dimensions, the difference between any set of limits being known as the "tolerance."

Allowed Variations Defined

The terms "allowance," "tolerance," and "limits" have long been a part of the technical nomenclature of repetition and interchangeable manufacture, but are only recently beginning to receive the detailed study they merit. It is not the purpose of this book, however, to do more than trace their application in the development of working standards of dimension, as a resultant of the basic idea that quality is a variable.[1]

The following definitions are taken from the "Progress Report of the Committee on Limits and Tolerances in Screw Thread Fits, to the Council of the American Society of Mechanical Engineers," as published in the *Journal* of that Society for August, 1918:

> *Allowance*—Variation in dimensions to allow for different qualities of fit.
>
> *Tolerance*—The allowable variation in size equal to the difference between the minimum and maximum limits.
>
> *Limits*—Two sizes expressed by positive dimensions, the larger being termed the maximum, and the smaller, the minimum limit.

In some cases, as in mating threaded parts, or in moving parts which must not touch each other (such as in turbines, pumps, and so on), an actual clearance must be provided for.

> *Clearance*—A difference in dimensions, or in the shape of the surface, prescribed in order that two surfaces, or parts of surfaces may be clear of one another.[2]

The opposite situation arises in certain cases, when parts are fitted with a "pinch."

Necessary Precautions

The process of working from the allowance to the determination of tolerances and limits involves a nice application of judgment (both to the theory of the design and

---

[1] For an interesting discussion of this subject the reader is referred to a paper on "Gage Limits in Interchangeable Manufacture," by Colonel E. C. Peck in the October, 1919, issue of *Mechanical Engineering;* also to some notes on the "Theory of Tolerances and Comparison of Symmetrical and Asymmetrical Systems," (*Ibid.*, July, 1919), together with a very practical comment thereon by J. Airey (*Ibid.*, October, 1919).

[2] British Engineering Standards Association definition.

to the current shop processes), which should consider especially the following:

1. The effect on the allowance for one dimension, of the errors accumulated from the variations in dimension of any other mating part or bearing point, if any. For example, if we are determining permissible variations in the diameters of two mating gear-wheels, we must consider the effect of the play to be allowed in their supporting bearings.

2. The effect of wear of the parts after the mechanism is in use in service. The tolerances should be proportioned to favor the parts that probably will wear most rapidly, with the object in view of insuring uniform and even wear.

3. The relative difficulty of manufacturing the parts concerned. The parts should be favored whose manufacture involves the use of mechanical operations or processes that are the most difficult to hold to dimensional accuracy.

4. The effect of wear of cutting tools, dies, fixtures, jigs, gages, or other special manufacturing equipment, in order to secure the greatest economy in their cost. The most expensive equipment should be given the longest wearing life.

The above process will give a set of limits for all important dimensions of the finished parts only, so that a process, somewhat similar in principle, must be gone through with to determine similar limits for the vital dimensions of *unfinished* parts after each mechanical operation involved in the process of manufacture.

If "close work," requiring a high quality of dimensional accuracy, is involved, it is specially important to consider the possible effects of errors accumulated from process to process. This suggests, at once, the importance of a well-worked-out list of mechanical processes to be used in making any given part, which list should show not only the sequence in which the work will be processed ordinarily, but also the alternative arrangements of operations that may be used in

Figure 59. Reading Inside Micrometers after Measuring Inside of Cylinder
Brown and Sharpe Manufacturing Company.

case shop exigencies indicate the desirability of rearranged routings. In this way we are enabled to foresee what accumulated errors may arise in the case of emergency changes in routing, and, being forewarned, to guard against them.

The selection of locating and reference points is closely inter-related with the above. Working from holes provides a safe method when too much wear is not involved. The same scheme may often be simulated by the use of temporary holes or by adding locating lugs which are cut away after they have served their purpose.

It is sometimes desirable to minimize the effect of accumulated errors by distributing them—a procedure known in precision of measurement as "solving the problem for equal effects," i.e., the errors allowed in each variable are calculated to give the same effect in the final answer.

Dimensional Working Standards

After the limits have been worked out, they should be shown as a part of the working drawings. If these drawings are then furnished to the shops as the final references for production purposes, they become the practical working standards for dimension, as the term is used herein. With highly skilled operators, working on processes inherently accurate, these plans may be all that is necessary. Where a relatively small number of parts are to be made, and especially in large work, it would not be the part of good sense to supply the shops with anything in addition to the plans as the standards. In many cases all the information required may be set forth on the working drawing for the finished part, including both the limits for the finished work and the amounts of stock to be allowed for grinding, turning, and similar operations.

In passing from the classes of work just indicated, to the quantity production of interchangeable parts of small size, we enter a field where economy of manufacturing indicates the desirability of increasingly specialized equipment, such as special cutting tools, holding devices, and gages. In such cases if working plans are supplied to the shops at all, it usually is best to do so only as a matter of information and to substitute for adjustable precision measuring instruments fixed-dimension gages of various sorts which have the limiting dimensions worked into them in physical form.

It is safe to say that the next few years will see a great extension of the use of limit gages in American factories, with corresponding benefits as regards both quality and economy. The introduction of a gaging system, however, will cause new conditions to arise which will involve special problems peculiar to the system in question. It is a matter in which some very small things become paramount, and hence require the most careful and systematic attention, as will be discussed in a later chapter. For the present, attention is invited to the fact that *when gages are used*, as just stated, *they constitute the working standards*, and the plans cease to function as the working standards.

It remains to be said, for completeness, that it may not be considered desirable in certain cases to incorporate, in the gages as furnished to the shops, the maximum limits that may be used while still assuring proper functioning of the parts after their assembly into the mechanism. This practice of making the shops work to closer limits than the inspectors are permitted to pass finds its justification sometimes in a longer useful life for the gages. The practice, however, rests chiefly on the idea that it may help to reduce the losses in spoiled work by permitting the salvage of some of the parts that are bound to fall outside of the limits given to the factory, while also encouraging the cultivation of greater accuracy in the operators. This savors somewhat of the theory of the traffic laws that have given rise to signs

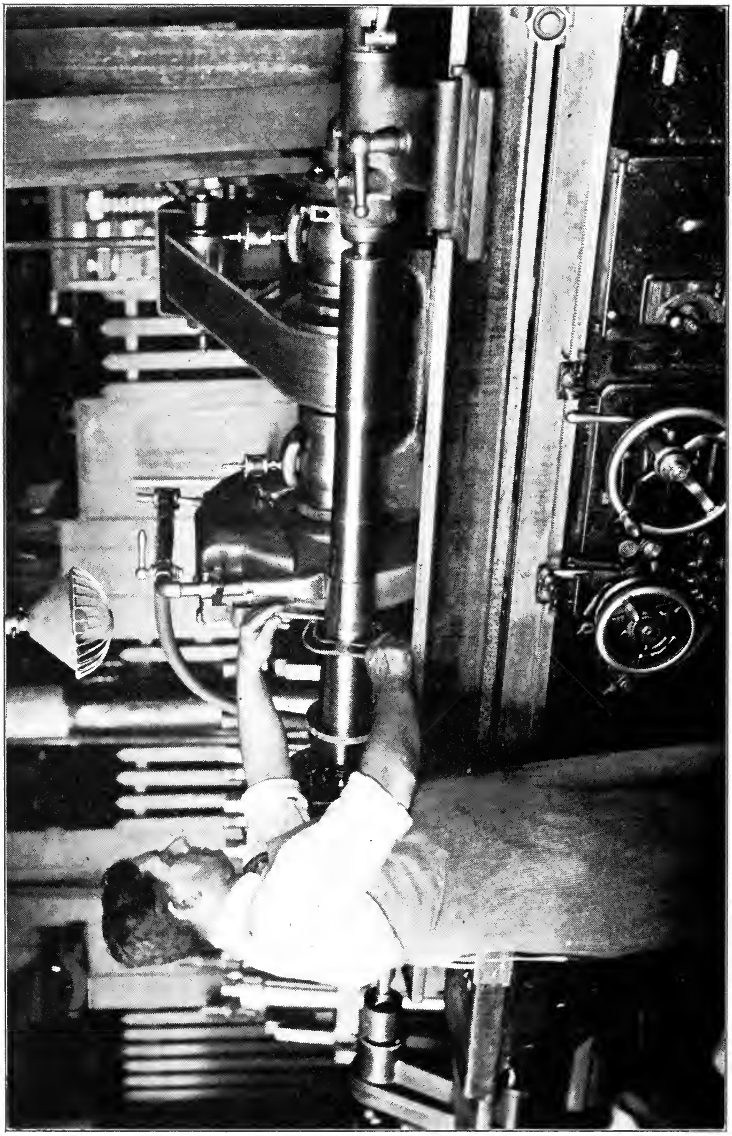


Figure 60. Measuring Large Diameter of Piece in Grinder.

Notice that the machine is stopped. (Brown and Sharpe Manufacturing Company.)

reading "Speed limit 15 miles," which one so often sees outside small towns. The sign probably is put there in the hope that the motorist will reduce his speed to 25 or perhaps 20 miles, depending on the degree of hopefulness of the authorities, but usually he keeps his foot on the accelerator. Now the machine operator will answer to the same psychological reactions if he knows there are two standards in use, unless and only in case conditions are so arranged that he is made to realize it as being to his best interest to stick to the limits given him. It may be necessary, in fact, to keep the larger limits a secret, which involves using them in a separate salvage department. As a rule, however, it would seem to be better practice, with the possible exception of certain very special cases, to try for the same result by the more direct route of frankly making known the maximum permissible variations, and then taking proper precautions to safeguard these limits.

Assembling Standards

Theoretically, in strictly interchangeable work it should not be necessary to check up the fit of parts after they have been assembled, except possibly as an additional assurance that the constituent parts of the assembly are within the allowed tolerances. As a practical proposition, however, it is often advisable to provide for the verification of certain important functioning dimensions in subassemblies, as, for example, when parts are assembled on a tapering shaft, or where the effect of improper fits is multiplied by a long arm (as in the case of a long rod with a short bearing on one end, working under conditions that make side play of the other end of the rod undesirable). In work made partially interchangeable, such assembling standards should be provided for, by setting limiting dimensions for the assembled parts in the case of all vital dimensions.

Final Tests

After the parts of the mechanism have been assembled, a final test, or series of tests, should be made, simulating the maximum demands to be made on the mechanism after it is placed in service. Strength tests are, in themselves, the maximum limit—an armature will spin at twice its rated speed without bursting, or it will not; a derrick will lift the specified overload without permanent set, or it will not; a gun barrel will stand a heavy proof charge without bursting or bulging, or it will not. Thus, in such tests there is but one limit. But, in many of the final tests and trials used to demonstrate standards of quality, the same idea of permissible variations in quality (expressed in terms of limits) finds application, whether these tests are to be applied to the complete assembly or to some subassembly. In the testing of the trigger pull of a rifle, for example, the limits may be set at given minimum and maximum pulls stated in pounds; or the economy and the speed regulation of a motor may be demonstrated by trial to be within certain limiting percentages.

Final tests must be made under as nearly the same conditions as the mechanism will encounter in service when reasonably possible. If this cannot be done, the test conditions should always vary from service conditions in a known way and to the same degree, i.e., all mechanisms should be tested under like conditions.

Recapitulation

Working from the theory that quality is a variable, and hence that the ideal standard or design cannot be reproduced exactly, the conclusion is reached that practical working standards should be supplied to the factory in form to indicate the limits within which it is desired to have the work made. These practical standards should cover the various matters affecting quality, such as dimension, finish, and so forth; and all should be formulated with a reasonable mental attitude that makes provision for variations, because they are bound to occur. With this clearly understood, we are in a position to take up the consideration of the steps necessary to secure results in the factory as nearly as may be in accordance with the standards of quality desired, it being noted in this connection that the above principles apply regardless of what the product of the manufacturing operations may be. Metal work has been used merely because it is more inclusive and complete as an illustration.

CHAPTER XVI

REPETITION MANUFACTURING

Uniformity for Economy

The thought of quality as something that is continually shifting and varying, when translated into form for use in the factory, gives rise, among other things, to the whole subject of tolerances and limits. Thus it becomes apparent that no design is sufficiently complete for intelligent manufacturing purposes unless the limits for each and every governing characteristic are known. Furthermore, just as a clear appreciation of this idea of variations is essential in repetitive work, so also is it desirable that the principles of repetition manufacturing be understood.

True manufacturing involves making a quantity of the same article, uniform within limits. In this respect it is the diametrical opposite of art work. The manufacturer seeks to make things alike, but the artist strives for the creation of things that are different and individualistic. The first system is far less costly; and therein lies the real value of manufacturing, because its product is thereby made more generally accessible to mankind. We make things alike because it is cheaper rather than for the sake of having them alike, although many secondary advantages accrue from this property of uniformity. In fact, it is so very much cheaper to make things alike that the manufacturer can afford to incur very heavy expenditures in preparation alone —merely for getting ready to manufacture. Because he does incur this heavy initial expense, and because all his later operations are more or less fixed and governed by these preliminary arrangements, it becomes of serious importance for him to make them correctly in the first place.

Uniformity of Product Means Uniformity Throughout Production

In making these preliminary arrangements the manufacturer must not consider the preparatory work in a general way as affecting the finished product, but rather in its relation to, and effect on, each individual process. This raises a point that is frequently lost sight of in repetition manufacturing, namely, *the continuous manufacture of one product of uniform and standardized quality implies an equal uniformity and standardization at all stages of its production.* Why? Because it is cheaper to manufacture in this way, and it is cheaper to manufacture in this way because large errors in the earlier stages of the work require correction later on, when it is not so simple to bring the work into line. Consequently each component process should be considered as a separate production point for the continuous manufacture of uniform quality. If one process is left as a loophole for large variations to enter, throughout the remaining processes a constant struggle must be engaged in to correct them. Obviously, this attention to uniform quality must be extended to include the raw material itself, clear back to the original source of supply.

It will prove useful in what follows to note incidentally that *excessive variations in the finished product mean simply that there are variations in the earlier processes.* For differences in the completed articles are the algebraic sum of the errors made in all of the earlier manufacturing processes.

Noting for the moment that interchangeable manufacturing is only one of the several classes of repetition work, let us now use it as a specific example in studying some of the interesting phenomena of such work.

Interchangeable Manufacturing

I have before me an Ingersoll watch of the Reliance model, also an Eversharp pencil. Both are products of standard quality and must be made by the methods of interchangeable manufacturing. In other words, the attempt is made, in manufacturing a quantity of any one of the component parts, to make all of these individual parts so nearly alike that any one of them may be used in the assembled mechanism with the assurance of subsequent successful functioning. Except for the crystal, the springs, and perhaps one or two minor parts of the watch, there is no special object in having any of the parts interchangeable after the mechanism has been sold and placed in use, as there is little likelihood of any of them having to be replaced. In fact, if all our mechanisms could be proportioned and built as perfectly as the "wonderful one-horse chaise," so that all the parts would wear evenly and all become worn out at the same instant of time, the only value of interchangeability of parts in service would be in the rather remote case of an accident. Nevertheless, there seems to be a somewhat popular misconception that parts are made interchangeable for the express purpose of securing the possibility of replacing parts, whereas the real purpose is to secure certain economies in manufacture that are possible only by the methods of interchangeable manufacturing. The interchangeability of parts in service, while often convenient and frequently important, follows as a by-product quite secondary in value to the primary purpose, which is economical production.

The Industrial Revolution

Now let us see wherein making parts interchangeable decreases manufacturing costs. When Adam Smith wrote the "Wealth of Nations" (1776) he described the principle of the division of labor by citing the well-known example of the manufacture of pins, pointing out that if the work was divided up into several operations so that one man concentrated on, say, heading pins, and so on for each worker, the number of pins produced per man would very greatly exceed the production of any one man making complete pins, without this analysis or dividing up of the work. Thus there results a saving or conservation of the experience and skill gained in doing the same thing over and over, and we recognize the outstanding feature of the great change in production which is known as the "industrial revolution"—a method that has almost entirely replaced the earlier household and handicraft methods of manufacturing.

The Mechanical Revolution

The application of labor-saving machinery to production, known as the "mechanical revolution," is closely related to the industrial revolution, because as a very early result of the division of the labor of manufacture into small parts or operations, special labor-saving devices and machines were developed. Usually, in order to apply such devices effectively, the work obviously must come from one operation or mechanical process to the next operation in pretty much the same shape and size. Thus the division of labor involves making things very nearly alike, and in so doing makes it possible to realize economy of effort through the greater production secured. Furthermore, the smaller subdivision of work permits an unskilled worker to acquire quickly the skill necessary to accomplish his part of the work. Incidentally, the fact that pieces are more nearly alike means that substantially the same thing is done to each piece at each stage of its manufacture, in order to advance it to the next operation. This must be easier than if each piece required special treatment. Incidentally, a better quality of work results, and quality tends to become more uniform; and from uniformity marked commercial advantages accrue.

Afterward, and when, as an eventual working out of the division of labor, certain processes are combined in an automatic or semiautomatic machine, of course it becomes still more necessary to have the work more nearly exact to given dimensions and shape. While the division of labor, however, leads to making parts alike, the parts do not necessarily have to be so much alike on this account alone as to permit

Figure 61. Height Gage Used with Johansson Blocks

full interchangeability, nor even such partial interchangeabilty as will allow assembling by selection of parts that fit each other well enough to function properly.

Economy in Assembling

The greatest economy, however, in making things sufficiently alike to be interchangeable comes from the possibility not only of the more rapid assembling of component parts into the complete mechanism, but also of the use of less skilled labor for this work. A workman of very ordinary experience and skill can be taught to assemble all, or a portion, of a complicated mechanism, provided he can use the parts just as they are supplied. If, on the other hand, the parts must be selected in order to secure an assembly that will function properly, much more skill is required; and if fitting of parts in the form of doing work on them in the assembling room is necessary, then in all probability a very high order of mechanical skill and experience is requisite. Take the watch for example. Like all mechanisms containing a source of power, there is a means of regulating the rate of power discharge of the mechanism, within limits. While the limits may appear to be narrow, they are great enough to take up the differences in action due to the different combinations resulting from assembling parts which have been passed on to the assembling rooms as within the allowed variations. Certainly such assembling is not a very serious undertaking. But suppose the parts, or some of them, required additional treatment in order to fit them and adjust them into the mechanism in a way to insure proper working. What sort of labor would be required then, and how long would it take to complete an assembly? Also, would the product be improved by the hand-fitting of parts which would be required?

A small article like a watch is not an extreme illustration of this truth, as can be seen very easily by observing the strenuous work involved in the regulation of inaccurately punched plates in a ship or other steel structure. The work required to get the plates into position for bolting-up and riveting is greatly in excess of the effort required to punch them accurately in the first place; and if the holes are enough out of alignment to require reaming to a larger size, still more unnecessary labor is expended, extra sizes of rivets must be kept on hand, and so on. Furthermore, and most important, any such corrective process is not the best thing for the structure itself.

Naturally these same considerations govern in all lines of manufacturing. There is a field, no doubt, for hand-work in special and distinctive bodies for high-grade motor cars, whereas hand-work on the parts of the engine (which have been machined already to a high degree of accurate conformity to the ideal standard) is not only out of place from the standpoint of economy, but actually detrimental as well. It is very rarely indeed that anything is improved by tinkering.

The Work of Simeon North and Eli Whitney

It would be rather interesting to know just when and why there arose the present general misconception that work is made interchangeable for the simple purpose of replacing parts, inasmuch as the early exponents of the system, like Simeon North, Eli Whitney, and their contemporaries, certainly understood exactly what the principle of standardization really meant.

"Simeon North—First Official Pistol Maker," a memoir by S. N. D. and R. H. North, was published in 1913. It is a most interesting contribution to our knowledge of the early development of interchangeable manufacturing in America. This investigation has made it quite evident that North, for reasons of economy, lack of skilled men, and similar considerations, which had nothing to do with interchangeability for its own sake, was willing to incur heavy initial expenditures and delays in order to achieve an ultimately better result.

In a letter to the Secretary of the Navy dated November 7, 1808, he makes this significant comment:

> I find that by confining a workman to one particular limb of the pistol until he has made two thousand, I save at least one quarter of his labour, to what I should provided I finish^{d} them by small quantities; and the work will be as much better as it is quicker made.

His contract of April 16, 1813, with the United States, for 20,000 pistols, contains the provision: ". . . the component parts of pistols, are to correspond so exactly that any limb or part of one pistol, may be fitted to any other pistol of the twenty-thousand." But a later contract for carbines (dated May 2, 1839) added to the requirement for uniformity of parts and interchangeability the provision that this must be done "without impairing the efficiency of the arms"—showing already an evolution in precision requirements for better functioning of the complete mechanism.

This early contribution to the economy of manufacture is well illustrated by Simeon North's biographers, when they quote Daniel Pidgeon's reference[1] to the Connecticut man, whose remarkable blending of the engineer and the mechanic has done so much for American industry:

> His method of attacking manufacturing problems is one which, intelligently handled, must command markets by simultaneously improving qualities and cheapening prices.

Continuous Standardized Production

In the early part of the present chapter, interchangeable manufacture was referred to as one sort of repetition manu-

---

[1] In "Old World Questions and New World Answers," by Daniel Pidgeon.

facturing, and was used as an example to illustrate the features that are generally applicable in repetition work. In explanation of the statement, attention is invited to the fact that interchangeable work applies particularly to a mechanism built up of standardized parts in such a way as to permit disassembling if need be. For even pieces that are riveted together may be taken apart. On the other hand, the same idea of standardized work applies in all kinds of manufacturing. It is, in fact, at the root of success in all production, and for precisely similar reasons.

The most inclusive definition of modern manufacturing, from this aspect, is that it is the continuous production of articles whose qualities have been standardized within given limits. Since errors in the finished product mean errors all along the line of manufacture, it follows as a corollary to the general rule that the unfinished articles should be similarly and at least equally standardized at each stage of their manufacture.

The first need of standardized quality arises at the very beginning, with the recovery of raw materials from nature. Everything in nature varies, from place to place or from season to season, and the variations are large, except in unusual cases. It makes no difference whether we speak of wheat, cotton, wool, iron ore, lumber, or what-not. It is the duty of the basic industries which prepare these materials so that they are suitable for use, to reduce the variations as much as is reasonably possible.

Resort must be had first to separation of the raw material into classes or grades. This, in a sense, divides the differences up, and thus reduces them for practical purposes. As a second step in the ordinary procedure, two courses are open and usually both must be used. Differences due to impurities may be removed, and differences in size, shape, and so on rectified, and here both chemical and physical processes come into play. Any remaining variations from lot to lot of the same material may often be rectified and a larger body of uniform material produced by using the method of mixtures. Finally the need of some sort of conditioning process may be indicated, before the material is ready for use in the factory.

Vital Importance of Uniform Quality in Raw Materials

The importance, in repetition manufacturing, of raw material of uniform character and condition cannot be overstated. Very often the lack of such uniformity is the

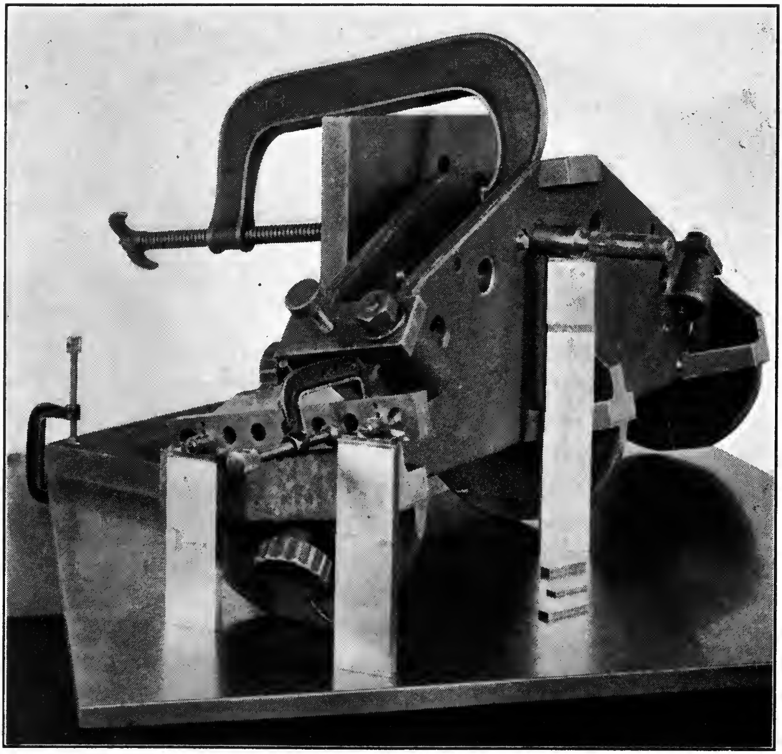


Figure 62. Set-Up of Johansson Blocks to Check Drill Jig

root source of the subsequent trouble encountered in trying to make a uniform product. What is the value of accurately standardized heat treatment, if each lot of steel is different in behavior from its predecessor? It is cheaper in the end to start with material of uniform character.

It may seem a far cry from steel to fibers and dyestuffs, but the principle just stated holds generally. If textiles are manufactured from fibers whose affinity for dyes varies materially from lot to lot, and if each lot of dyestuff is of different hue and strength, the work of producing articles uniform as to color-matching is a great deal more difficult than if the variations are reduced or removed by careful standardizing of the raw materials.

One often hears complaints in the factory about lack of uniformity and standard quality in raw materials, but what a pitiful admission of weakness it is to throw the blame on the producer of the material. He can hardly be expected to know the needs of the consumer, and if the man who uses the material will make his exact needs known, he is pretty apt to get what he is after. Competition will gradually force the producer of material into line, even if he is reluctant to attempt finer standardization. But to be in a position to call for better materials, the manufacturer must first know what qualities he requires and why. Also, once the required standards are set, means must be provided for measuring the incoming deliveries, for it is useless to set standards unless one is prepared to enforce them.

The factory should be protected by filtering out unsuitable material at the receiving platform of the stockroom. This is the first place for the application of control laboratories of various sorts: physical, chemical, metallurgical, or perhaps some new kind invented for the needs of particular plants. The control of quality begins at this point, in so far as the individual factory is concerned.

Continuous Processing

Perhaps the next logical class of industries, after the basic order of raw material preparers, is that large group which deals with the assembling of various raw materials by methods which involve more or less continuous processing. Paper-making and textiles, for example, are highly standardized as to their final products, which must be suited in each case to meet some definite need of the consumer and to render a definite service in relation to price.

Now, as we have seen already, a uniform product is most economically obtained by making all the contributory processes equally uniform, as nearly as may be with consistency to the requirements of manufacturing economy. Weaving a piece of cloth on the loom is a continuous process of assembling various standardized elements or like parts. It hardly can be called interchangeable work, because there is no possibility of interchanging parts after the goods are completed. Yet the general principle of standardization of the process holds—it is advantageous commercially and technically to hold the process to a uniform standard *within specified limits* or allowed variations.

The fact that the errors are worked into the goods might seem on first consideration to make a marked difference between this type of manufacturing and so-called interchangeable work. In one sense, this is so, but from the wider viewpoint, identical principles apply. Thus costs would be raised to prohibitive levels if we tried to eliminate *all* broken threads, *all* missing picks, and *all* other defects—even if we could do so. The only practical way to handle the situation is, *first*, to define what kind of errors and what percentage of each kind are to be allowed for a given standard of quality, i.e., to set limits; and *second*, gradually to raise these standards in step with the improvement of processes, increase in workers' skill, and so on, that will flow

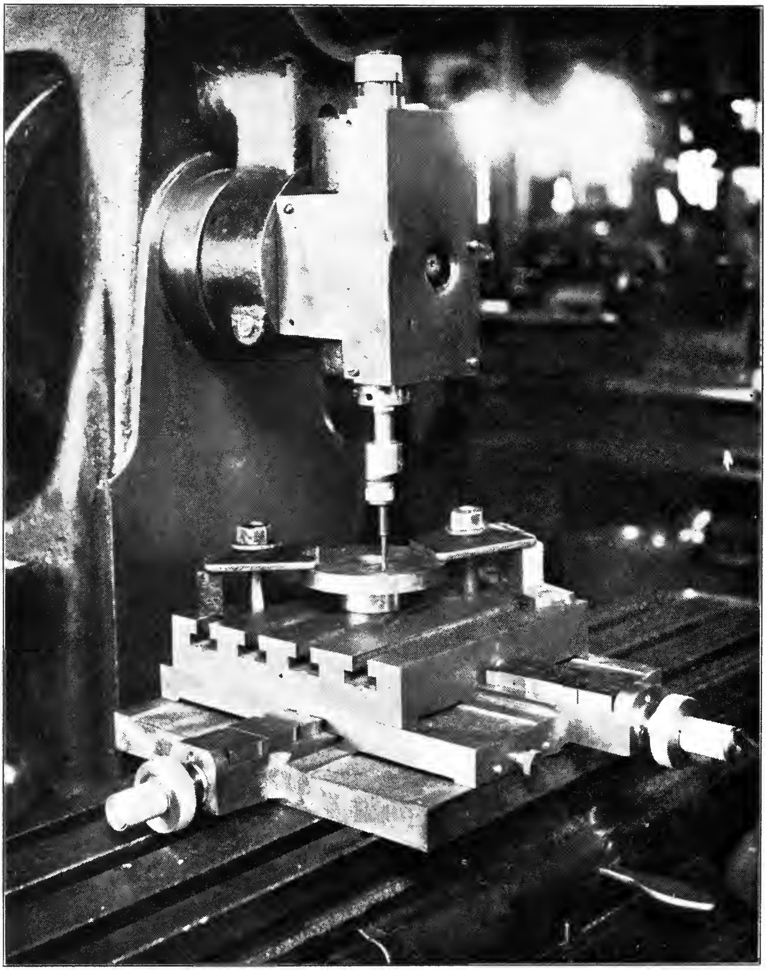


Figure 63. Special Milling Fixture Using Johansson Gage Blocks for Locating Purposes

from attacking the production problem with quality as our basic criterion.

Duplicate Manufacturing

There is a large class of manufacturing, known usually as "duplicate manufacturing," which is distinguished by the use of standards (usually of size, material, and form) for the product. Screws, nails, and many other kinds of hardware are typical. The ordinary uses of many of these articles do not require such close limits as the manufacturer chooses to follow. It is but another case where economy of manufacture, resulting from the division of labor and the use of labor-saving machinery, dictates the adoption of the methods of standardized repetition work. It is cheaper and the product is not only more useful but in every way better, because quality yields to control when processes are standardized and quality held uniform—*within limits.*

Partial Interchangeability

In the case of assembled mechanisms the various classes of repetition work differ among themselves, chiefly in the degree of accuracy with which the component parts are made. Thus, in passing from work that requires fitting to assemble, we find a sort of transitional stage before we reach the ultimate form of complete interchangeability. This intermediate class of work is known as "selective assembling." The parts are accurate enough to require no hand-work to prepare them for assembling, but are not sufficiently standardized to permit using any part in any assembly. Resort must be had to selecting parts that go together properly.

This style of work should never be resorted to except when the processes will not permit of the precision necessary for complete interchangeability, which sometimes occurs; it is a mistake in this case, just as it is generally wrong to assume that loose fits make for easy assembling, except when very few parts are mated. A long series of interrelated parts requires close work if the assembling is to be done without adjustment. Such considerations at once require modification of the generally accepted idea that low cost and easier manufacture are best obtained through allowing the greatest freedom in the fit of mating parts without interfering with proper functioning.

The advantages of true interchangeability may be obtained in selective assembling if the selected parts are first segregated into classified sizes, thus simulating interchangeability by making groups of parts that assemble without selection.

Production of Machine Tools

In concluding this chapter it should be noted for completeness, that the manufacture of machine tools follows the general rule, but occupies a middle position. Economy of manufacture requires the use of the methods of interchangeable manufacture in the tool-making factory, whenever the quantity made warrants its adoption. The great standardized markets of this country, by providing conditions that permitted the use of such methods, are largely responsible for our advanced position in machine tool development.

The fact that the plants which are the users of the machine tool maker's product must standardize their processes, makes it incumbent on the tool manufacturer to provide machines that are highly standardized as to performance. But machines that give uniform results are best made uniform in all their parts, and so the chain of uniformity, once started, must remain unbroken. It may be observed, moreover, that the quality of machine tools should be controlled to a greater nicety than the work those machines are to produce. This flows from the fact that there is an unpreventable slip in accuracy between the work and the pattern which the machine follows as a guide in generating the work.

This need for great precision, combined with manufacturing relatively small quantities of machines, has resulted in a certain amount of hand-work in assembling. This work is necessarily done by highly skilled mechanics and may furnish an explanation of the scattered character of the inspection organization in many machine tool factories. The latter situation is especially interesting at present in connection with the overhauling of inspection methods that has been going on since the war in a number of these factories.

The General Principle

We have just traced the ideas involved in the continuous production to uniform standards of quality. Without any attempt toward a strict classification of industries, we have analyzed manufacturing sufficiently to show that *the positive and continuous control of quality to definite standards within limits and at all stages of manufacture is at the root of production economy.* Beginning with the preparation of raw materials, it was observed that the same principles held good, up to and including the highest type of interchangeable work. In the latter case all types are present. Starting with a uniform material from which are made uniform parts, these like finished parts in their turn provide a uniform raw material stock for the assembler, who is thus enabled to produce uniform articles to meet some special demand of the ultimate consumer. The latter demands uniformity because his needs are best met when he receives a known performance and a known return in quality for his money.

At each stage of the industrial line the general rule applies—the output is greater, the effort is less, the quality is higher. Hence it requires less of the consumer's labor to exchange for a higher degree of satisfaction of his needs; and thus the economic situation of everyone is improved.

But when we generalize that it is best to make things uniform, we must remember always that quality varies, and that what we really mean is likeness, uniformity, or standardization of quality *within limits*. This, in a word, is why quality requires control.

CHAPTER XVII

THE DIMENSIONAL CONTROL LABORATORY

Practical Value of Precision

The most important advantages of precise dimensional accuracy in manufacturing the component parts of an assembled mechanism are:

1. The elimination of hand-fitting, with quicker and cheaper assembling.
2. More even wear with consequent greater resistance to wear and longer life in service, with correct functioning of parts.
3. Less noise after use, smoothness of action, and smaller power losses. "Noise is an automatic alarm indicating lost motion and wasted energy. Silence is economy. . . ."[1]

With the possible exception of some of the makers of very high-grade machine tools, probably no industry has advanced precision workmanship to such a high degree of perfection as the automotive manufacturers. It is in recognition of this fact, and with admiration for their achievements, that we must turn to them for examples of what our methods should be in seeking to bring dimensional quality under control. For this reason much of the accompanying illustrative matter is taken from automobile factories. The lessons are by no means confined in application to that industry.

The basic requirement of precision is that means shall be provided for making very exact measurements, and the

---

[1] From "Creative Chemistry," by Edwin E. Slosson.

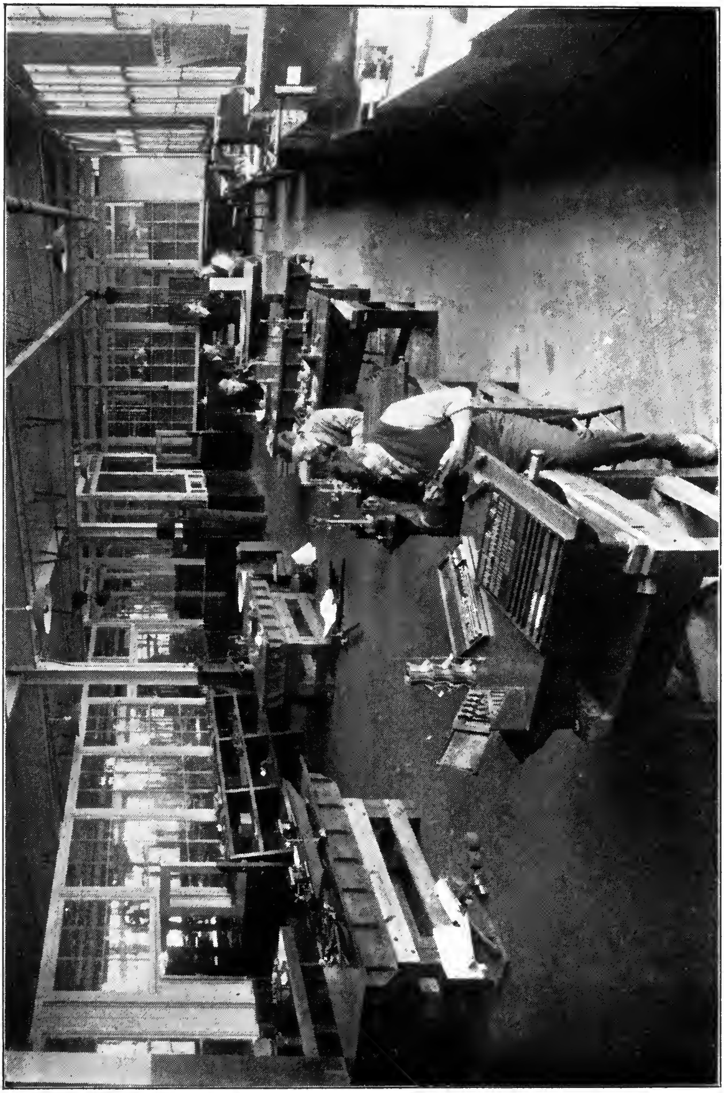


Figure 64. An Excellent Dimensional Control Center

Tool- and gage-checking room of the Lincoln Motor Company.

most sensible way to secure proper surroundings for the use of this equipment is to provide a central place suitably designed for this purpose.

The Laboratory Proper

Since uniformity of conditions is the great essential of manufacturing, it is even more necessary for a control center of quality in manufacturing. Let us now consider some of the things which require attention at such a control point, in order that influences which are disturbing to the personnel or destructive to the equipment may be reduced to a minimum.

Temperature changes, the greatest cause of variation, due to weather changes, can be eliminated by providing artificial heat and cold, under uniform control. When this is done the temperature is held around 70° F. There remain then three other principal causes of disturbance: body heat of operators, heat differences of objects brought in from outside, and heat from light rays. The first can be dealt with in various ways which are obvious, such as specially insulated holding places on instruments. (See Figure 52, page 222.) Anything brought in from outside should be allowed to stand until temperature equilibrium has been reached. When heat from rays of sunlight or from an electric light near the work is permitted to affect either work or instruments, a serious error is likely to occur. For small dimensions, direct expansion is quite small (for tempered steel it is about 0.0007 inch per inch for one hundred Fahrenheit degrees, nevertheless the effect may be specially serious when direct expansion is magnified by lever action, e.g., sunlight striking the anvils of a snap gage for a few minutes would have little effect, but might easily be serious if allowed to shine on the handle side, because the effect of the direct expansion would be increased and thereby materially change the distance between the anvils.

Humidity and cleanliness are matters requiring consideration. It would not be extremely difficult or costly to make the measuring room dustproof and to supply washed dry air in connection with temperature control. The many advantages hardly require mention. Such a system would seem especially desirable in moist climates, where polished steel rusts almost overnight at certain seasons of the year. Any system of the sort should have automatic control and should be designed to run continuously, as it will not make for uniformity if operated only during working hours.

As regards lighting, daylight illumination should be from the north in order to avoid the admission of direct sunlight. Greater uniformity and, with certain work, better definition will be secured for local illumination if the artificial light is taken from "artificial daylight" lamps instead of ordinary tungstens. The Trutint lamps made by the Nela Specialties Division of the National Lamp Works (General Electric Company) are made in an inexpensive factory-type fixture suitable for such work. Care should be taken to place artificial lights for local illumination so that their heat will not be concentrated in objectionable ways. Good general illumination requires white or light neutral gray walls, with a dark dado at the bottom. It is always bad to have light shining from below the bench level.

Vibration and noise should be avoided as much as is consistent with convenient location of the room; the latter because it is a distraction, the former because it is likely to interfere with close reading. Accurate work with optical projection apparatus which makes use of the optical lever for magnifying (for screw threads, shape, etc.), is out of the question if vibration is present to any appreciable extent, and for such work a separate room may be required, well removed from the machine shops.

Floor covering may be wood, or, better still, battleship linoleum, which may reduce, if not avoid, the occasional accidental error due to dropping things.

Furnishings should be limited to articles of use in the work, but all furnishings should be first class and kept so. The laboratory is no place for an old wooden work bench or rickety stools. There should be shelf space in cabinets for all equipment not in use, and safe cabinets, or preferably vaults, for master control standards and models. A convenient wash basin should be provided, unless there is a complete toilet room handy. In the checking of accurate measurements the tactile sense is no more helped by a coat of grease and dirt than it is in mechanical drawing.

The Surface Plate

A true plane surface supplies the level foundation upon which we build for accuracy. The control laboratory should have one large surface plate say, 4 or 5 feet by 8 feet, mounted on a firm foundation. Such a plate is of massive construction and is not likely to become distorted from irregularities of the supporting structure; nevertheless it is certain to change with age and use, even if it is made from well-aged metal in the first place. Consequently, it should be watched very carefully, and this may develop the need for resurfacing at least once in its career. The danger of its being affected by temperature changes is slight, if the laboratory is kept at nearly standard temperature.

With careful surfacing when needed, it should be possible to keep the surface within 0.001 inch of a true plane for the greater portion of its area; yet every surface plate will have small hills and valleys whose location should be known and allowed for in placing work for measuring. Large accurate measurements should be checked by placing the work in different positions. In checking the plate to locate these irregularities, the first step should be to apply a long and accurate straight edge (with reinforced ribbed back) and use a feeler gage. The second step should be to sweep the plate thoroughly with a surface gage, mounting a sensitive dial indicator at the end of the arm, a short arm being first used and then a long extended arm. If a further check is desired, recourse may be had to the method Whitworth used in creating the first standard, namely, by contact application of other plates, using Prussian blue between the plates to show the humps and hollows revealed by rubbing them together. In ordinary shop practice a smaller surface plate may be used for this purpose.

Where much work is to be done, and for other reasons of convenience, it is desirable to have one or more smaller surface and bench plates. It is idle, however, to attempt small measurements accurate to ten thousandths with such equipment. For such work optically correct plates should be used. The crome alloy steel, tool-makers' flats manufactured by the Pratt and Whitney Company, are about 5 inches in diameter by 7/8 inch thick, hardened and heat treated by a special stabilizing process. They are finished by the Hoke method of lapping (like the Pratt and Whitney Hoke precision gages) with surfaces (top and bottom) finished flat, well within .000,01 inch and parallel within half that error. Precision gages will wring onto them as they wring onto each other.

The Dimensional "Court of Highest Appeal"

Prior to the invention of the Swedish gage blocks, the measuring machine was the only available device for very accurate measurements. For some kinds of measuring, such as occur in originating or duplicating manufacturing standards, an instrument of this type is highly important. Some sort of end measure (rod or bar) is often needed to check positively an accurate large dimension, and it would be difficult to conceive of an easier way of insuring accuracy than by the use of a measuring machine.

Resort to such instruments was necessitated by the early attempts to obtain real standards of length. In 1742 beam compasses were used for that purpose in England, using both parallel jaws and pointed ends as usual. By the use of micrometer screws with graduated heads this instrument was considered accurate to within 0.000,62 inch for comparing yard length standards. At the same time the French compared their standards to 0.003 inch, until La Condamine, in 1758, said they should be compared to 0.000,89 inch, "if our senses aided by the most perfect instruments can attain to that." Fifty years later a lever comparator was designed by Lenoir, "which was regarded as trustworthy to 0.000,077 inch." The use of high-powered microscopes in combination with a carefully graduated scale in later measuring instruments has brought this error down to 0.000,01 inch, although accurate comparison of length standards of 3 feet and greater encounter a number of complications, principally due to molecular forces in the material and to temperature effects.[2]

From these beginnings various types of measuring machines have been evolved. There are several European models of modern design, while in this country the Brown and Sharpe measuring machine (see Figure 65) and the Pratt and Whitney machine (see Figure 66) are well known.

The Brown and Sharpe Measuring Machine [3]

The Brown and Sharpe measuring machine (shown in Figure 65) operates on the principle of taking measurements by means of a moving scale under a microscope, used in

---

[2] See Harkness, "The Progress of Science as Exemplified in the Art of Weighing and Measuring," for these and further details. The way in which these figures are stated is significant of the earlier failure to appreciate the principles of the precision of measurement.

[3] From data supplied through the courtesy of Luther D. Burlingame, Industrial Superintendent of the Brown and Sharpe Manufacturing Company, Providence, R. I.

Figure 65. Brown and Sharpe Measuring Machine

conjunction with a micrometer screw and vernier, the entire mechanism being supported upon a rigid bed of accurately careful construction. Measurements are taken directly from the scale and the machine can be set to measure up to 16 inches.

The micrometer wheel is graduated to read to 0.0001 inch and the vernier plate used in connection with the wheel makes it possible to read to 0.000,01 inch. The accuracy of the machine, of course, rests fundamentally upon direct readings taken from the graduations of the scale, and thus depends upon the perfection of the scale and the micrometer screw. The sensitivity of the machine may be shown by placing the hand on the bed plate between the slides and holding it there for approximately 60 seconds, at the end of which time the piece will drop from between the measuring points. It is interesting to note, however, that the machine requires about 20 minutes to return to its normal condition after this test.

The Pratt and Whitney Standard Measuring Machine [4]

The well-known measuring machine made by the Pratt and Whitney Company of Hartford, Connecticut (shown in Figures 66 and 67) provides not only a scientific instrument for use in the laboratory, but, because of simplified and standardized methods of manufacture, it is sold at a price which permits its wide commercial use and allows any manufacturer to originate or duplicate his own standards.

The four principal factors which determine the accuracy of this machine are the bed, the dividing screw, the control of the measuring pressure, and the standard bar from which the sliding head is located in known relationship to the stationary head.

The bed is of cast iron, seasoned, machined, and lapped

---

[4] From information furnished through the courtesy of Oscar E. Perrigo, M. E., engineering department, Pratt and Whitney Company.

straight and parallel for its entire length, and the processes through which it passes are of such a nature that the finished product is not materially affected by changes of temperature or torsional strains which would tend to destroy its accuracy.

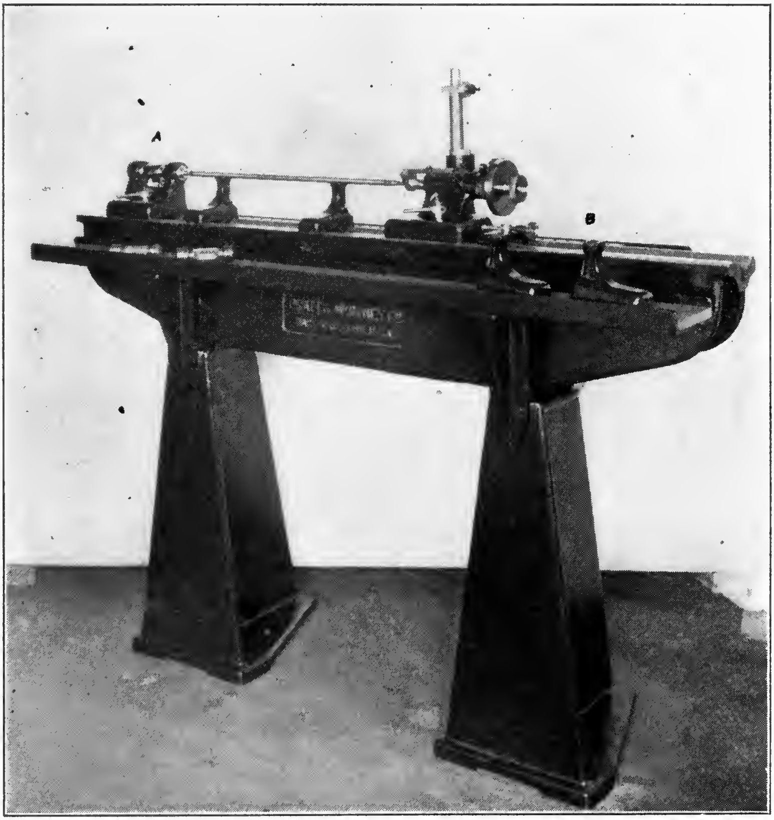


Figure 66. Pratt and Whitney Measuring Machine

The dividing screw for the sliding head is cut on a specially designed engine lathe which is kept in the laboratory *where a uniform temperature is maintained at all times.*

Compensating devices and adjustment provide a screw of a degree of accuracy far beyond that hitherto produced.

The mechanism for controlling the measuring pressure is located in the stationary head. The control is accomplished by means of a sensitive spring arranged so that when pressure is applied to the measuring anvil it is communicated to another pair of anvils between which a small plug is suspended by spring tension. When the exact measuring point is reached the little plug drops from a horizontal to a vertical position indicating that the reading can be taken. By this means the human element is eliminated, with the result that accurate measurements can be duplicated indefinitely without dependence upon the "feel" of the operator.

The fourth factor is the method of locating the sliding head in a known relationship to the stationary head. This is accomplished by means of a standard bar located at the rear of the machine. Mounted on this bar are a series of buttons with highly polished faces upon which are etched fine lines exactly 1 inch (or 25 millimeters) apart. The graduations on the standard bar are transferred by specially designed apparatus from a known bar furnished by the Bureau of Standards at Washington, D. C., which, needless to say, is accurate to within the narrowest limits permitted by human skill.

In taking measurements the index circle is set to zero and the sliding head located to the zero line on the standard bar. A microscope (*C*, Figure 67) equipped with an electric light enables the etched line to be seen, the microscope tube being adjustable so as to obtain a clear definition. When the cross line drawn on the ground glass at the bottom of the microscope coincides exactly with the etched line at zero on the standard bar *K*, the tailstock (*A*, Figure 66) is moved up into contact (indicated by the fall of the drop plug) and locked in position, where it remains.

After the stationary head is located, the sliding head is moved back, and then relocated, the compensating zero adjustment *F* taking care of any variation of position. A tangent screw *G* and lock screw *H* are provided on the index circle for obtaining the last fine adjustment when taking measurements. Its multiplied leverage provides a slow

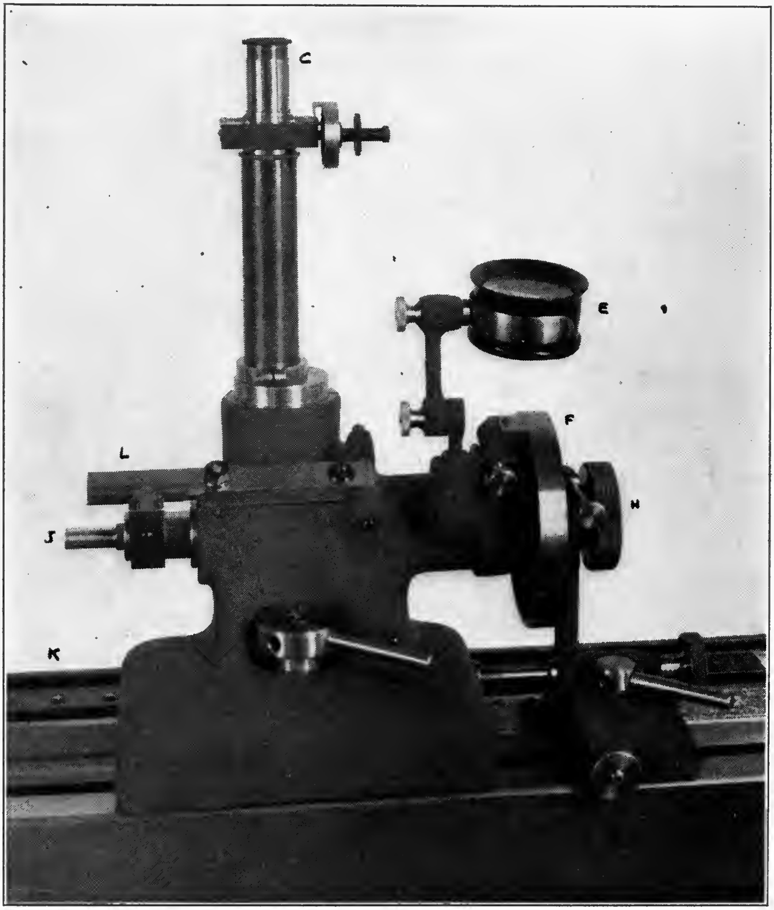


Figure 67. Details of Measuring Head—Pratt and Whitney Measuring Machine

easy movement of the dividing screw and prevents "going by" the measuring point (when the drop plug falls clear out of contact). The index circle is also provided with a magnifying glass *E* for easier reading of the scale, which is graduated to 1/10,000 inch (or 1/500 millimeter). There are 400 divisions on the English circle and 500 on the metric. One turn of the circle is indicated on the linear scale *L*.

Vernier. The index circle divisions (.0001 inch, or 1/500 millimeter) can be subdivided five times by estimation on the older machines, but to assist in obtaining very fine accurate measurements, a vernier is now supplied which will subdivide to .000,01 of an inch, or 1/5,000 millimeter. Adjustments are provided to take up any wear in the dividing screw should it ever occur. All anvils are hardened, ground, and lapped flat and parallel, and with reasonable care the entire machine will give accurate service for years with the simplest of adjustments.

The machines are set and are standard at 62° F. It is not necessary to use them at the initial temperature, as variations will affect both the work and machine practically alike. When used for scientific research, however, the initial temperature should be closely adhered to. The machines are regularly furnished in 12, 24, 36, 48, and 80 inch, or 300, 600, 1,000, 1,200, and 2,000 millimeter measuring lengths.

Cylindrical supports (*B*) for holding work to prevent springing, are furnished regularly with the machines as follows:

Two	with	12-inch	or	300	millimeter
Three	"	24 "	"	600	"
Four	"	36 "	"	1,000	"
Four	"	48 "	"	1,200	"
Six	"	80 "	"	2,000	"

The machine regularly requires no special foundation, as it has a three-point bearing on the case for equalization.

The Johansson or Swedish Block Gages

We now open one of the most interesting pages of modern technical achievement—a story of little blocks of steel of unbelievable fineness of workmanship. It was indeed fortunate for the development of greater precision in machine shop processes that a man of the mental qualities of C. E. Johansson happened to work in a government arsenal engaged in the manufacture of military small arms.

The technique of this business several years ago required something more nearly absolute in accuracy than the measuring methods generally in use at that time in machine shop work, for it was highly desirable to make military firearms with the greatest degree of precision that was reasonably obtainable. In order to insure this result, I believe I am correct in stating, it was the usual practice to resort to positive end measures for all important dimensions, these measures being used for checking master or reference gages. The consequence was that each government arsenal soon accumulated a large quantity of such gage templates, or end measures, which constituted their own dimensional standards. This will account for the fact that by the use of modern finely standardized measurements certain government arsenals have been found to be using an inch which varies slightly from the standard inch. It is interesting also to note in passing that the use of limit gages is of fairly recent adoption for such work. The output was generally small (being just enough to keep the arsenal busy in peace time), so that an organization of very highly skilled men was developed. Owing to their finely cultivated sensitiveness of touch, and by taking careful precautions in gage-checking, these men were able to produce extremely accurate work, using a single fixed dimension on the working gage. All of this procedure resulted in the accumulation of a very large quantity of end measures whose exact values in terms of the standard inch were not known with any special precision.

C. E. Johansson, after three years in the United States, during which he acquired both a practical and a theoretical education, returned to Sweden and shortly afterward began his work as a tool-maker in the Carl Gustavs Stads arms factory at Eskilstuna, Sweden; later he became tool-room foreman. He soon came to note that the usual measuring equipment differed in its results, which lead him to attempt the creation of a system of measuring for such work which would give beyond question the accuracy required. Realizing the great value of solid blocks of steel, or end measures, and guided by the experience gained in the arsenal (which adopted the tolerance or limit system in 1889, so that parts could be made in quantities and assembled without fitting) he proceeded to develop the famous Swedish or Johansson block gages, which in 1906 he announced to the mechanical industries at large.

Much more recently a factory has been established at Poughkeepsie, New York, for the manufacture of the Johansson standards in this country, where they find a wide application in industry.

These blocks possess the following interesting characteristics:

1. They are made of steel which has been heat treated and seasoned to practically eliminate warping or "growing."

2. The surfaces are flat and parallel to within .000,01 inch or less.

3. These parallel surfaces are distant from each other to within .000,01 inch or less of the absolute dimensions stated on the block.

4. These accurate surfaces permit of wringing the blocks together, and they are arranged as to dimension so that by suitable combinations of the blocks, as indicated in the va-

rious illustrations, practically any dimension desired may be obtained without appreciable error.

When packed together in this manner, not only is the variation per inch kept as low as .000,01 inch or less, but the surfaces are in such perfect contact that they adhere to each other (probably because of surface tension of the minute film of oil between them) with a force far in excess of mere atmospheric pressure. It is almost certain to result in "freezing," if the blocks are left in contact for several hours.

As will be observed from the various illustrations, positive end measures of this sort find wide and useful application in any tool work that requires accurate determination of dimension. No matter how many sets are used in the factory—and it is an economy to use several—each dimensional control laboratory should be equipped with one set of such blocks to be retained solely as a final check for dimensional control purposes. If the blocks are given proper care, they should remain practically unchanged from year to year. Ordinary inaccuracies due to wear, accident, or abuse, may be discovered quite readily by checking them against each other in different combinations. The result is a court of last appeal for dimension in the fool-proof form of flat steel blocks, or end measures, in fixed sizes.

As an example of continued precision of the block, it may be noted that a set (No. 3353) purchased in October, 1918, was returned to the Johansson Company in October of 1920 for rechecking. This set bore an engraved copper plate on the box stating that it was to be used only for checking other Johansson standard blocks and could be used only upon requisition by certain specified officials of the owning company, which happened to be the Ford Motor Company. This reference set, of course, had received excellent attention and very slight use. Inspection by the Johansson Company at Poughkeepsie showed that two blocks had worn approximately .000,01 inch below normal size. All the rest of the blocks, including the 2, 3, and 4 inch blocks, showed variations from normal size of less than .000,01 inch and most of them less than .000,005 inch.[5]

The Johansson methods of manufacture and measurement have been kept a business secret, although Mr. Johansson has disclaimed the use of the interferometer or light wave method of measuring, which has caused a good deal of speculation on the part of mechanical engineers and toolmakers as to just what method of measurement he uses. Despite the absence of information on this subject, we must nevertheless admire so remarkable an achievement. In fact, one can form a fairly good idea of how much mechanical sense anyone has by observing his attitude

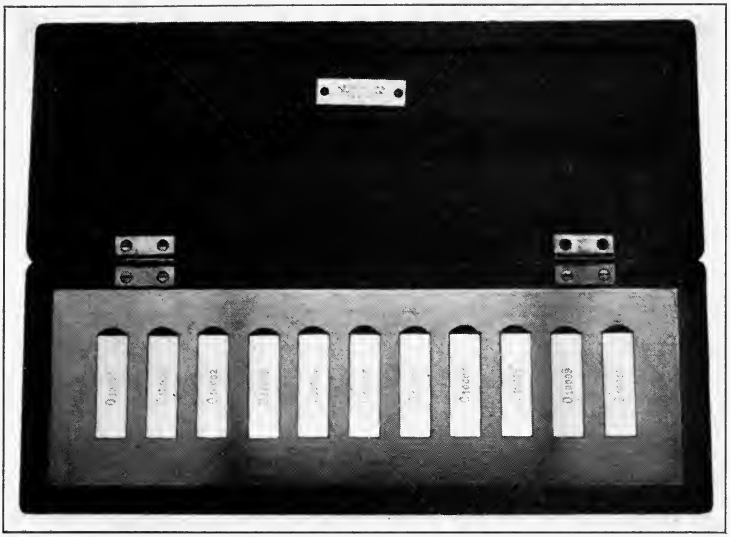


Figure 68. Special Set of Johansson Block Gages
Accurate to within one-millionth of an inch.

---

[5] From information furnished by Huber B. Lewis, Vice-President, C. E. Johansson, Inc., Poughkeepsie, N. Y.

toward the Swedish block gage itself. As an example of what *can* be done, attention is invited to the set shown in Figure 68, which was made by Mr. Johansson in order to provide a set of blocks accurate within the one-millionth part of an inch.

The Pratt and Whitney Precision Gages

During the war the need for precision end measures of the Swedish type was greatly increased, and it is much to the credit of the United States Bureau of Standards that it became possible to develop very precise gage blocks through the Hoke method of lapping and the use of the interference of light waves for measuring. William E. Hoke of St. Louis began this development with the Bureau of Standards, and later as a major in the Ordnance Department was enabled to make further progress. Gage blocks are now made by several concerns in the United States. An interesting description of how the Hoke type of gages are made by the Pratt and Whitney Company may be found in the April, 1920, issue of *Machinery*. The method of measuring by the utilization of light waves is described in the May 22, 1919, issue of the *Iron Age*.

Comparators

It will be noted from a number of the illustrations of gage blocks in use that the blocks are being applied with the assistance of an instrument for accurately *comparing* measurements. Figure 69, for example, shows the blocks being used with an American amplifying gage, as made by the American Gage Company of Dayton, Ohio. The American amplifier operates on the lever principle re-enforced by a dial indicator, as shown in the illustration. Figure 38 shows a similar application, using the Prestometer or Prestwich fluid gage, as supplied by the Coats Machine Tool Com-

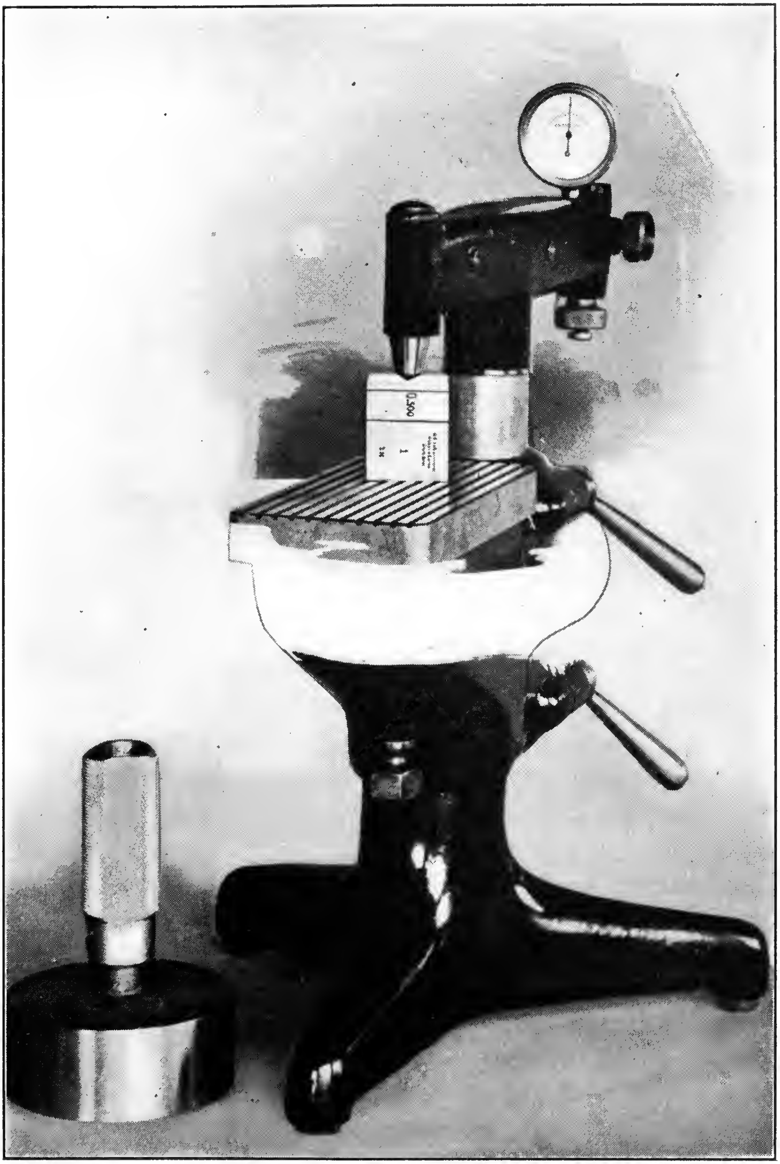


Figure 69. American Amplifying Gage Used with Swedish Gage Blocks

pany, Inc., of New York. The Prestwich fluid gage largely eliminates the sense of touch and measures differences of dimension with extreme accuracy through the use of fluids and capillary tubes in connection with metal diaphragms and a micrometer scale. If this instrument is used with care in the selection of suitable sized tubes for the work in hand, and if the adjustments are made with reasonable attention to the elimination of air bubbles, setting to zero, etc., it is an invaluable auxiliary device for use with gage blocks.

While it is true that fairly accurate comparisons may be made by using the holders or straight edges provided with the gage block sets, very precise comparisons are much simplified by using an instrument of the comparator type, in which differences in reading are magnified by some form of mechanical or fluid lever and the reading scales of which can be set to zero for each dimension.

Miscellaneous Equipment

Various well-known miscellaneous auxiliary equipment for measuring are listed in detail in most small tool catalogues, and these should be found in every dimensional control laboratory. New devices of considerable usefulness are continually coming to the front, however, such as the following:

1. Optical projection apparatus for comparing screw threads and profiles is valuable for several purposes, as referred to in Chapter XIX on the gaging of screw threads. It should be noted that such apparatus requires freedom from vibration.

2. The Johansson set of precision angle blocks. This is a very useful outfit for precisely checking angles and should find much wider application.

3. While not directly connected with dimension, various control instruments for measuring hardness, such as the

Brinell tester and the Shore scleroscope, should form part of the laboratory equipment. The Bureau of Standards Technologic Paper No. 11 gives a "comparison of five methods used to measure hardness."

Personnel

Thus far only the material equipment of an ideal dimensional control center has been discussed. Needless to say, the selection of the personnel of such a control center is also extremely important. Probably everyone inexperienced in the use of measuring apparatus starts out with the idea that manual dexterity and tactile sense is associated only with the slender tapering fingers of the so-called artistic hand. But any such notion is quickly dispelled by observing the accurate work turned out by men with fat pudgy fingers. The only proper and scientific test of measuring ability is actual trial. There is no reason why candidates for jobs of this kind should not be tried out by actual measurement of their work, which will soon reveal, if the test is scientifically conducted, any lack of tactile sense, accurate eyesight, or skilfulness in making fine adjustments.

One of the first requisites for the proper use of scientific apparatus is cleanliness. The laboratory itself should be kept immaculately clean and clear of everything except what is needed for the work in hand. The same comment applies to the personnel, who should be encouraged, by the provision of facilities for washing, to keep their hands clean. In hot weather this may be especially important, because there are some people whose perspiration quickly rusts and soon destroys highly polished steel surfaces. "The Atlas Ball Company of Philadelphia tests the hands of applicants for the positions of inspectors, with a view to detecting acid perspiration. The hands of many people affect a fine steel surface seriously. In some cases breathing on steel discolors the surface. The Atlas Company also tests for this."[6]

Assuming that the people engaged are well suited to the work in hand, it is highly important to impress upon them the wide influence of the control work they are performing. In any work of the sort special attention should be paid to a standard technique for making various measurements. Many errors which cause lack of uniformity may be eliminated if certain measurements are always made in the same manner. It hardly need be added that a part of this warning applies equally well to the high cost of hurrying. Swiftness is one thing, and a very desirable thing, but hurrying has no place in work of the sort, where one blunder will be almost indefinitely repeated when the tools or gages get out into the shop.

---

[6] The Johansson Journal, Vol. I, No. 1.

CHAPTER XVIII

GAGES AND GAGE-CHECKING

When Should Fixed-Dimension Gages Be Used?

Various types of gages have been developed for special purposes, and in approaching any manufacturing problem where the question of dimension is important it must first be decided whether any special operation should be controlled through the use of flexible measuring instruments, such as micrometer calipers, or some special form of gage in which the dimension is physically worked into the gage, usually in permanent form. In each instance special consideration should be given to such questions as:

> Which type will give the best results from a mechanical standpoint?
> Which is best suited to use by the available labor?
> Which is the more economical, both as to first cost and in use?

Flexible measuring instruments such as micrometer calipers require greater skill in their application and are more subject to personal errors due to inaccurate reading of the scale, incorrect remembrance of the dimension, and differences in "feel." Ordinarily it takes more time to apply the measuring instrument than it does to use limit gages with fixed dimensions. This does not always hold true, however, because there are many expert mechanics who take very rapid and accurate measurements with micrometer calipers. It must be remembered also that such measuring instruments are capable of application to several different jobs and, consequently, should be used where the quantity of work prohibits the making of special gages, although the recently developed commercial types of adjustable limit gages obviate this difficulty of expense for many applications.

No gage, and especially no measuring instrument, should be applied to work in motion. To prevent this requires a certain amount of supervision and education of the operator. It is by no means uncommon to see a skilled workman applying a micrometer caliper to work on a grinding machine or a lathe with the spindle still in motion. Frequently, too, the proper way of holding and applying micrometer calipers is not appreciated. Through the courtesy of the Brown and Sharpe Manufacturing Company a number of photographs have been secured showing the proper way of holding and using micrometers of various types. (Figures 4, 5, 51, and 60.)

Fixed-Dimension Limit Gages

Fixed-dimension gages without limits are practically a thing of the past. They depend entirely upon the feel of the operator and have nothing to commend them, for even their expense of manufacture is little increased by making a double opening, to the limit sizes of the tolerance.

There would seem to be little doubt that fixed-dimension limit gages are mechanically suitable for all work that ordinary micrometers will handle. From the standpoint of first cost their application depends upon the quantity or work to be done, but since their use requires less skill and greatly reduces the chance of error, it is probable that their use will be widely extended.

Frank O. Wells in an article[1] calling attention to the probability that the widespread use of gages will be a dis-

---

[1] "Future of Gages in Manufacturing," published in the March, 1920, issue of *Industrial Management.*

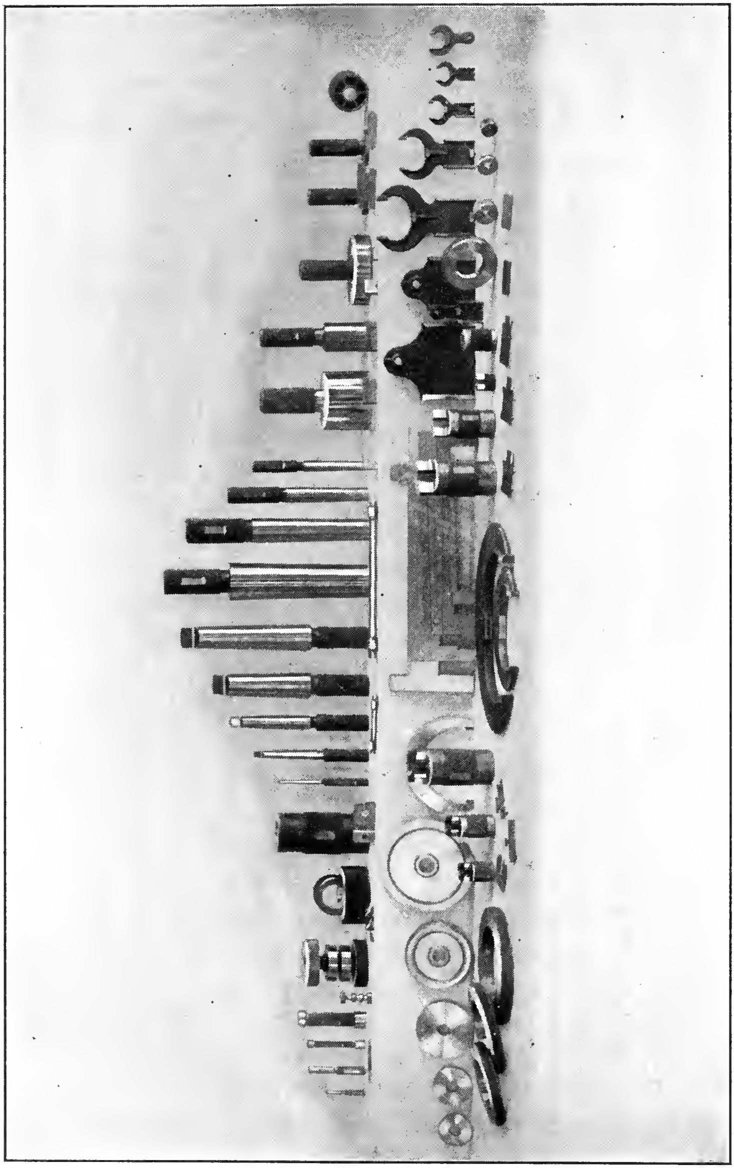


Figure 70. Group of Brown and Sharpe Gages

tinguishing feature in American industry, makes the point that "gages allow departments which cannot see each other, which are separated by walls or courts or other departments, to act in exact coordination." The following quotation from his paper is of special interest:

> A workshop establishing a definite tolerance system, in almost every instance, unless the shop is in serious condition, will find that the desired tolerance will be greater than has been taken advantage of in the great majority of pieces made before a definite tolerance was set. The installation of limit gages will merely find and throw out the small minority of pieces which have wandered from the standard the mechanics themselves set up, but have no definite means of adhering to. It is the exceptions to the rule which cause the most bother. The gage cuts out the exceptions.

In the automobile industry, which has brought dimensional control to such a fine point, the use of fixed-dimension limit gages has been widely extended. In the Packard Motor Car Company's factory, for example, over 40,000 gages are in use. Throughout all divisions of the factory limit gages are used extensively and are set with tolerances ranging from plus and minus 0.0005 inch to plus and minus 0.010 inch. On tolerances less than plus and minus 0.0005 inch better results are obtained by using an amplifying gage or a fluid gage, as described later.

In gage design both economy and technical requirements point to the advisability of using simple single-purpose gages. The use of flat plate gages, on which several openings are shown, has little to recommend it, for almost always some one of the dimensions will show greater wear than the others, so that if the gage is to be saved for future use this opening must be peened. The appearance of the gage is thus destroyed, and, as everyone knows, no battered-up gage ever receives the same respect from the user, as one in perfect condition.

Adjustable Limit Gages

There are several types of adjustable limit gages on the market which permit the economical extension of what are practically fixed-dimension limit gages. (See Figures 52 and 54, showing the general features of the Johansson adjustable limit gages, both snap and plug; also Figures 71 and 72, showing similar information for the Pratt and Whitney gages.)

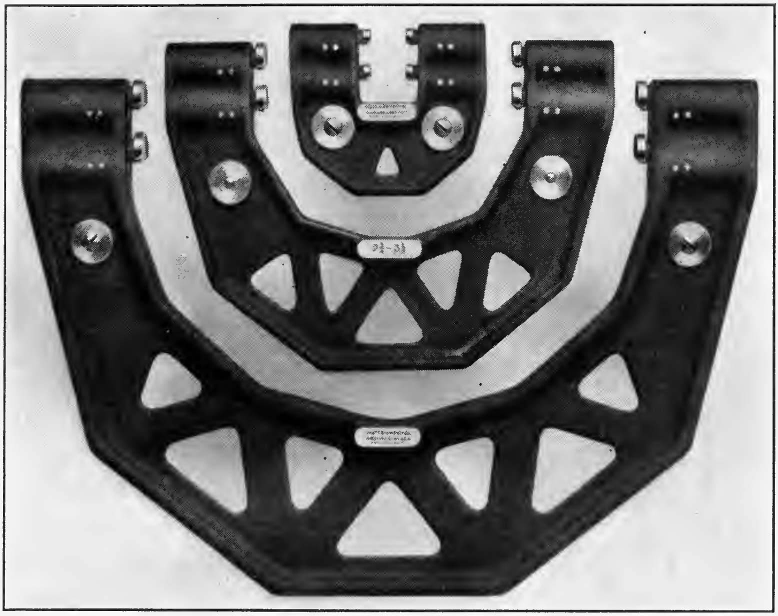


Figure 71. Adjustable Limit Snap Gages—Pratt and Whitney Type

The wide anvil gage is coming into greater use and has very much to recommend it, not only because of decreased wear but because the greater bearing surfaces tend toward more accurate results. Attention is invited to a similar economy in the use of plug gages with reversible ends which

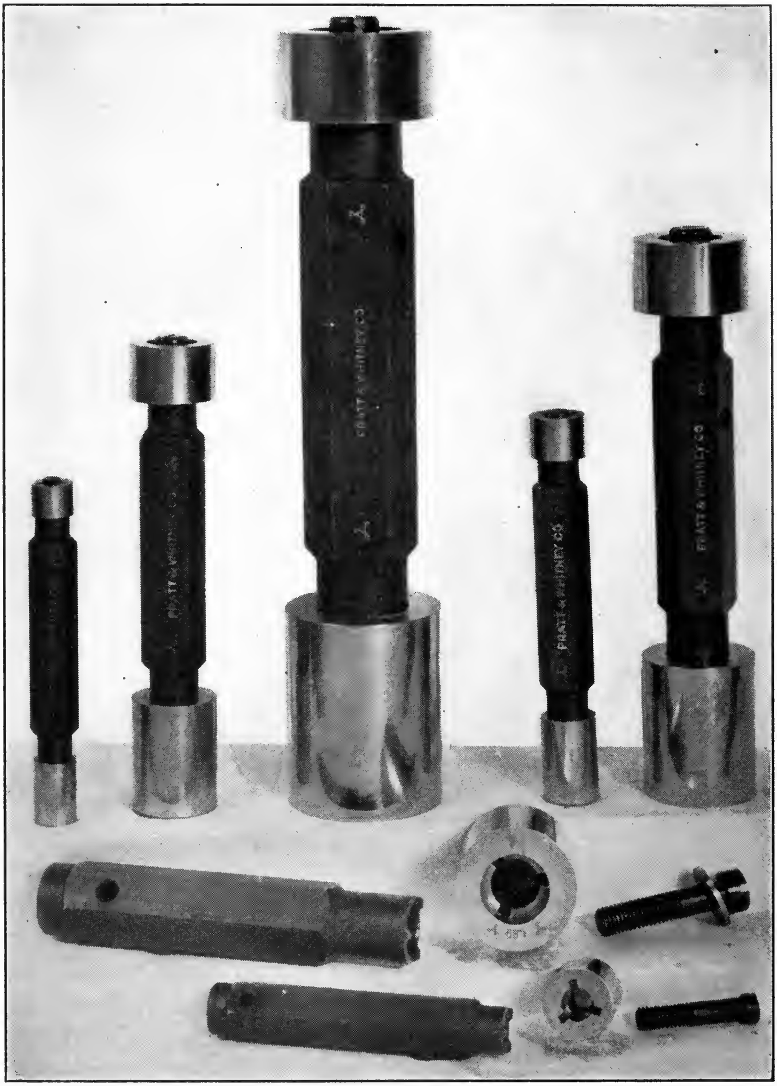


Figure 72. Adjustable Limit Plug Gages with Reversible Ends—Pratt and Whitney Type

permit a longer useful life. (See Figure 72.) The fact that ends are removable is advantageous, as the "no-go" end always wears less than the other.

Multiplying Gages

It is an interesting fact that in the application of close limit gages there may be a difference of as much as 20 per cent or more in the number of pieces passed by the inspector, depending upon his mental attitude and material surroundings. Very slight actual differences may thus become very great quantitatively. A purchaser's inspector may differ very decidedly from the factory inspector in the use of the same gage. This fact alone accounts for the increasing use of gages in which such small differences are enhanced or magnified to a point where measurement becomes impersonal. Where the work warrants the expense, the use of such gages is almost always desirable for better work, and especially so when it is necessary to use less skilful help and to obtain a greater assuredness of results with such help. The Packard practice, for example, has developed that for tolerances less than plus and minus 0.0005 inch much greater certainty is obtained by using an amplifying gage or the Prestwich fluid gage. Figure 38 shows a photograph of an operator using a Prestwich fluid gage on piston pins, the size of which is held to plus zero and minus 0.000,25 inch. These gages are set from a "master" and are checked against the "master" after every 100 pieces. The gages are used in both production and inspection on such work, and at times it has been found that, if the work is held to a closer limit than plus or minus 0.0005 inch, the operator will hug the high limit for fear of getting the pieces undersize. With fixed gages on work of this kind, the points or anvils will wear quite rapidly and as a result crib inspection would show about 25 per cent of the pieces oversize.

The principal types of multiplying gages are as follows:

1. The multiplying lever type. With this type of gage it is important to avoid backlash or slip by keeping the chain of levers under pressure from one direction in order that the spring or other tension device may quickly restore the parts to the zero measuring position. The points of juncture in the link work are important. Flexible tape connectors or conical pointed ends in conical hollows are desirable for great accuracy, but wear must be provided against with care. All gages of this type should have positive adjustment for the zero point and should be provided with standard test pieces.

2. Dial indicators may be used to accomplish the same purpose of multiplying errors (see Figure 36), and so may the micrometer heads which are commercially obtainable.

3. The amplifying gage (Figure 69), and the fluid gage (Figure 38), which are primarily multiplying comparators. These also are suitable for use in this connection, as has been stated heretofore.

4. Flush pin gages. These are made to utilize the tactile sense for the detection of small differences, as the finger-tip is very sensitive and is able to feel very small errors. Their use should be restricted, however, to work on which other less complicated devices are unsuited.

Special Gages

Special situations may be handled by various designs of gages and measuring instruments, in which there is room for the greatest ingenuity and resourcefulness of the gage designer. These include such devices as special testing fixtures, (e.g., as used for measuring cam-shafts, etc.); contour, profile, or outline gages, and so on.

It is often useful, in drop forge work, to provide hot gages for checking forgings more promptly. In such gages allowance is made for expansion of the work while hot. Another method is to keep the gage hot and to fit an insulated handle to it.

Modern methods of thread-gaging have developed a great many special devices, including the use of the optical lever in projection apparatus. A number of these special devices are treated in detail in Chapter XIX.

Gage Tolerances

The economical use of gages requires that even greater care be given to setting the tolerances on the dimensions of the gages themselves, than for the work. Speaking mathematically, this process is like the second differential, in which the tolerance for the work is the first differential. With adjustable gages the matter of wear is easily disposed of, but there are many instances in which the task is not so simple. As a general guide the rule is sometimes followed of allowing a gage tolerance equal to 10 per cent of the tolerance for the work proper. It is good practice to make limit plug gages 0.0002 inch full on the "go" end to allow for wear, since the "go" end of any gage wears much more rapidly than the "no-go" end. Copper plating is sometimes resorted to, in order to build up the wearing surface for gage anvils. It is good practice in many instances to have a systematic plan for replacing worn working gages with worn inspection gages.

The Application of Gages

Investigation will reveal that there is a great field for educating workers in the use of gages. Special attention should be given to gage instruction cards (see Figure 49, showing a portion of one such card as used in the Lincoln Motor Company's factory). The technique necessary for accurate application of gages demands separate study and there is undoubtedly great room for development of motion study in this work. More gages should be mounted upon flexible stands which will permit the gage to adjust itself readily to the work as well as allow the operator to use both hands.

Gage-Checking

The use of limit gages brings with it a special problem of co-ordination. In a large factory using thousands of gages there is every need for the intensive and practical application of systematic methods in gage-checking. Troublesome gages and gages subjected to hard usage should be checked very frequently indeed. As a general rule gages with limits of plus or minus one-quarter thousandth should be checked at least twice a week, those with limits of plus or minus one-half thousandth at least once a week, and those with limits of over one-thousandth, at least once a month. In addition, to provide against accidental errors, all of the devices for catching such errors should be utilized. These have been listed in detail in Chapter IV, pages 60 and 61.

Naturally a problem of this sort requires that the individual gages be numbered, that there be a card catalogue system and a tickler file, and, more important still, that some responsible individual be charged with the duty of following up this work. This control of dimension of course proceeds from the dimensional control laboratory referred to in the preceding chapter. The work will be more easily controlled if handled entirely through the inspection department and if all working gages are issued from inspection centers throughout the plant, whether they be central inspection groups or merely the offices of department inspectors.

As noted before, the fact that gages wear makes it necessary to provide a chain of checking devices reaching from the working gage (which is subject to the most wear) back to some master gage template or standard measuring machine which is subject to extremely little wear and, therefore, reasonably sure of remaining constant. The number of links in this chain is frequently dependent upon the number of times the working gages are to be applied and upon their relative wear. Thus, for a very close dimension, a soft steel or even a hard steel template might be applied by an expert in 1,000 checkings without serious wear. Then in such a case, if the quantity of work contemplated more than 1,000 checkings or applications of the template, we should have to construct one more link in the chain in order to have something to check the template.

In building up this chain for dimensional control several terms have been employed, but there is no set of definitions in general use. The definitions recommended in the Progress Report of the Committee on Limits and Tolerances in Screw Thread Fits, as published in *Mechanical Engineering*, August, 1918, are:

> *Master Gage.* A gage which is kept as a standard solely for comparing reference gages.
>
> *Reference Gage.* A gage used by the manufacturer and by which the workman's gage is tested. A copy of the master gage.
>
> *Standard Gage.* The English term for Master Gage.
>
> *Shop or Workman's Gage.* A gage used by the workman in everyday practice. It is tested by or with the Reference Gage.

The above definitions are a sufficient guide for ordinary purposes, but many gages will be checked with greater ease if they are provided with close-fitting templates as an additional step in the chain. Further, for straight dimensional work (that is, excluding special shapes, such as screw threads and profiles) several of the early steps in the chain of control gages may be eliminated by the use of Swedish gage blocks. The basic principle, however, must be observed with care: *One master set of blocks should be retained solely for checking* *the other sets of blocks which are used in the direct dimensional checking of gages and tools.*

The Slip in Transferring Size

Another chain of error arises in the possibility of slip in passing from dimension to dimension. With the feeling that the Johansson Company's experience in the matter of making fine adjustments would be of interest in this respect, they were asked for their opinion on the matter. The following information was furnished by C. E. Johansson, Inc. through the courtesy of Huber B. Lewis, Vice-President:

> It is possible to transfer size without any observable slip. We do it regularly in our laboratory work. Our checking instruments are, of course, of extreme delicacy and we are dealing, in most cases, with surfaces of extremely accurate finish. It seems to us that the amount of slip which might occur in the practical application of measuring implements depends, first upon the sensitiveness and the uniform accuracy of the comparator, and second upon the finish of the surfaces being compared. As an illustration: if a comparator were set by using a standard plug with a fine lapped surface, a ground part checked on this comparator would probably register large because of the surface irregularities. A clearer comparison might be the slip between the plug templet and a ring made to fit this templet. In practical tests we have made on plugs and rings 1″ in diameter, we find that a clearance of approximately .0001″ should be allowed in order for the plug to enter the ring with a nice wringing fit. Actual measurement would, therefore, show the ring to be .0001″ larger than the plug to which it was fitted which would probably establish for practical purposes, a slip in measurement of .0001″. By using extreme care in the finish of the surfaces of the plug and ring, paying particular attention to roundness, this slip can be reduced to .00005″ and the plug inserted in the ring without using force. On the other hand, a clearance of more than .0001″ would be required if the plug or ring were not round and smooth.
>
> Two Johansson Standard Gage Blocks can be checked against each other where the slip would not exceed .00001″. Take two new 1″ blocks which are exactly alike within .00001″ or better, wr ng end-radius jaws on one block; the other block can be inserted in the recess

between the extension jaws so that it will remain in place when suspended, through the niceness of fit. It may be said that some slip occurs in the union between the first block and the end pieces due to the filament of oil or moisture between the surfaces; whatever that slip may be, if at all appreciable, will also exist between the jaws and the second block when it is inserted between the extension pieces. This would also be true in rougher work, for instance, a snap gage set to a templet. Assuming that some slip occurs in mating the snap gage to the templet, a corresponding slip would occur between the snap gage and the parts checked by it so that the parts would correspond very closely with the original templet.

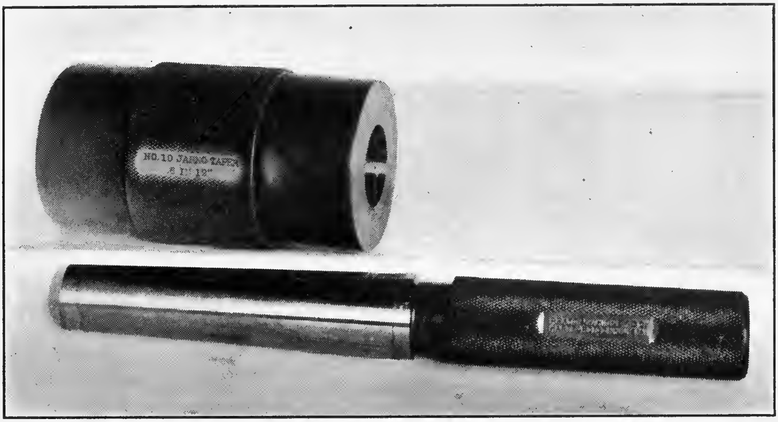


Figure 73. Pratt and Whitney Taper Gages

Mr. Johansson illustrates this principle of fit in a very interesting way. He takes a 1″ Standard Gage Block with the radius jaws extending down each side and stands the block on the table before him. By the side of the block he stands a 1″ plug gage, finished to the same degree of accuracy as the standard block. After making sure that both pieces are of the same temperature, he inserts the 1″ plug gage into the snap gage opening formed by the 1″ block and the end pieces. You will note that the surfaces of the plug gage and the extension pieces are in contact only along a hair line on each side. Notwithstanding the slightness of this contact, the fit is sufficiently nice to permit Mr. Johansson to raise the entire combination by lifting the end of the plug gage.

> Mr. Johansson then takes the standard block combination and holds it in his hand while he counts five slowly. The plug gage is again inserted and this time it is impossible to lift the standard block combination with the plug due to the expansion of the block. The plug is then held in the hand while he again counts five, thus bringing the plug approximately to the same temperature as the block again and this time the fit is the same as it originally was and it is possible to lift the standard block combination by lifting the end of the plug. The amount of expansion would, of course, depend upon the difference between the body temperature and the temperature in the room where the experiment is performed, but the change would not account for more than two or three hundred thousandths of an inch, perhaps, and this again illustrates the very small amount of slip that may occur when surfaces of equal finish are compared.

After every precaution has been taken to see that the proper gages, correctly checked from time to time and kept to dimension, are provided, and even if they are properly used, there still remains much to be done if precise work is to be secured with certainty. For this reason in Chapter XX will be found some comments on the points to be observed in precision processes, as well as data indicating the present state of the machining art in the matter of dimensional accuracy.

Chapter XIX is devoted to the presentation of the very special and intricate business of screw thread production and gaging. Many of the devices and methods, however, are more generally applicable to irregular outlines, contours, and forms.

CHAPTER XIX

THREAD-GAGING[1]

Evolution of Thread-Gaging

The evolution of thread-gaging is an epitomized history of all gage development, beginning with simple ring and plug gages and micrometer calipers and then running the gamut through a long series of specialized measuring and checking devices up to the use of the latest methods of optical projection. This array of equipment and the great and continued effort of many expert engineers involved in its creation, is warranted by the value of the screw thread as an element of mechanism and is made necessary by the difficulties inherent in accurate thread-making.

The beneficial influence of munition and automotive requirements are clearly traceable in this evolution. More perfect interchangeability without sacrifice of dependability or strength in relation to weight have operated to enhance the importance of precision in the manufacture of threaded parts. In fact these characteristics have been greatly improved, with corresponding improvement in the apparatus for controlling their quality in manufacturing.

So great a variety of gaging devices is now available as a result of the recent intensive development just mentioned, that the first practical problem encountered in building up a control system for threaded work is the selection of apparatus sufficiently positive in effectiveness without being too cumbersome or complicated. It is very easy indeed to build up a long chain of control from the working gage through

---

[1] The author is indebted to the Honorable James Hartness, Governor of the State of Vermont (and formerly President of the Jones and Lamson Machine Company of Springfield, Vt.) for his kindness in furnishing much of the material presented in this chapter.

inspection, reference, and master gages with their check templates, up to final master models. But the ramifications thus introduced are all potential sources of error and necessitate solicitous watching.

Anything that can be done without sacrificing efficiency to reduce this complexity by shortening the chain between the work itself and the final control equipment is highly desirable for many and very apparent reasons. It has been shown already how the chain may be shortened in simple or single dimensional work by the use of Johansson block gages. It is now proposed to show how the same thing results in precise thread control from the use of modern optical projection apparatus.

Again quoting L. P. Alford's frequent statement, "The purpose of industry is to make goods," thread-gaging devices are of no value for their own sake, but merely as a means for assuring the production of threaded parts in accordance with the desired standards. The more direct and simple such devices can be made the better, but the first step, as always in the control of quality, is to study the product, the errors which enter into its production, the causes of these errors, and the means of regulating the manufacturing processes where errors are made.

In the analysis of screw-thread elements essential to strength and dependability, James Hartness states:[2]

> On account of the vagueness of our general knowledge of the conditions under which it takes its stress, we frequently underestimate the importance of the screw, and, through ignorance, continue practices that greatly increase the hazard of life in travel by rail, automobile or airplane, as well as lessen the reliability of performance of other pieces of machinery. A screw-thread fastening is very dependable if the two component parts are properly fitted.
>
> While it is not possible to attain perfection in this work, an analysis of the various elements that are essential for strength and

---

[2] "Optical Projection for Screw-Thread Inspection" in *Mechanical Engineering*, Feb. 1919.

dependability, and the reduction of weight, will greatly simplify our efforts and make it possible to attain a point much nearer perfection.

Briefly stated, a screw's reliability depends upon the following elements:

A Material
B Form of profile of the thread
C Diameter of the screw
D Lead or number of threads per inch.

After the foregoing general characteristics have been determined, we must consider the following details which depend on the methods and skill employed in production:

1 Smoothness and density of surface
2 Fit, which relates particularly to the exact relationship of the size of the two component parts
3 Precision of lead, which relates to the precision of advance of the helix or degree of precision with which the number of threads per inch are made
4 Uniformity or steadiness of advance of helix
5 Form, relating to contour of a single thread
6 Roundness, as relating to the circular path of the helix
7 Parallelism or taper.

These elements are all inter-related.

Inter-relation of Thread Elements

The last sentence is particularly significant. Before threading, the problems of ordinary cylindrical or tapered work are encountered, such as maintaining diameters, roundness or concentricity, and parallelism. These difficulties are carried over into the threading, where they are accentuated by the creation of spiral-warped surfaces which add the complications of pitch or lead of the screw, the angular form of the thread, and several diameters instead of one. Thus errors accumulate in three dimensions. In the case of a single screw thread considered alone the inter-relation of errors must be carefully taken into account; for example,

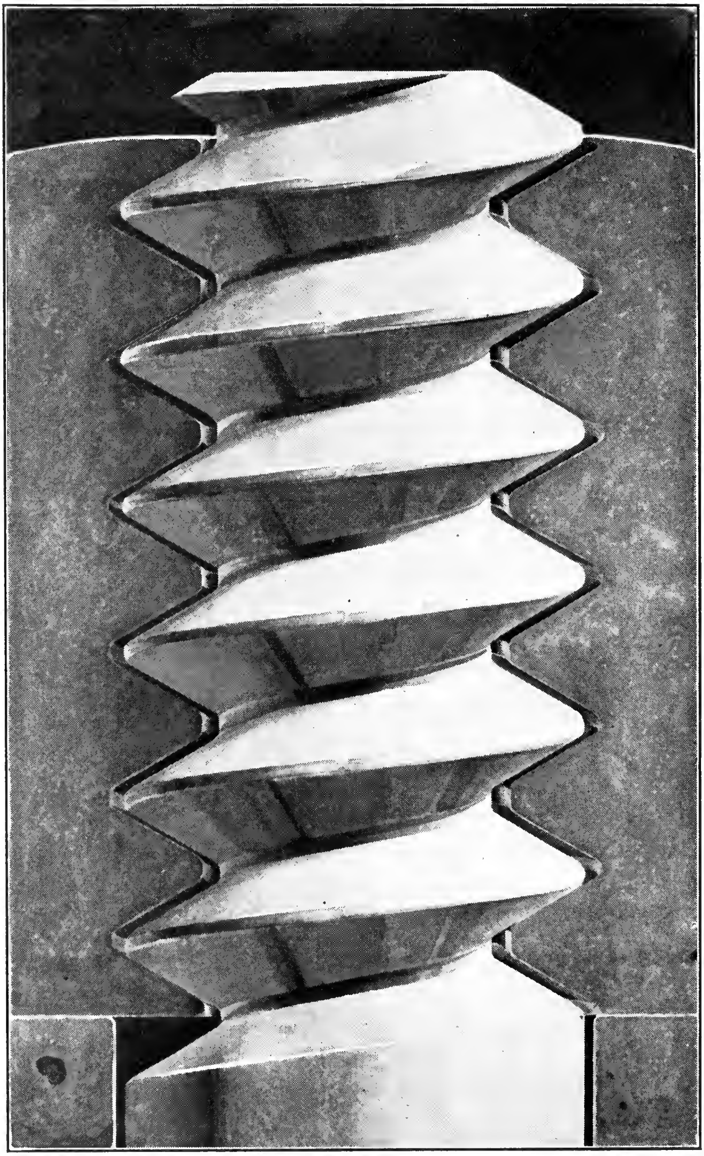


Figure 74. An Exaggerated Form of Stud

To illustrate the fact that when there is a difference in lead between the screw and the nut or threaded hole the middle threads do not touch either in the gage or the work until the opposing end threads are crushed. It also illustrates the conflict between the stresses at the two ends of the engagement. Courtesy Jones and Lamson Machine Company.

a variation in pitch may involve a much greater error in effective diameter.

When the investigation of inter-related errors in screw threads is extended to include mating parts, as it ultimately has to be in every case, the percentage feature of precision is involved because the error in the lead of the thread varies with the length of the thread. The possibilities in the latter case are well illustrated in Figure 74.

The preceding general discussion of the elements of threads and their accompanying errors assumes theoretically smooth surfaces. In practice, however, the surfaces of threads are not smooth, nor are edges continuous lines and true curves. The manufacturing processes inevitably leave their marks in the form of irregularities, chips, and so on, which vary in magnitude with the character of the work. No matter how slight these irregularities, their effect, singly or collectively, is to increase errors of gaging or measuring.

It is not the purpose of this book to go into the technicalities of the various features of design, and it is assumed, therefore, that the design provides for safe clearances between mating parts, especially bottom and outside clearances. It is assumed also that the design provides for normal wear of cutting tools, especially at the points and edges where wear may ordinarily be expected to reach its maximum effects. With these assumptions, then, we are chiefly concerned with the remaining factors of lead, pitch-diameter, and slope or angle. The first two usually require, and in fact warrant, the most attention. Their inter-relation is such that lead, especially in long screws, is of paramount importance.

Working Thread Gages

The usual gages for inspecting threaded parts in the shop are of the well-known plug and ring type (see Figures 75 and

76). A series of similar gages can be made for gaging the various elements of the thread separately, but it would hardly be wise or worth while to furnish such a series as working gages or even as inspection gages for use in the shops. Consequently the use of several gages for such work finds little application outside of the tool-room in thread-chasing. The gaging system for practical shop use, therefore, reduces to limit threaded plug and ring gages which gage all essential elements at once. This involves for the threaded hole:

(a) Threaded "go" plug of a length equal to the longest engagement of work

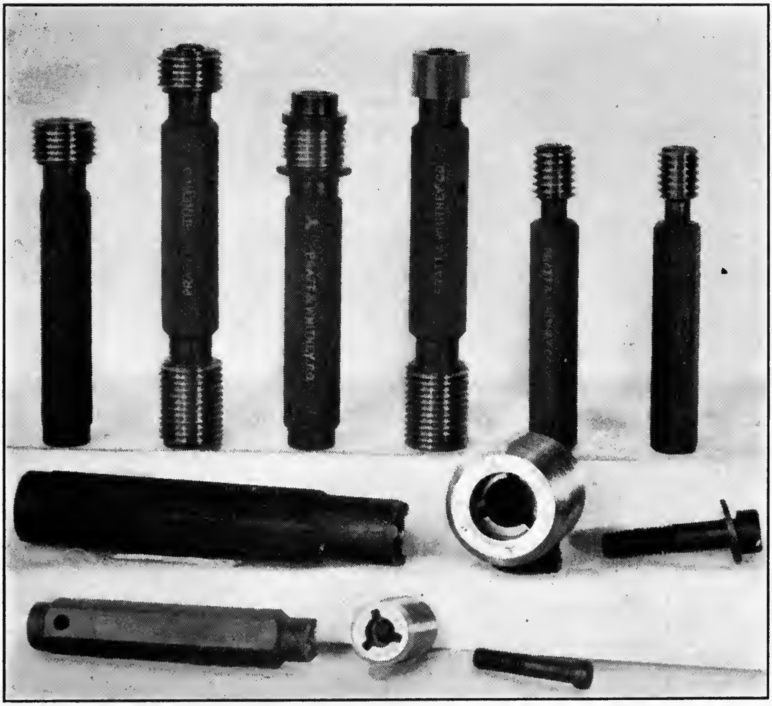


Figure 75. Typical Thread Gages—Pratt and Whitney Company

(b) Threaded "not go" plug, made short and with clearance for full and root diameters;

and for bolt or screw:

(a) Threaded "go" ring of a length equal to the longest engagement of work

(b) Threaded "not go" ring made short and with clearance for full and root diameters.[3]

The Hartness Comparator

Now, the fact is that such gages are blind in the sense that the gage covers the work while the latter is being gaged, and knowledge must be based upon the feel of the fit of the gage with the work. This might do well enough were it not for the fact that the work inevitably carries with it the little errors already referred to, such as roughness of the surfaces, chips, and slight variations or wabbles in the pitch, in addition to direct dimensional variations which are always present. These hidden dangers are without doubt at the root of most of the aggravating and perplexing troubles so frequently encountered in the assembling of threaded parts, troubles which are augmented in marked degree with increase in the precision required for neat fits and complete interchangeability. Owing to the conditions just set forth, the use of snap and ring gages actually discards some of the best

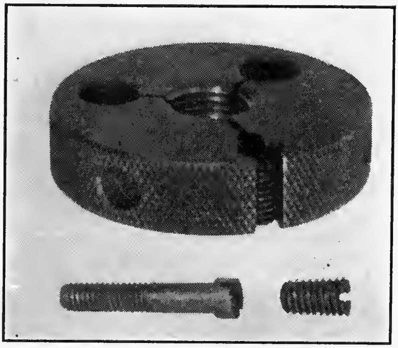


Figure 76. Typical Thread Gage—Pratt and Whitney Company

---

[3] "Progress Report of Committee on Limits and Tolerances in Screw-Thread Fits," *Mechanical Engineering*, Aug., 1918.

threaded parts of a lot and accepts some of the worst. Consequently, even with gages in excellent shape, it is important to base our control system on the work itself, since gages of this type are apt to be misleading. Furthermore, it is not enough to know that errors exist because we can feel them; they must be brought out into the open and measured before we can proceed to correct them with any degree of assurance as to final results. Several designs of optical projection apparatus have been developed for this purpose, both in this country and abroad, and these mark a decided advance in apparatus for checking both threaded work and thread gages.

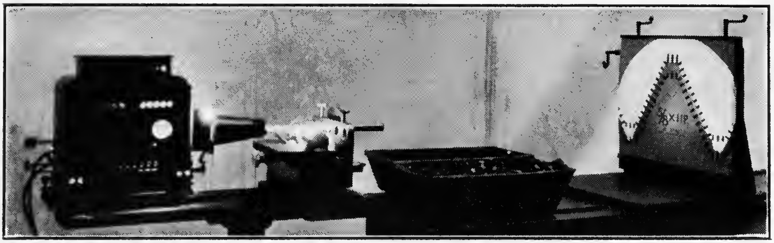


Figure 77. General View of Hartness Screw Thread Comparator

Figure 78. Another General View of Hartness Screw Thread Comparator

The Hartness screw thread comparator, illustrated in Figures 77 and 78, positions the work in a cradle or work-holder (see Figure 79), in such a relation to its helix and diameter as to show the situation at a glance, by visual comparison of the projected outline or shadow with the tolerance chart of the screen.

Internal threads may be checked with the same apparatus by the use of sulphur casts, after the method long in use in measuring the cartridge chambers of small arms. Graphite may be mixed with the sulphur (7 per cent of graphite by

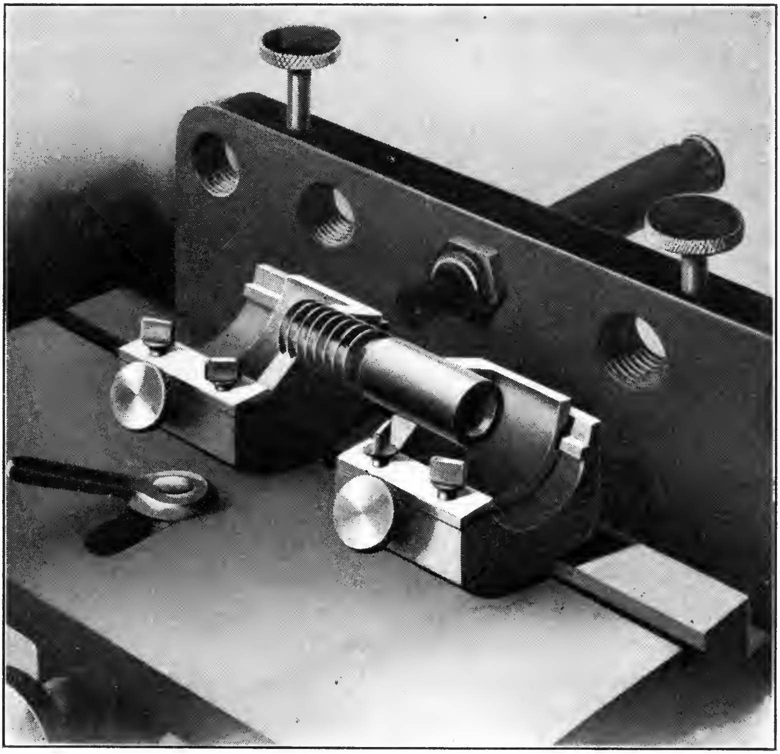


Figure 79. The Work Holder and Projection Lens of Hartness Screw Thread Comparator

Showing a standard plug in the cradle. The machine is adjusted by use of a standard threaded plug. The plug is a perfect check that may be used during the run of gaging.

weight) to reduce shrinkage and surface reflection.[4] Or, the tap used in threading the hole may be checked.

There is then made available a simple means for verifying threaded work (both passed and rejected parts), so that errors may be revealed and measured. This apparently is the proper starting point for bringing the work under control. The same procedure is then extended to correct the tool equipment so that it will produce work of the desired character; and finally to check such gages as are needed for convenience, being guided always by the principle that it is more useful as a measure of a gage's effectiveness to check the work which the gage passes than it is to regard the absolute measurement of the various elements of the gage proper as final and conclusive.

It may be mentioned incidentally that there is a useful field of application for projection apparatus in irregular profile and contour work, as well as for threads; but in all work with such equipment due attention must be given to locating the apparatus away from troublesome vibrations.

Other Equipment for Measuring Threads

For a complete description of the equipment employed by the Bureau of Standards in measuring thread gages, the reader is referred to the paper by H. L. Van Keuren, mentioned above, which may be used as a guide in equipping the control laboratory for thread gage-checking. The gaging system should be adopted with reference to the character of the work to be handled. For precise work the optical projector will usually be supplemented by a special lead testing machine. An excellent instrument of this type was brought to a high state of perfection during the war by Major H. J. Bingham Powell, who was Director of the Joint Gage Laboratories of the British War Mission and the

---

[4] "The Measurement of Thread Gages," by H. L. Van Keuren, chief of Gage Section, United States Bureau of Standards, in *Mechanical Engineering*, Nov., 1918.

United States Bureau of Aircraft Production. For such work the West and Dodge Company's lead tester (see Figure 8) is often found in the dimensional control rooms of factories doing precise work. Similarly, the well-known three-wire method for measuring the pitch diameter should be provided for by supplying accurate apparatus for this work. The method is a most useful one, but requires careful application for accurate results.

Ordinary ring and plug gages are frequently supplemented in close work by special types of gages, such as combined lead and diameter gages, using micrometer heads in combination with compound levers or dial indicators for enhancing errors in the work—making them appear greater. For simple work the ordinary type of screw thread micrometer still has a useful field.

Thread Gage Tolerances

There probably is no other branch of gaging which requires so much attention to the effect of wear as does accurate thread-gaging, and this, of course, brings in the matter of gage tolerances. In this connection Frank O. Wells[5] states:

> One great difficulty with the business of manufacturing thread gages is the unreasonable and useless accuracy of gage tolerance and wear allowance sometimes requested by purchasing firms. When a tolerance of 0.0002 in. is set on a gage specification it should mean that the customer's tolerance on product is as close as 0.001 in. If the purchaser's manufacturing tolerance is any broader than that, there is no use in keeping the gage so close. A 0.0002 in. error would be lost in the comparison. In order to facilitate the making and to lessen the cost of thread gages, it is well to allow quite liberal tolerances in their manufacture, and we recommend the following as being applicable for most cases where medium tolerances are allowed on product:

---

[5] "Present Practice in Thread Gage Making," by Frank O. Wells, President, Greenfield Tap and Die Corporation; member Congressional Screw Thread Commission, in *Mechanical Engineering*, Dec., 1918.

> From 4 to 6 pitch allow a tolerance of 0.0006 in.; from 7 to 18 pitch allow a tolerance of 0.0004 in.; from 20 to 28 pitch allow a tolerance of 0.0003 in.; from 30 to 80 pitch allow a tolerance of 0.0002 in.

The foregoing applies to master gages. For inspection gages the tolerances would be slightly wider, and would begin where the master inspection gage tolerances leave off. These would be as follows:

> From 4 to 6 pitch a tolerance of 0.0009 in.; from 7 to 10 pitch a tolerance of 0.0006 in.; from 11 to 18 pitch a tolerance of 0.0004 in.; from 20 to 28 pitch a tolerance of 0.0003 in.; from 30 to 40 pitch a tolerance of 0.0003 in.; from 44 to 80 pitch, 0.0002 in.
>
> All of the foregoing tolerances would be applied plus in the case of go male gages and no-go female gages; and minus on no-go male and go female thread gages.
>
> The plus and minus tolerances given apply to pitch diameters of all thread gages and also to root or core diameters of templets or female thread gages.
>
> The maximum, or go, templet gage represents the maximum or basic screw and its manufacturing tolerances should be minus on pitch diameter and root diameter. The minimum or no-go, templet should be made to plus tolerances with an extra plus allowance on the root diameter, which will insure this gage's really checking the effective size of the screw. The wear and adjustment tolerance on a gage should be coarse or fine on a sliding scale according to the manufacturer's tolerance on his product.

As Mr. Wells shows, the matter of gage tolerances refers back to the tolerances required for the work itself. The latter subject has received much attention from engineering organizations in recent years, and the results of their conclusions as set forth in various publications should have the careful attention of manufacturers.

Precision Depends upon Service Requirements

It may be noted again that the problems of this subject necessitate at the start a determination of the things we wish to accomplish with our product. What service are the threaded parts required to perform? What are the elements of these parts which make the principal contribution to the rendering of such service? What variations from the ideal for the sake of economy of manufacture is it sensible to tolerate without too greatly compromising effectiveness? When the subject is analyzed in this order, it may readily develop that the best results will flow from easier tolerances but with closer adherence to these standards in the dimension and finish of the product. Thus better attention to the quality of the work may permit the gage tolerances to be a fifth instead of a tenth of the tolerances allowed for the work; especially when the work is more positively checked from time to time by independent methods, such as by the use of the optical projection apparatus referred to.

CHAPTER XX

THE PRECISE CONTROL OF PROCESSES

What Dimensional Precision Is Practicable?

In the study of dimensional control it is sometimes desirable to consider what degree of accuracy is commercially obtainable for a given job. The logical starting point for such an investigation is the examination of the results obtained in various processes which are in actual use at the time. It should be observed, however, that any such figures are subject to correction from time to time as the manufacturing arts are advanced toward greater precision. To be sure, a very high degree of accuracy has been obtained in certain businesses at the present time, and it would be difficult to see any advantage at the moment in further improvement; but experience shows quite clearly that progress has not stopped. As the advantages, both commercial and technical, of higher precision come to be recognized, there is no doubt that further and even more startling advances will be made.

The manufacture of automobiles has developed a very high degree of accuracy on a commercial scale, so that our first examples of obtainable precision are taken from that industry. In the Lincoln factory, for example, "there are more than 5,000 operations in which the deviation from standard is not permitted to exceed the one thousandth part of an inch, more than 1,200 in which it is not permitted to exceed a half of one thousandth; and more than 300 in which one-quarter of a thousandth is the extreme limit of tolerance." The large number of closely held operations in this industry has been a matter of frequent and general comment. It is only a year or two since the Marmon Company, for example, at the Motor Show in New York put on an exhibition in which two men took down and reassembled a complete engine in 1 hour and 45 minutes. Such precision kills the need of hand-fitting.

Automobile Experience

A former associate, G. D. Stanbrough (in response to the author's request), writes the following setting forth his experience with precision work in the automobile industry:

> With regard to commercial limits on different forms of machine work I may say that at the time a new model is placed in the factory[1] the limits are carefully gone over by a committee representing the Engineering, the Manufacturing and the Inspection Departments. The committee sets the limits which the Manufacturing Department knows from past experience are commercially possible, and yet within the tolerances desired by the Engineering Department. It is our practice to give all information necessary on the drawing, as to roughing and finishing dimensions, also, forging and casting dimensions.
>
> It might be well to point out at this time that an understanding is not always had as to the matter of limits in manufacturing. The matter of design and its relation to limits is quite frequently misunderstood and much trouble can be avoided by thoroughly understanding these functions. It should be borne in mind that the design of a piece of apparatus involves the strength of materials and the appearances. That is, you must have the necessary strength to perform the function and to have a finish compatible with the condition under which the piece is used, or the particular ideas from a sales policy that is to be carried out. While on the other hand the matter of limits is purely manufacturing and involves the practices of the shop in which the work is done.
>
> It naturally follows that as closer limits are approached in manufacturing, the design in turn can be improved. An automobile manufactured to give satisfactory service over a long life must of necessity be built to close limits. Noise probably more than any other one cause is responsible for the comparatively short period of

---

[1] The Packard Motor Car Company's factory is referred to.

time in which a machine gives satisfaction to the customer. In order to manufacture an automobile that will give noiseless operation over a period of years close limits are essential, and it has been our constant aim in designing tools and in laying out our processes to decrease our limits.

To date we are able to hold the grinding on such parts as the piston pin, the cam roller pin, and other parts subject to reciprocating motion to a limit of plus .000 minus .00025. We are holding turning dimensions to plus or minus .0005—this limit being held on bushings and bearings. On milling work we are holding to plus and minus .001, in fact we have a 4½″ dimension on our crankcase which is held to this limit. On milling key-ways we hold the width to a limit of plus or minus .0005. On reamed work we hold to a limit of plus or minus .0005 with the exception of the cramshaft sprocket, the piston pin bushing, and some other close parts, where by hand reaming we hold a limit of plus or minus .00025.

We are holding today, in the commercial practice of the shop, to limits which but a few years ago were only called for on the most accurate tool room work. However, this is the result of first class inspection methods combined with properly designed jigs and fixtures.

Of course you realize that in the manufacture of large numbers of interchangeable parts, speed in manufacturing can only be obtained through close limits which give a high degree of interchangeability. Quality can be controlled, if quality is the idea of the Management; if the people behind an enterprise have a genuine desire to get quality and are willing to pay the price, it should be borne in mind that it costs money initially to produce quality, to get a job up to the highest standard of manufacture. However, once that standard is reached it can be maintained cheaper than it is possible to maintain a lower standard, owing to the fact that pieces assemble with greatly increased speed when fitting in an Assembly department is entirely eliminated.

With reference to the crankshaft and the camshaft, we check the overall and intermediate dimensions in a fixture gage which has stops at different points, allowing the use of a "go" and "no go" feeler. Inspection by this method is quicker and more accurate. We find that the twin-six crankshaft supported only on the front and rear bearing will not sag anything over night, but in a test covering a week's duration we found a sag of .0005.

> It might be of interest to you to know that our Liberty Engine crankshaft supported on the front and rear bearing would sag over night from .001 to .0015 while the sag in a week would be .003. Of course, this was due to the extremely long shaft and a fair degree of flexibility. However, I do not think that any close comparison can be drawn as to the sag of a crankshaft, because so many items enter into the consideration, such as: design, material, heat treatment of the material, manner in which it is processed, the amount of straightening that is done, room temperatures, and consequently tests of this kind may be only considered comparatively. Of course, comparisons will be useful provided they are made on shafts of similar design. This question, however, reaches into technical details which are beyond consideration of ordinary inspection practice.

The tolerances disclosed in these cases are typical and indicate the precision *obtained* in daily manufacturing in those motor car factories where dimensional control has been carried to the highest practicable standard of achievement. Works of this sort employ from 20,000 to 40,000 limit gages, whose cost runs into the hundreds of thousands of dollars. The inspection of finished parts alone may require 72 hours per car. Some other industries apply more gages, occasionally as many as 50,000 in one factory; but few, if any, achieve the precision of the automobile factories, on a quantity production basis—day in and day out. With over 10,000,000 motor vehicles in the country, everyone has a chance to familiarize himself with their various parts. Consequently, the precision for principal dimensions gives a pretty good general idea of commercial possibilities for various sorts of machine work.

Tables of Tolerances

Another source of information as to precision is to be found in tables of tolerances. In a sketch furnished by the C. E. Johansson Company, Inc. (see Figure 80), various kinds of fits are shown, together with two tables of tolerances

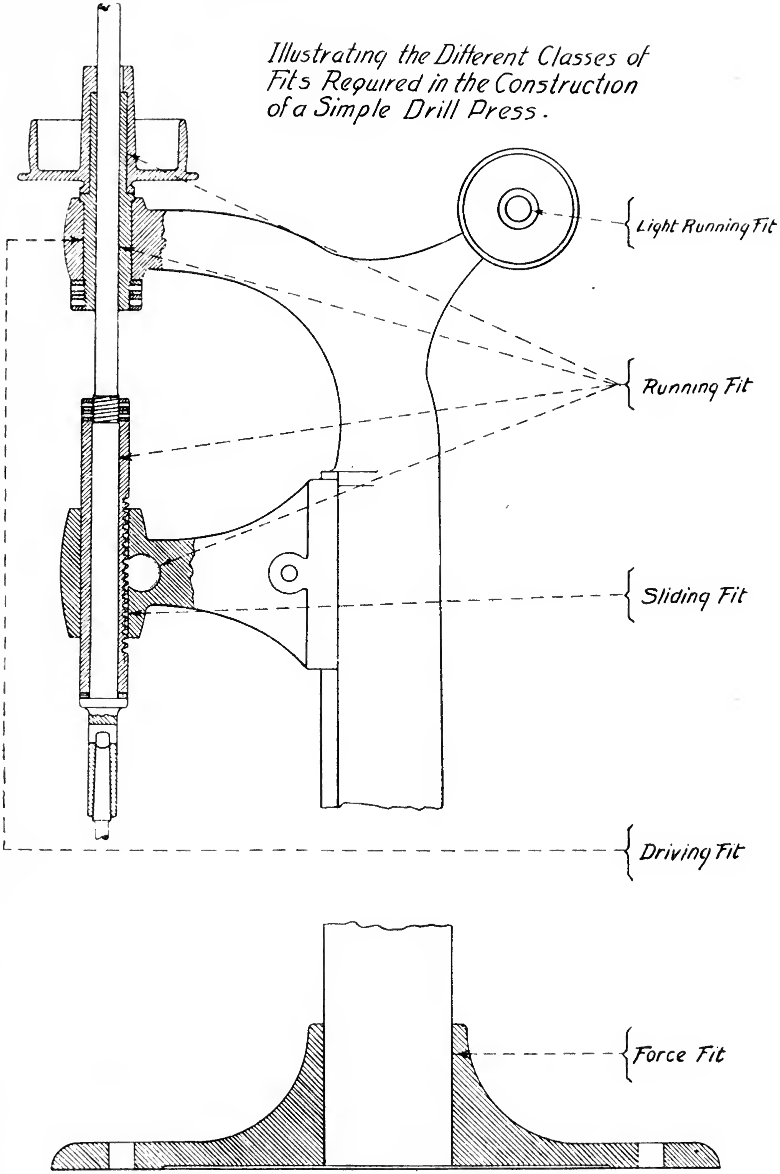


Figure 80. Sketch of Drill Showing Various Fits—Johansson

and limits (Figures 81, 82, 83, and 84). One set of data is based upon the hole system, in which the hole is taken as the reference point of greatest accuracy, and the other is based upon the shaft system. Since the recent developments in greater precision of work, especially as regards grinding, there would seem to be little need of considering whether we should work from the hole or the shaft, but the figures are interesting as a guide nevertheless.

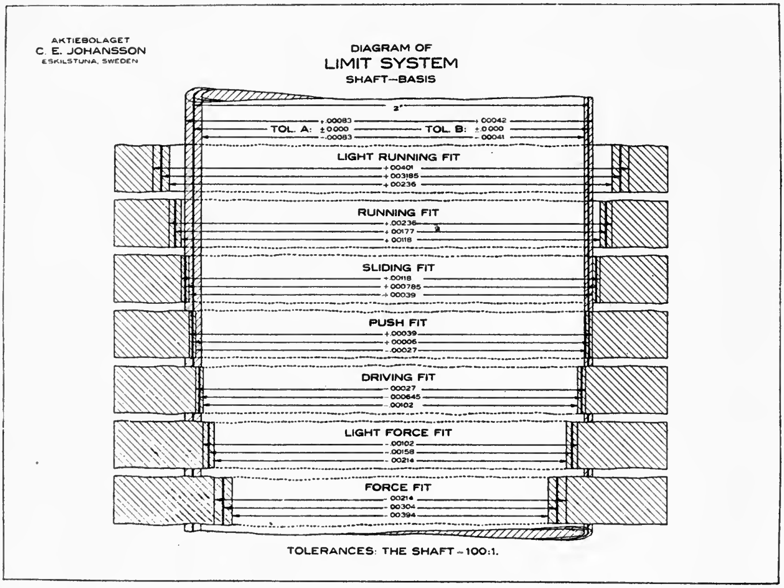


Figure 81. Diagram of Limit System—Shaft Basis—Johansson

In recent years considerable pioneer work has been done in England toward assembling useful data on precision and pioneer work of the same sort has started in this country. In July, 1920, *Mechanical Engineering* announced the formation of a sectional committee of the American Society of Mechanical Engineers for the purpose of studying and reporting on plain limit gage standards and machined fits.

TOLERANCE SYSTEM WITH THE HOLE AS BASIS
TABLE FOR TOLERANCES IN INCH

Diam		LIMIT PLUG GAGE						LIMIT SNAP GAGE																				
		A *)			B **)			Loose Fit			Running Fit			Sliding Fit			Push Fit			Driving Fit			Press Fit			Force Fit		
		Min	Max.	Tol.	Min	Max	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Max.	Tol.	Min.	Max	Tol.	Min	Max	Tol.	Min	Max	Tol.	Min.	Max	Tol
2/64	1/2	- 00016	+.00016	00032	- 00008	+ 00008	00016	- 00083	- 00043	00040	- 00043	- 00020	.00023	-.00020	- 00008	.00012	- 00008	+.00012	00020	+ 00012	+ 00024	.00012	+ 00024	+ 00039	00015	+ 00039	+ 00059	.00020
9/64	1/4	- 00024	+ 00024	.00048	- 00012	+ 00012	00024	- 00122	- 00063	.00059	- 00063	- 00031	.00032	-.00031	-.00012	.00019	- 00012	+ 00020	.00032	+ 00020	+ 00035	.00015	+ 00035	+ 00059	00024	+.00059	+ 00098	.00039
17/64	27/64	- 00033	+ 00033	00066	- 00017	+ 00016	00033	- 00165	-.00087	.00078	- 00087	- 00043	.00044	-.00043	-.00016	00027	- 00016	+ 00028	00044	+ 00028	+ 00047	00019	+ 00047	+ 00063	00036	+.00063	+ 00146	.00082
7/16	23/32	- 00043	+ 00043	00086	- 00022	+.00021	.00043	- 00216	- 00119	.00097	- 00119	- 00059	.00060	-.00059	- 00020	.00039	- 00020	+ 00032	.00052	+ 00032	+ 00059	.00027	+ 00059	+.00110	00051	+.00110	+ 00197	.00087
47/64	1 3/16	- 00055	+.00055	.00110	-.00028	+.00027	.00055	- 00274	- 00157	.00117	- 00157	- 00078	.00079	-.00078	- 00025	.00053	- 00025	+.00032	.00057	+ 00032	+.00071	00039	- 00071	+.00141	.00070	+ 00141	+ 00253	.00112
1 13/64	1 37/64	-.00068	+ 00068	.00136	- 00034	+ 00034	.00068	- 00334	- 00196	.00138	- 00196	- 00098	.00098	- 00098	- 00031	00067	- 00031	+ 00031	.00062	+.00031	+.00086	00055	+ 00086	+ 00176	00090	+.00176	+ 00319	00143
1 29/32	2 61/64	- 00083	+.00083	00166	- 00042	+ 00041	.00083	- 00401	- 00236	.00165	- 00236	- 00118	.00118	-.00118	- 00039	.00079	- 00039	+.00027	.00066	+ 00027	+.00102	.00075	+ 00102	+ 00214	00112	+.00214	+.00394	.00180
2 31/32	4 17/32	- 00099	+.00099	00198	- 00050	+ 00049	00099	- 00472	- 00275	.00197	- 00275	- 00137	.00138	- 00137	-.00047	.00090	-.00047	+.00023	.00070	+ 00023	+ 00118	.00095	+ 00118	+ 00256	.00138	+.00256	+.00480	.00224
4 35/64	6 57/64	- 00118	+.00118	.00236	- 00059	+.00059	.00118	-.00551	- 00315	.00236	- 00315	- 00157	.00158	- 00157	- 00056	.00101	- 00056	+.00021	00077	+ 00021	+.00137	.00116	+.00127	+.00303	.00166	+.00303	+.00579	.00276
6 29/32	10 7/16	- 00138	+.00138	.00276	- 00069	+ 00069	.00138	-.00630	- 00355	.00275	- 00355	- 00177	.00178	- 00177	-.00066	.00111	-.00066	+.00020	.00086	+ 00020	+.00157	.00137	+.00157	+.00355	.00198	+.00355	+.00689	.00334
10 29/64	15 3/4	- 00158	+ 00158	00316	-.00079	+.00079	.00158	-.00709	-.00394	00315	- 00394	-.00197	00197	- 00197	-.00075	.00122	- 00075	+.00020	00095	+.00020	+.00177	00157	+ 00177	+ 00413	00236	+.00413	+ 00807	.00394

*) LIMIT PLUG GAGE "A" IS USED IN GENERAL FOR LESS ACCURATE WORK WHERE THE FUNCTION OF THE MACHINE PARTS ALLOWS LARGER TOLERANCES

**) LIMIT PLUG GAGE "B" IS USED FOR ACCURATE WORK WHERE SMALLER TOLERANCES ARE NECESSARY

TOLERANCE SYSTEM WITH THE HOLE AS BASIS

C. E. JOHANSSON ESKILSTUNA	DR. BY	DATE 10-2-1918	SCALE
	COP. BY B. N.	DRAWING NO 15—95	
	CH. BY H.		

Figure 82. Tolerance System (Table) with the Shaft as Basis—Johansson

The questionnaire prepared by the committee, as published in *Mechanical Engineering* for February, 1921, states that the practice of one well-known firm is as follows for various classes of fits:

Class No. 1 Loose Fits

Machined fits of agricultural, domestic, and other machinery of similar grade (wagons excepted)
Mining machinery
Controlling apparatus for marine work, etc.
Textile and rubber machinery, candy and bread machinery, and others of similar grade
Some parts of ordnance
General machinery for manufacturing.

Class No. 2 Medium Fits (Moving Parts)

2a High Speeds (over 600 r. p. m.) and Heavy Pressures
Electrical machinery
High-speed parts of woodworking machines

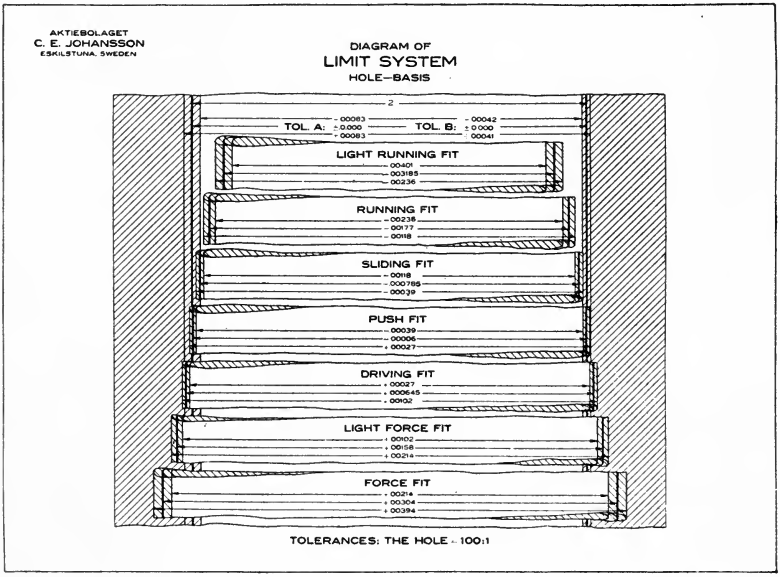


Figure 83. Diagram of Limit System—Hole Basis—Johansson

TOLERANCE SYSTEM WITH THE SHAFT AS BASIS
TABLE FOR TOLERANCES IN INCHES

Diam		LIMIT SNAP GAGE						TOLERANCE PLUG GAGES																				
		A *)			B *)			Loose Fit			Running Fit			Sliding Fit			Push Fit			Driving Fit			Press Fit			Force Fit		
		Min	Max	Tol	Min	Max	Tol	Min	Max	Tol	Min	Max.	Tol.	Min	Max	Tol.	Min	Max	Tol	Min	Max	Tol.	Min	Max	Tol.	Min	Max	Tol
3/64	1/8	+ 00018	- 00016	00032	+ 00008	- 00008	00016	+ 00083	+ 00043	00040	+ 00043	+ .00020	00023	+ 00020	+ 00008	00012	+ 00008	- 00012	.00020	- 00012	- 00024	00012	- 00024	- 00039	.00015	- 00039	- 00059	.00020
1/8	1/4	+ 00024	- 00024	00048	+ 00012	- 00012	00024	+ 00122	+ 00063	00059	+ 00063	+ 00031	00032	+ .00031	+ .00012	00019	+ 00012	- 00020	00032	- .00020	- 00035	00015	- 00035	- 00059	00024	- 00059	- .00098	.00039
1/4	27/64	+ 00033	- 00033	00066	+ 00017	- 00016	00033	+ 00165	+ 00087	.00078	+ 00087	+ 00043	00044	+ 00043	+ .00016	00027	+ .00016	- 00028	.00044	- 00028	- 00047	.00019	- .00047	- 00083	00036	- 00083	- 00145	00062
27/64	23/32	+ 00043	- 00043	00086	+ 00022	- 00021	00043	+ 00216	+ 00119	00097	+ 00119	+ 00059	00060	+ 00059	+ 00020	.00039	+ 00020	- 00032	.00052	- 00032	- 00059	00027	- 00059	- 00110	00051	- .00110	- 00197	00087
23/32	1 3/16	+ 00055	- 00055	00110	+ 00028	- 00027	00055	+ 00274	+ 00157	00117	+ 00157	+ 00078	00079	+ 00078	+ 00025	00053	+ 00025	- .00032	00057	- 00032	- 00071	.00039	- 00071	- 00141	00070	- 00141	- 00253	.00112
1 3/16	1 57/64	+ 00068	- 00068	00136	+ 00034	- 00034	00068	+ 00334	+ 00196	00138	+ 00196	+ 00098	00098	+ 00098	+ 00031	00067	+ .00031	- 00031	.00062	- 00031	- 00086	.00055	- 00086	- 00176	00090	- 00176	- .00319	00143
1 57/64	2 61/64	+ 00083	- 00083	00166	+ 00042	- 00041	00083	+ 00401	+ 00236	00165	+ 00236	+ 00118	00118	+ 00118	+ .00039	.00079	+ .00039	- 00027	00066	- 00027	- .00102	00075	- .00102	- 00214	00112	- 00214	- 00394	00180
3 61/64	4 17/32	+ 00099	- 00099	00198	+ 00050	- 00049	00099	+ 00472	+ 00275	00197	+ 00275	+ 00137	00138	+ 00137	+ 00047	00090	+ .00047	- 00023	00070	- 00023	- 00118	00095	- 00118	- 00256	00138	- 00256	- 00480	.00224
4 17/32	6 57/64	+ 00118	- 00118	00236	+ 00059	- 00059	00118	+ 00551	+ 00315	00236	+ 00315	+ 00157	00158	+ 00157	+ 00056	00101	+ 00056	- .00021	00077	- 00021	- 00137	00116	- 00137	- 00303	00166	- 00303	- 00570	.00278
6 57/84	10 7/16	+ 00138	- 00138	00276	+ 00069	- 00069	00138	+ 00630	+ 00355	00275	+ 00355	+ 00177	00178	+ 00177	+ 00066	00111	+ .00066	- .00020	00086	- .00020	- 00157	00137	- 00157	- .00355	00198	- .00355	- .00689	00334
10 7/16	15 3/4	+ 00158	- 00158	00316	+ 00079	- 00079	00158	+ 00709	+ 00394	00315	+ 00394	+ 00197	00197	+ 00197	+ 00075	00122	+ 00075	- 00020	00095	- .00020	- 00177	00157	- 00177	- .00413	00236	- 00413	- 00607	00394

*) LIMIT SNAP GAGE "A" IS USED IN GENERAL FOR LESS ACCURATE WORK WHERE THE FUNCTION OF THE MACHINE PARTS ALLOWS LARGER TOLERANCES

**) LIMIT SNAP GAGE "B" IS USED FOR ACCURATE WORK WHERE SMALLER TOLERANCES ARE NECESSARY

TOLERANCE SYSTEM WITH THE SHAFT AS BASIS			
C. E. JOHANSSON ESKILSTUNA	DR BY	DATE 11-14-1918	SCALE
	CON BY J B	DRAWING NO 15—96	
	CR BY		

Figure 84. Tolerance System (Table) with the Hole as Basis—Johansson

Sewing machines
Machine tools
Locomotives
Printing machinery
Automotive
Ordnance
General machinery for manufacturing.

A well-known firm uses allowances of 0.0005-0.004 in. up to 6 in. for work of this class.

CLASS NO. 2 MEDIUM FITS

2b Ordinary Speeds (under 600 r. p. m.) and Light Pressures

Machine tools
Printing presses and machinery
Typewriters, calculating machines, etc.
Locomotives
Automotive—general parts
Textiles, rubber machinery
Ordnance
General machinery for manufacturing.

A well-known firm uses allowance of 0.0005-0.0025 in. up to 6 in. for work of this class.

CLASS NO. 3 SNUG FITS

(Designated as the closest fit that can be assembled by hand.)

3a Slight Allowance (0.00025 to 0.00075 in.)

Gear trains and change gears for general work
Mating parts, fixed or not, moving on each other, such as studs for gears and levers, keys
General machinery for manufacturing.

3b Close Fit (commonly known as wringing fit, no allowance, not considered interchangeable manufacturing but selective assembling)

Crankshafts
Precision-ground machine spindles
Gears in index train of precision gear-cutting machines
Slots and tongues such as are used for grinding machines, milling machines, etc.
Surveying and scientific dental instruments, etc.
General machines for manufacturing.

Class No. 4 Tight Fits

4a Drive Fits for Light Sections
    Automotive
    Ordnance
    General machines for manufacturing.

A well-known firm uses negative allowance from 0.00025 to 0.001 in. up to 6 in.

4b Force Fits for Heavy Sections
    Locomotive and car wheels
    Crank disks, armatures, flywheels
    Automotive
    Ordnance
    General machines for manufacturing.

A well-known firm uses negative allowance from 0.00075 to 0.005 in. up to 6 in.

4c Shrink Fits
    Locomotive tires and similar work
    Ordnance.

A well-known concern's practice is as follows: Where thickness exceeds 3/8 in., 0.0005 to 0.005 in. up to 6 in. in diameter. Where thickness is less than 3/8 in., up to 6 in. in diameter, 0.00025 in. to 0.0015 in.

It is to be hoped that this committee will cover the field of practicable precision of machining processes in considerable detail, and that this data will be kept up to date for the guidance of industry.

Precautions for Obtaining Precise Work

Among the general considerations to which attention should be given in bringing processes under control, one of the most evident, but one of the least observed, is to make the tool set-up a fool-proof one. There is so much need of all available time, care, and attention to details in close work that everything which can be done to free the operator from unnecessary strain in these particulars should be done. Not once but several times during the last years, the writer has heard superintendents or engineers say something like this:

> We can't seem to get results in the . . . . shop, and it is due to nothing but the foremen's failure to handle their men so as to get the answer. I know that the tools and gages are O.K., because I have made the complete part myself. Only yesterday I carried a piece through each operation personally and it came to the gages in fine shape. That proves everything is all right except that the shop executives don't exercise proper control over production.

As a matter of fact it proves nothing of the sort. All it does prove is that a skilful mechanic with years of experience can make a good part with the facilities provided. We knew that already. It has been done before.

Having detected the fallacy in the above remark, let us consider some of the things that such a test does not prove. In the first place, such a test does not show that unskilled operators can produce good work with the available equipment, nor does it prove that they will do so, especially if the wage system is such as to create a strong incentive for quantity of individual output. Most large-scale enterprises are conducted in a way to place a heavy emphasis on quantity of output. Nor does it indicate that the gages will be applied correctly by unskilled inspectors, nor that the available machine-setters and adjusters are trained to their work, nor that the shop arrangements and system are suitable for the general conditions as they exist in fact. In short, we are faced with a condition and not a theory. The solution lies in shaping everything to the actual environment. We must deal with things as they are, not as they used to be, or as they might be under different circumstances.

There is a way to meet the situation. When a task calls for greater skill than the available labor possesses, split the task into simple operations, any one of which will be within the capacity of such labor. This is the old, well-known, thoroughly tested, but little appreciated, cure for the condition—namely, a judicious application of division of labor. Similarly the principle of analyzing everything into simpler parts must be used to the end that each man's work will be well within his capacity, for it is through these men that the result will be achieved, and only through them. This simplifying process must be used in every element of the project—tools, gages, shop arrangement, shop systems, and organization. This much is axiomatic; nor should it be forgotten that such a differentiation greatly complicates the problem of co-ordinating the different constituent parts of the work.

In the second place, the tool and gage designers can help safeguard standards by eliminating process hand-work as much as possible, and by simplifying the tool and gage designs in so far as is practicable. Tool equipment should be simple and much more rugged than heretofore. Forcing light work should be made difficult. The factor of careless machine operation should be discounted by skilful designing for chip clearances and bedding points, because careful placing of work cannot be counted upon. The same line of thought applies to gages—the complicated gage with several gaging points, flush pins, etc., should give way to single measurement limit gages. Adjustable limit gages can be used to great advantage. In some cases working gages should have closer limits than salvage gages, but this is a practice that must be settled with reference to individual problems. Templates of form, outline, or profile should be preserved systematically and checked methodically for both cutters and gages. In this checking there should be employed the most sensitive tactile skill obtainable.

In the endeavor to make things fool-proof—a process in which nothing must be taken for granted and every detail carefully considered because the effect of such details is multiplied enormously through repetition, so that little things determine results—there is usually no occasion for continuing to worry about such matters as keeping the bedding points free from chips. A little care in the design of the tool will permit chips to fall away from the work instead of onto the bedding surfaces. Very often an auxiliary device may be provided for blowing the chips away automatically.

The work itself, as well as the tool, should be designed so as to reduce the chance of error from forcing a tool and so as to permit accurate holding of the work when it is presented to the tool. It is good practice when possible to work from holes as locating points for a series of operations. The objection to this practice for many operations lies in the fact that the work is soft for machining, and the holes wear. A little ingenuity will avoid this trouble. Very frequently a false hole or slot may be created in the place where the metal will be cut away later. When this cannot be done, there seems no reason why holding lugs cannot be added to the part, hollow-milled in a jig, used for bedding points throughout the machining, and finally cut off. In fact, there are cases where this has been done.

The Principle of Balance

For very careful and accurate control of a process used in creating a uniform product, a nice balance should be provided, as a direct and practicable application of Newton's third law of motion—"action and reaction are equal and opposite." Now in a machine tool the whole supporting structure which presents the work to the tool should provide a wall against which to build up the pressure imposed by the tool itself. In laying out the equipment for any process this principle should be carefully considered if a nicely balanced application of force must be made. The same idea is applicable in many other processes where irregular or jerky action may be avoided by balancing the opposing forces.

When difficulties are encountered in bringing processes under uniform control, one good way of deciding whether the method is correct is to carry it to the extreme in the opposite direction. Thus, Professor John E. Sweet states:

> To demonstrate that this is right, a good way in this, as in most mechanical problems, is to carry the wrong way to an extreme and note the consequences, and it will be found that the right way has already been carried to the extreme in the right direction.

The Effect of Finish on Accuracy

One of the most important points to be observed in instructing machine operators is care of the work. Attention to quality brings about the creation of finer work and that of itself usually demands respect; nevertheless our factories are full of workmen who would treat bricks with much more respect than they do steel parts—bricks would break if they were thrown around, whereas steel parts only become dented. But dents and scratches require more polishing, more grinding, and uniformity of dimension is lost. On the machine itself one way to insure greater uniformity is to remove vibration, but this is merely another application of the principle of balance referred to above. To meet the same condition, it is probable that finishing operations, such as automatic polishing and tumbling, will see wider application and greater refinement in the future because of their marked advantages.

Quick Checks on Precision

It will be found useful, from time to time, to apply the method of taking check "borings" in the factory, in order to develop additional information as to what requires correction for greater uniformity. It is suggested, for example, that some important part be independently checked and measured, beginning with the tools and gages and concluding with the *measurement of the parts themselves*, proceeding from operation to operation straight through to the completely assembled mechanism. There are other quick tests which may be applied. For example, a check on the uniformity of heat treatment may be obtained by supporting like parts in like positions for the same length of time and measuring their sag. It was in connection with getting data for such a test to check up the work of a certain factory that the information relative to sag of crank-shafts (referred to on pages 332 and 333 of this chapter) was obtained. The work as performed in the Packard shops was taken as standard in comparing work in a somewhat similar shop doing cruder work and located many hundreds of miles away. The results were very interesting indeed, because of their divergence and lack of uniformity.

CHAPTER XXI

THE CONTROL OF COLOR[1]

Application of Measurement to Other Qualities

Up to this point we have dealt with dimension as exemplifying cases where excellent means of measurement exist. Very often in such work special tool equipment is provided which works from a pattern made with the greatest care, the tools almost automatically following this pattern over and over. Even in the case of straight machine work without special tools, a high degree of precision is possible. Many other processes, however, have not yet been regulated with such precision. Bringing them under uniform control involves the process outlined in Chapter XIII, "Measurement and Errors," but before we are in a position to tabulate the various errors in the work produced by such operations or processes, it is necessary to develop some systematic method of *recording* both the kinds of errors and their relative occurrence both as to frequency and size. Color is a typical instance of this general class of work—a class which is extremely large in industry today, but which will be gradually reduced and brought under control as time goes on and the fight continues for greater production of better and more uniform qualities at a lower expenditure of effort.

In discussing the subject of measurement in Chapter XIII, it was shown that the control of any quality depends upon measurement as a starting point, and that measurement itself is a process beginning with the selection of an

---

[1] For an authoritative and most interesting treatise on the subject of color, the reader is referred to "Color and Its Applications," by M. Luckiesh, Director of Applied Science, Nela Research Laboratories of the National Lamp Works, General Electric Company.

arbitrarily chosen sample which is suitable as a standard of comparison for the quality under consideration. The next stage consists in developing a scale of values to permit measures of the quality to be stated in figures, and the final step is the development of impersonal measuring instruments. Dimension and weight, for example, have reached the last stage and very precise instrumental means are available for control purposes. Many other qualities, however, have barely reached the first stage of control by direct comparison with standard samples.

Appearance and Color

Of the several qualities that define the character of the factory product, certainly appearance is not the least important, and throughout a wide range of industries color is one of the important, if not the most important, quality which goes to make up appearance. Frequently, as in the case of chemicals and food products, color is an indication of other qualities in addition to appearance. Just how valuable a uniformly good color is as a commercial asset must be decided in the light of the special business situation. If color is worth controlling to a commercially uniform standard, then, as in the case of the qualities of dimension and form, we must define the standard which is to be followed, adopt processes for its creation that are uniformly controllable within the limits set, and provide a means of comparing the results by some suitable method of measuring.

Now measurement, as we have seen, is the proper starting point, and this involves the selection of a standard for comparison. If the standard is one which permits comparisons in figures, like the standard of length, so much the better. Then, instead of saying that an article is "slightly red" or a "little too green," we should be able to say *how* red it is, or *how much* too green. In that event we might hope to do with color what we have already accomplished with dimension, by working out the relationship between cause and effect. When it became possible to measure in ten-thousandths of an inch, we were presently in a position to work to that degree of accuracy—but not until then. Hence, in the case of color, the first step is to search for a proper basis of establishing such a standard of measurement.

Standard Samples

The simplest scheme would be to select a series of samples of the goods and grade them according to an arbitrary scale with reference to their appearance. Thus, ten samples arranged in a scale, in which each one differed from its neighbors by an equal amount of color, or luster, or smoothness, would provide us for comparative purposes with a scale of ten. Sometimes, a simple scheme such as this is all that conditions warrant, or perhaps it may be the best we can do; but it is entirely too coarse for precise and careful work. The lack of quantitative comparison greatly hampers any systematic attempt to evaluate deviations from standard and therefore to develop means for correcting such errors.

The Standard Color Card

The first movement in our industries for standardizing color for commercial purposes was made by The Textile Color Card Association of the United States, in developing a series of color cards which find wide use in most of the industries engaged in the manufacture of clothing and the basic materials of clothing. The fact that the paint, paper, and some other industries are making use of these color cards indicates their great practical value in reducing losses of various sorts. A numbering system is used in accordance with the following scale, standard colors being indicated by the letter *S* used as a prefix:

1st, 2nd, 3rd figures indicate the relative proportion of the component parts of a color:

1	White
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet
8	Gray
9	Black
0	No change

4th figure indicates the strength of the color designated by the first three figures:

1	Lightest
2	Second lightest
3	Light
4	Medium light
5	Medium
6	Medium dark
7	Dark
8	Second darkest
9	Darkest

To illustrate: Turquoise is "S. 6153"

6	1	5	3
BLUE	WHITE	GREEN	LIGHT
Principal Color	Principal Blend	Secondary Blend	Strength

The establishment of this systematic classification of colors for commercial purposes in the textile and allied industries is evidence of a highly commendable and far-sighted attitude toward solving the problem of color control. It will be noted, however, that in its last analysis any such classification depends upon the integrity of the standard samples supplied by the color cards themselves; the samples on the various cards must be alike for a given color, and each sample should be as little likely as possible to change as time goes on. The necessity for such assumptions can only be offset when the art has been advanced to a point where construction formulas for the reproduction of standard colors can be stated in terms of the exact proportions of the color-creating factors, and the colors themselves can be stated in impersonal figures.

A similar practical contribution towards color standardization was made by the late A. H. Munsell in the form of a color notation and an atlas of colors.[2] The atlas consists

---

[2] A. H. Munsell, "A Color Notation"; "The Atlas of the Munsell Color System."

of a series of charts in which colored samples are arranged in accordance with the Munsell color system. A scientific investigation of this system was undertaken by the Bureau of Standards and a very interesting report of it is published under the title of "An Examination of the Munsell Color System."[3]

Dangers of Standard Samples

The great trouble with standard samples is that we have no assurance that they are not continuously changing. On the contrary, we can be sure that they do change, and by such insidiously small increments that the changes are hard to detect. The sample is one thing today and something else almost before we know it. More dangerous yet, we may not know that its appearance has altered. In many plants.where this is fully appreciated master standards are kept. When it is the custom of the color expert to carry in his mind and to allow for any slight difference between the working and the master sample, the practice usually leads to interesting results.

Just as in the case of dimension, precise control of color requires a more absolute method of measurement. But to fix upon that, we must first get some idea of what makes color. Perhaps this would be expressed better by saying that our first problem is to determine, as nearly as we can, what color is.

What Is Color?

If a truism may be pardoned, color (and for that matter any quality which goes to make up appearance) is something which you see with your eyes. What else can it be? And the eye is sensitive only to light. It makes no differ-

---

[3] Bureau of Standards, "Technologic Paper No. 167," by Irwin G. Priest, K. S. Gibson, and H. J. McNicholas.

ence whether the particular kind of appearance we are dealing with is caused by a mechanical treatment of the surface of the article, or by stains, pigments, or dyes, or whether the subjective sensation of color is due to some inherent property of the raw material from which the article is made. But irrespective of the cause of color, the effect is light, so that as a starting point the use of optical methods is indicated at once as the only sure way of attacking the problem, both for standardizing the final result and for measuring the effects as a step toward controlling the agents used to create that result. Thus, color considered as the final effect must be reduced to a measured basis for comparison with a view to studying the causes of errors or differences, as well as the means for modifying errors and making the results more uniform.

In approaching the subject, then, from the standpoint of color considered as light, it should be observed that three principal factors are involved, since without any one of these three there will be no color—first, the illuminant, or source of light, which may be regarded as the effector; second, the subject, or the thing which is said to have color; third, the eye of the observer, which, as the receptor of the sensation, is merely a lenticular instrument adjustable within limits but varying from individual to individual and from time to time even for the same individual. Let us now consider each of these subjects separately.

The Illuminant

The sensation of light is now generally considered to be caused by a form of radiant energy which occurs in a variety of wave lengths and frequencies of vibration, but which passes through empty space without appreciable change in velocity. The nervous system of the eye is sensitive to this radiant energy only within a comparatively narrow range, as indicated in Figure 85.[4] Beyond this range, in one direction, are found the ultra-violet rays, whose presence is made known by their chemical or actinic properties. In the other direction are the infra-red rays, which are noticeable on account of their heating effect. It will be noted also from the relative visibility curve (Figure 85) that the eye is not equally sensitive to all the visible rays, but that these rays begin to become visible at the edge of the ultra-violet region, reach a maximum effect in the greens and yellows, and then gradually fade away and disappear at the beginning of the infra-red region.

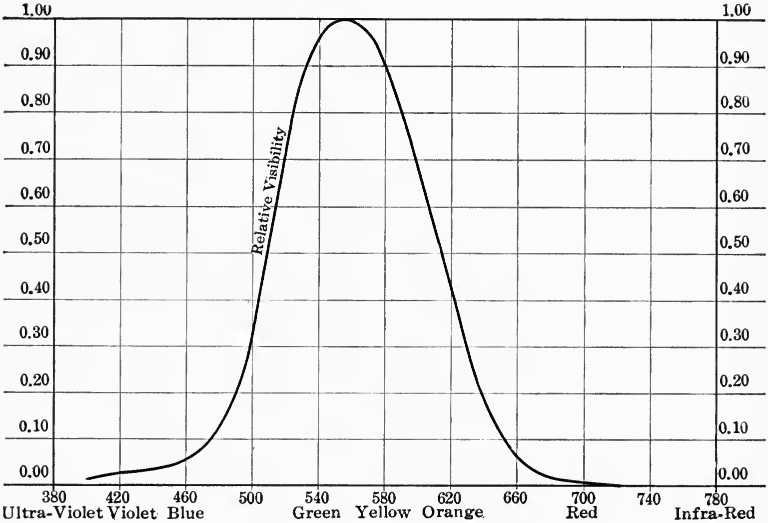


Figure 85. Chart for Spectral Analysis of Color Showing Relative Visibility Curve

Since radiant energy is transmitted in the form of waves, and since each wave length of the visible rays is associated with a very definite color sensation, we have a

---

[4] This follows the chart used by the Bureau of Standards in the Munsell color examination already referred to.

convenient way of exactly indicating any particular hue due to a given wave length, or a small group of similar wave lengths, by stating that wave length in figures. This is especially useful since the eye itself is capable of a very sensitive differentiation between the various wave lengths. The lower scale of Figure 85 shows the wave lengths associated with the principal colors. The figures stated for wave lengths are in millimicrons, or millionths of a millimeter (about a 25-millionth of an inch).

White light is, of course, a mixture of all these rays in more or less definite proportions, depending upon the source of light. For practical purposes it may be taken as the effect on the eye of average noon daylight. It should be noted also in this preliminary summary that daylight itself is varying all the time and from place to place. Consequently, it is usually anything else but pure white light.

This fact must be remembered in connection with any careful work with color for the reason that, no matter what the subject is, only such color can be seen as has corresponding colored rays in the source of the illuminant. Thus, a so-called green surface, which reflects only green light, if illuminated by a red light will appear black, because no light is reflected. Consequently, the importance of having a standard illuminant for color work becomes obvious, and as it is merely common sense to keep all of our work in consonance with the ordinary conditions with which we are acquainted, a light source as nearly as may be like natural north sky daylight is generally taken as most suitable for color-matching and study. Such lights are obtainable commercially and are made by filtering out the rays which are in excess of those contained in average north sky daylight. When the light is reflected for instrumental use, it is the usual practice to employ a white magnesia block or some equivalent, as the standard white for comparison.

The Subject

In studying the characteristics which cause an object to have color, let us consider the limiting cases first. A perfect mirror would reflect practically all of the light from the illuminant and the result would be the same as looking at the illuminant. At the other extreme, a perfectly black surface would absorb all of the light and reflect none. If the object, on the other hand, reflected only a portion of the incident light without changing the relative distribution of the constituent light rays, the color of the object would not be different from that of the illuminant, but it would be less bright. Thus, if the illuminant were a white light the object would appear gray. We have now defined white light or white, black or the absence of light, and the neutral grays, as intermediate stages between the two extremes of white and black.

Suppose, however, the subject does not equally reflect all of the incident rays, but that it absorbs some of them and reflects the remainder. This process of selective absorption and reflection brings about an unbalanced distribution of the light rays as compared with the normal distribution in white light, with the result that some one group of rays becomes dominant. For example, if a red predominates in the light reflected by the subject, we say that the subject is colored red.

If the subject is a fluid, essentially the same process of selection takes place, except that in this case certain rays are absorbed and others transmitted so that we have selective absorption and transmission. That is to say, the words used are different, but the ideas are identical.

Color is caused in several other ways, such as by the interference of light rays (as for example, by a drop of oil on water), or by dispersion of light (with a prism), or as in the case of fluorescent and phosphorescent substances, or by polarization, to mention a few instances of color phenomena. In industrial work, however, selective absorption is by far the most frequently encountered.

The Eye

For our present purpose the eye may be considered as an optical instrument of lenticular form which is the intermediary between the brain and the external causes of light and color. The eye views a group of colored rays, or rays of different wave lengths, solely as an intermingled group and sees only the average result of the mixture, e.g., white light. In this sense it is a synthetic instrument incapable of analyzing the light presented to it, or of separating out the individual rays. In order to accomplish such analysis, the eye requires the assistance of an instrumental device such as the prism, or the ruled grating, or a color filter, as will be shown presently. Without such a device it is impossible to view the constituent colors of any mixture separately. Thus when one mixes a blue powder with a yellow, the eye presently sees only the green effect of the combination.

The Color Constants

On the other hand, the eye can analyze color with reference to three so-called color constants known under various terms as set forth below. Says Dr. M. Luckiesh:

> One of the greatest needs in the art and science of color is a standardization of the terms used in describing the quality of colors and an accurate system of color notation. . . . The quality of any color can be accurately described by determining its hue, saturation or purity, and its brightness.

Hue (sometimes called "color tone" or "quality") is the kind of color with reference to the spectral color scale. Thus a color whose predominating group of rays are in the red is said to have red as the dominant hue. When color is measured instrumentally the dominant hue is stated in figures as the wave length of the spectral color corresponding to the dominant hue. The hues of the non-spectral purples are handled by taking the dominant hues of their complementary [5] colors.

Purity (also called "saturation," "chroma," "strength," or "intensity") indicates how closely the constituent rays approximate to none but rays of the dominant hue. Spectral colors are pure, but other colors are composed of many other rays than those which predominate—hence the purer the color, the nearer it is in composition to the spectral color of corresponding hue.

In instrumental measurements of color, since any color may be matched by diluting a given spectral color with white light, the relative quantity of white light required for the match is used as the measure of purity and is expressed in figures as a percentage. The purity becomes greater as the percentage of white light required for a match becomes less. As stated under "hue," purples form an exception, but these are handled by working in terms of the corresponding complementary colors.

Brightness (also called "luminosity," "value," or "tone") relates to the total amount of light reflected or transmitted, regardless of hue or purity—thus a neutral gray photograph of colored objects shows variations in brightness only. It is measured by comparing the subject with a surface of known brightness, the result being expressed as a percentage of the standard of brightness.

The ideas conveyed by the above definitions will be clarified by referring to the graphs shown in Figure 86. Curve *a* is a gray because it contains equal proportions of all the special colors and differs from white only in reduced *brightness*. Curves *b*, *c*, and *d*, are all colors of red *hue*, of which *d*

---

[5] A complementary color may be defined by stating that when white light is split into two parts the colors thus formed are complementary to each other.

is the *brightest*, since it reflects the most light, and *c* is the *purest* because it has the least admixture of other rays than red rays. Curve *e* is a blue. Differences in purity may be accentuated by plotting the curves on logarithmic paper.

Tints are formed by diluting a color with white, i.e., by reducing the purity; e.g., spectral colors are pure—pinks, which are tints of red, are not found in the spectrum. *Shades* are produced by admixing black, i.e., by reducing brightness without affecting hue or purity.

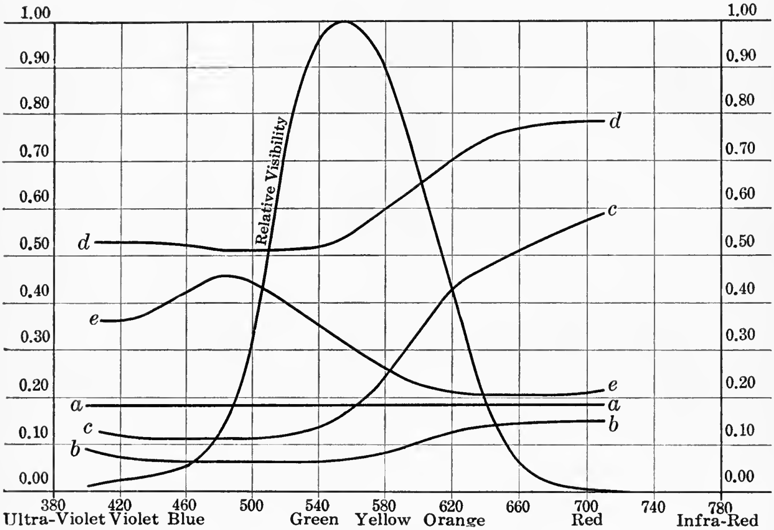


Figure 86. Chart for Spectral Analysis of Color Showing Typical Color Analyses Plotted as Curves

The above facts are of interest in the practical study of color, for the reason that it would seem desirable to analyze and measure color in terms of the dimensions, such as hue, purity, and brightness, which the eye is capable of seeing without instrumental assistance. This would appear to be the natural way to approach color problems instead of using some system of combining primary colors, but in either case practical difficulties must be overcome in any given industrial application.

Color Vision

As might be expected, the human eye is quite variable in the way in which it sees color. It varies from time to time with the same individual and very seriously from individual to individual. The lack of a definite and precise terminology for color among the general public has resulted in a looseness of usage which accentuates this source of personal error. Many cases of so-called color blindness have been found to be nothing but lack of education of the eye.

The eye of a highly trained color expert or matcher is extremely sensitive to very small color differences and distinctions. This fact is, in the writer's opinion, one of the reasons why color in the arts has not been reduced to a basis of measurement to any considerable extent, outside of the physics laboratory. The chemistry of dyestuffs and pigments has received very intensive study, because for their intelligent application such study has been absolutely necessary; but the very ability to perceive small differences in the color effects resulting from the use of such tinctorial agents has lead to ignoring the very desirable and vitally important features of measurement. Thus, in the factory one hears such expressions as the following: "The color is a little too much on the red"—"It has a slight red cast"—"It is too fine"—"Too nice"—"Too quiet"—"Not enough depth"—and so on. The absence of any means for quantitative measurement, or the failure to develop and utilize means for stating in figures how much these color errors are, has stood in the way of progress toward finding out the proper adjustments and corrections of processes so that they could be standardized.

Methods of Analyzing Color

Color can be analyzed for purposes of study in much the same way that it is created, if use is made of various devices which break up light into its constituent parts. Thus, diffraction by the use of a parallel-ruled grating is one means which may be used, but the best known device is a simple prism when used as a means of dispersion. As shown in Figure 87, light rays of different wave lengths bend differently in passing through a prism of glass of triangular cross-section and thus are dispersed in a systematic way. The consequence is that the rays of different wave length are separated so that viewing a ray of light which has been dispersed by a prism shows a band of separate colors which is known as the "spectrum."

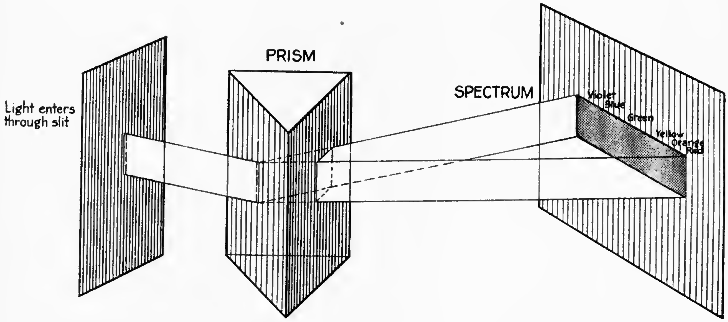


Figure 87. Sketch of Prism and Spectrum

In other words, each color in the spectrum is a small group of light of similar wave lengths and is the nearest to a truly pure color to be found in nature. It is for this reason that purity, as defined on page 356, is expressed as a percentage, indicating its nearness in this respect to the spectral color of the same hue, and showing its degree of freedom from all other colors except the dominant hue.

The use of a simple piece of glass to produce a spectrum should be a constant reminder that the world is not only given to us as a great problem to solve, but also that the means of working out the problem are at hand and in fact very often exist in very simple and readily accessible form. Who would suspect that the ordinary white light of a gloomy day contains the hidden beauty which is to be found only in the pure spectral colors? The eye cannot see them without the assistance of very simple means, yet it was not until 1666 that Sir Isaac Newton used the prism to create a rainbow at will.

Analysis by Primary Colors

Color may be analyzed also by allowing light to pass through monochromatic filters. Viewing a subject or, more properly speaking, the ray of light from the subject through a filter (of stained glass or gelatin) which allows only green to pass, will give a very good idea of the amount of green present. Similarly, the use of other color filters permits a more complete analysis. Further, as is well known, it is possible to match any hue with a suitable combination of three primary colors. There are two or three things to remember, however, when speaking of primary colors. First, since the eye is an averaging instrument, there are several combinations of three colors which will yield the same result *to the eye* although upon analysis the spectral composition would prove to be quite different in each case. In other words, the same effect may be brought about by mixture of different sets of carefully selected colors. Second, colored lights may be mixed by addition of colored light rays and each addition tends toward the production of white. This will be evident from a consideration of the fact that white light itself is the summation of all the colored rays. The "additive" primaries are red, green, and blue. Third, color as ordinarily produced in the arts is the result, on the other hand, of the successive subtraction of light, due to the fact that each stain, dyestuff, or pigment selectively absorbs some of the incident light. Consequently, as Paterson[6] says, "every admixture of colour is a step towards darkness." The "subtractive" primary colors are ordinarily termed red, yellow, and blue. Luckiesh states, however, that they would be more exactly described as purple, yellow, and blue-green. These subtractive primaries are what most people ordinarily call the primary colors. As a matter of fact, they are only primaries for color-mixing of stains, pigments, and dyes. They are, moreover, the complementaries of the additive primaries for mixing colored lights.[7]

Instruments for Measuring Color

A large number of instruments for analyzing and measuring color are in constant use in the physics laboratory. These instruments are based on various adaptations of the principles outlined above. Although some of them have been employed in the arts, their main use has been in laboratory work. In general, they have not been used to anything like the extent that the resultant economies to be obtained from their application would warrant. This is partly owing, as already stated, to the failure of manufacturers to realize the vital importance of measurement in bringing some of our long-established processes under more precise technical control, and partly owing to the fact that some of the instruments require modification to make them more suitable for general industrial use, as will be presently indicated.

Basic control instruments belong to the spectrometer class. Some of them look quite complicated, but they really

---

[6] See David Paterson, "Textile Colour Mixing," p. 34.

[7] "Color and Its Applications," by M. Luckiesh, Chapter III.

consist of a simple application of some equally simple optical parts. A prism (or sometimes a grating) is used to break light up into its constituent colored rays, lenses mounted in telescopes are used to magnify the image of the spectrum thus created by the prism, and these elements of the instrument are mounted in such an adjustable relation to each other that a scale can be marked off on the instrument to show the wave length of each color. To accomplish the latter purpose, either the telescope or the prism is revolved to bring each spectral color into the viewing axes, and the corresponding wave length is shown on a calibrated scale.

The Spectrophotometer

The spectrophotometer is an instrument for breaking up light from the subject into its constituent rays (this is the spectroscopic part of the instrument) and for measuring the quantity of each part of such light against, or as a percentage of the same rays from a standard white light (this is the photometric part of the instrument). Obviously, by reason of the fact that it measures the relative quantity of each colored ray present in any light, the spectrophotometer is the basic control instrument for color. As shown in Figure 88, it consists of two spectroscopes mounted so that the intensity of rays of like wave length in the two spectra can be compared by placing them side by side in the field of view. Light is taken from a standard source S and from the subject S_1. The two rays enter a Lummer-Brodhun photometer cube so arranged that after being dispersed by the prism they may be viewed in juxtaposition through the telescope. It is thus possible to select one spectral color after another and by the use of a flicker or other type of photometer, to measure the quantity of said color as a percentage of a standard spectral color.

The result obtained is more clearly shown by reference to Figure 86, in which the curves of several spectrophotometric measurements are plotted.

The Monochromatic Colorimeter

As has been seen, the spectrophotometer gives us a complete analysis of any color, and when the results are plotted graphically it is possible to get a very fair idea of the dominant hue, the purity, and the brightness. To measure hue, purity, and brightness of a color in terms of figures directly and without computation requires, however, one other instrument, which may be regarded as the second basic control instrument, known as the monochromatic

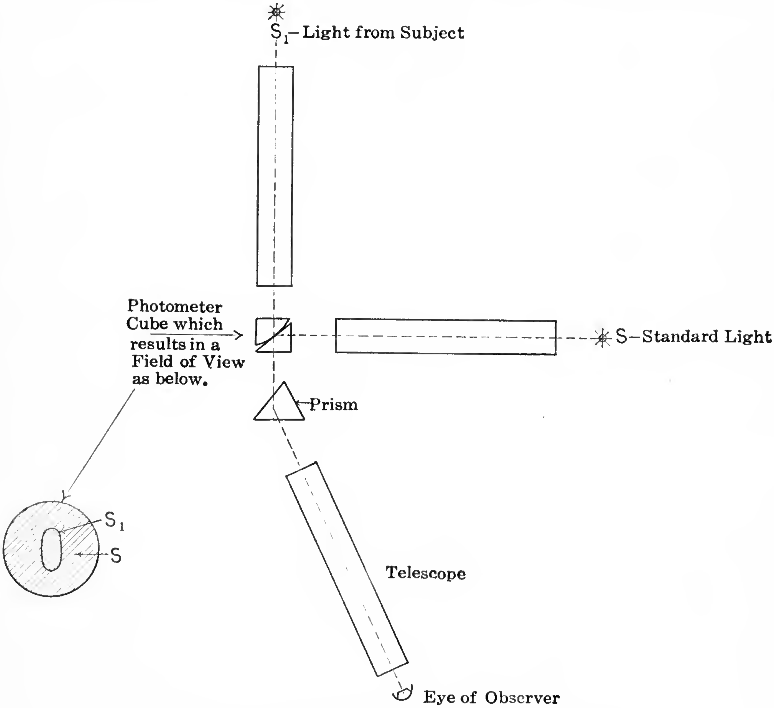


Figure 88. Diagram of Spectrophotometer
(After Luckiesh)

colorimeter, of which the Nutting colorimeter (made by Adam Hilger, Ltd., London) is doubtless the latest and best known type. It consists essentially of a spectrophotometer with an additional arm to permit the admixture of a known amount of white light. Briefly stated, the hue of the subject is matched by varying the angular position of one arm, the purity is matched by varying the amount of white light added, on the principle that any hue can be matched by mixing white light in suitable proportion with the corresponding spectral hue, and the brightness is measured by the photometer attachment.

By means of these two instruments it is possible completely to analyze a color, and to state the color in terms of figures for the constants, hue, purity, and brightness. Needless to say, the use of figures as a measure of color in the arts should be accompanied by the use of plus and minus limits, as in dimensional work. Quality varies in the case of color just as it does in dimensional work, and the same phenomena must be met by practices alike in principle. The precision used will vary with the character of the commercial requirements for the given case and with the economic and technical possibilities of the processes.

The spectroscopic type of instrument is available for control laboratory purposes. This apparatus may be used as a guide in the control of quality of basic materials, such as dyestuffs and pigments, and for the completed product, with this qualification that many of the colors used in the arts are what are known as "mode" or "fashion" colors, most of which are quite dark. A great many textiles, for example, reflect less than 5 per cent of the incident light and it is difficult to get precise measurements with instruments which themselves absorb a quantity of light in the optical parts. A sufficiently intense demand from the arts will doubtless bring about the development of instruments of this sort more suitable for general application and in which the light from a larger area is concentrated in order to provide sufficient light to analyze and measure with ease and precision. There is need also for an instrument which will more readily permit of analyzing color in terms of the reagents used to create that color. Such an instrument also will be merely an improved adaptation of existing instruments and will be used in conjunction with a technique for working out quantitatively the combinations of pigments, dyes, or stains required to produce a given color effect.

Auxiliary Instruments

A number of devices are available in which the method of analysis consists in filtering through monochromatic filters. It should be observed, however, that such instruments do not analyze color in terms of hue, purity, and brightness as the eye sees color. They are, nevertheless, suited to certain applications in the arts, although they do not give the same complete range of measurement obtainable by the use of the spectrophotometer.

A useful instrument for many sorts of industrial purposes is known as the Hess-Ives Tint-Photometer. With this instrument it is possible to take readings of a subject as a percentage of the light reflected from a block of magnesia, and to compute the brightness therefrom. For bright flat colors, such an instrument yields a measurement of the color in terms of the primaries, red, green, and blue-violet, expressed as percentages of light taken through the same filters from the 100 per cent magnesia standard.

Other filters are provided for special industrial uses. For the darker shades or mode colors the measurements would be less than 5 per cent and hence would be useless for practical purposes. For work of this sort, a neutral gray standard may be constructed for use instead of the magnesia block, care being taken to see that the new standard is a true gray. It may be made by mixing lamp black with magnesia (carbonate or oxide). The use of a gray standard will throw the measurement well up into the scale. The author had used such standards which reflected less than 10 per cent of the magnesia standard and consequently multiplied the scale readings by 10 or more. The instrument may be used also for direct comparisons between a standard sample and the unknown subject.

Reduction of Errors in Color Work

Those who are interested in color work in industry would do well to make a close study of the phenomena involved from the physical standpoint, i.e., the study of color from the standpoint of light. Such a study should reveal the need of a more definite and precise terminology, the desirability of measurement in all its applications, and for the evolution of simple measuring apparatus, as well as of evolving apparatus more nearly suited to the needs of applied science.

When instrumental means are not used, inspectors in color-matching should be checked by actual test, even if more exact methods are not available. In this manner, the dangers of large personal errors due to idiosyncrasies of color vision may be minimized. Everyone working with color should be warned against the errors due to contrast, and instructed in the relief of eye fatigue, caused by looking at brilliant red, for example, by such a simple expedient as an occasional glance at an equally brilliant green. The value of standardized matching lights would hardly seem to need mentioning.

Such a study as that recommended will reveal industry's great need for the measurement of color in terms of figures. The possibilities for resulting economy in the arts are astonishing.

Standards of Appearance

Needless to say the extension of the same precise control scheme to other industrial problems besides color holds forth interesting opportunities for reducing errors and minimizing losses. It is not at all unlikely that a similar application of optical methods may be profitably developed to reduce various sorts of finishes, such as polished metal surfaces, to a basis of definite standardization. Optical instruments of other sorts have already been used extensively in a variety of industrial applications (e.g., the sugar and oil industries) and it is only reasonable to expect the adoption of such methods in other fields.

Appearance, as previously indicated, is in reality nothing but light, but the qualities of this light which characterize a given appearance may be caused by a variety of things, such as the finish and texture of the surface, for example. That is to say, color is but one of the qualities which go to make up appearance; nevertheless, all of these qualities are subject to the same general treatment of analysis (both qualitative and quantitative), followed by the ascertainment of the relations between the final results and the causes thereof—in short, by the usual methods of science.

CHAPTER XXII

THE SCIENTIFIC ATTITUDE OF MIND AND ITS METHODS

Science and the Arts

It is usual for the people of the present day to observe with pride the progress made in the arts and sciences during the last century—a story of advances greater probably than in all previous time, and made at a rate that is still accelerating. There are one or two aspects of this situation which are not so much of historical interest as they are of value in pointing the surest way to further and more rapid progress, especially in the manufacturing arts.

The first of these thoughts is that the recent rapid improvements in industry are dependent upon and followed after a great advance in the sciences. As Jevons says:

> A science teaches us to know, and an art to do, and all the more perfect sciences lead to the creation of corresponding useful arts. Astronomy is the foundation of the art of navigation. . . .

The industrial arts have existed on a broad scale for ages, but in former times science shows only as a dim light, from time to time and in scattered places. Modern manufacturing followed the wonderful scientific movement which began in force but a few generations ago; it has progressed only so far as it has applied these scientific discoveries.

The second and somewhat startling thought is that the arts, in large part at least, have whole-heartedly and strenuously resisted every attempt to introduce and apply the discoveries of science. Everyone is quite inured to the attitude of labor leaders in opposing the adoption of labor-saving devices, in spite of the fact that the greatest hope of the rank and file for a greater share of the good things of this world, lies in the production of more goods and better goods, *with less effort.* And the extra effort thus released is available to produce still other things which never existed before. This attitude is an old story and a stupid one, but it is not entirely what is referred to here. For the source of much opposition to the adoption of improvements, or in fact of any conscious preplanned program for advancing industry, is to be found in the attitude of industrial executives, from foreman to manager to owner—especially the latter, or scientific workers would be better paid.

Science and the Practical Man

In short, there exists the contradiction that industry owes its present high position to science, but industry habitually opposes further improvement. Industry, however, will agree with one of science's principles, namely, that there must be a cause for every effect. That being so, there must be a cause for such a situation; which leads quite naturally to the conclusion that it ought to be worth the time and trouble to consider this matter rather carefully. Perhaps the inquiry may result in working out a compromise attitude of service to both parties.

It must be admitted at once that conservatism is a useful thing, provided it is not reactionary. Sane opposition to change is doubly valuable. If men rushed to adopt every new device without careful consideration and practical test, we should all be living in the chaos of Sovietism, if we succeeded in holding ourselves even at that level. Furthermore, opposition to change is necessary to secure the advantage of the change. Newton said this in his third law of motion—"Action and reaction are equal and opposite." A force requires something to push against in order to build up its potential; and the opposition which must be overcome is the thing which develops real strength in any movement. Thus the measure of your belief in a principle depends upon and varies with your willingness to fight for it. With this realization, you will prepare yourself better to convince people that your plans are correct and to persuade them that your ideas should be adopted. To do so, you must be thorough in your own preparation, which will result in having something better to sell than you had at first. In fact, a reasonable disagreement is encouraging because if everyone accepted what you said at once and without discussion, you would have nothing new or worth while after all.

In the factory, however, one often encounters—perhaps I should say, one usually and very certainly encounters—something that is more than just conservatism. This attitude is the particular hobby of the "practical" man, who takes genuine pride in being out of patience with all "theory." In the extreme form this type of factory executive recalls Lord Beaconsfield's definition of a practical man as one who practices the errors of his forefathers.[1] This attitude of mind can be spotted at once, by recommending some slight improvement or change in method of carrying out a process. The "practical" man will assert that he has been doing it successfully as it is for the last twenty years (thirty-five is a favorite figure also); and will then talk about his experience. The best way to meet this attitude is by education—proving the point by teaching, step by step. It sometimes requires almost infinite patience to save such a man from himself.

Theory or Theorists

In all fairness, it must be said that there is a good deal of justification for the practical man's rejection of theory, and

---

[1] "An Introduction to Mathematics," by A. N. Whitehead (p. 40).

especially of theorists. The man who has the job of making things has to confine his interest to proved methods; his business does not provide time for speculation or experimentation in working hours. When goods produced is the measure of achievement, as it must and should be in the shop, there is bound to be objection to even taking a chance of failure. Such losses should be confined to the laboratory, which should be kept separate from the shop for that reason.

Too often also, the charge is true that the scientific worker is wholly out of touch with the practical details of the arts which should depend upon his work for their future progress. The scientist finds some measure of explanation, when this situation exists, both because his work is apathetically received by the practical man, as well as because he is professedly in search of knowledge for its own sake rather than for its immediate money value. "There is a necessary unworldliness about a sincere scientific man; he is too preoccupied with his research to plan and scheme how to make money out of it."[2] His greatest compensation lies in the realization, as Dr. George Sarton has so ably said,[3] that man's intellectual advancement is the only real measure of progress. Anything which helps to solve the ever-present problems which the world offers, means progress to the true man of science. If the solution is not useful now, it will be later on; and, if in the meantime he can carry on in his chosen field only at great personal sacrifice, then all the more reason to speak the truth at any personal cost and to worry little about the criticism or opposition of the moment.

There is evidence on all sides of a lack of correlation of the sciences and the arts which doubtless is due to the difficulty an

---

[2] "The Outline of History," by H. G. Wells.

[3] See his essays in *Scribner's* on "The Message of Leonardo" and "Hidden History."

> individual encounters in adapting himself to these two viewpoints. For the benefit of his art, the artist should acquaint himself with the general sciences upon which his art is founded; and for the benefit of progress the scientist should bear in mind the viewpoint of the artist. There should be no misapprehension regarding the relation of science and art, because the former supplies the enduring foundation of the latter. For this reason it appears that those who primarily possess a scientific viewpoint should attempt to bridge the gap by laying their course upon facts.[4]

The Engineer as Co-ordinator

Granting that nothing but good can come from bridging the gap between science and industry, the only question to be answered is—"Who is the man to do it?" The engineer, either as executive or consultant, logically seems the man for the job. He either is or should be pretty close to both sides. If he is a real engineer he must be a fairly good scientist. If he is of any use in the manufacturing plant he must be practical in his viewpoint. As the friend of production, he will analyze its needs for science's help, and in the light of a sympathetic understanding bred of contact with the work. His observation, moreover, will be guided by a knowledge and appreciation of the methods of science, and his acquaintance with science will tell him where to look for further guidance. Once he knows the answer, his real task is to put it into form for practical use, and to make clear and convincing explanation of its fine points and advantages to the man who must do the actual work.

The engineer's purpose in industry should be to save effort by making it possible to do the job in hand more easily, and with a better product for a given effort. There are so many things to be done which have not even been started yet, that it is greatly to everyone's interest to free ourselves from just as much effort in doing our present work

---

[4] From the introduction to "The Language of Color," by M. Luckiesh, Director of Applied Science, Nela Research Laboratories, National Lamp Works of the General Electric Co., Cleveland.

as we possibly can. To carry out this project in systematic form requires recognition of the fact that material progress rests upon an intellectual foundation; and, as we have seen, this in turn receives its greatest impetus from a peculiar mental attitude or method of thinking which is known as "scientific." Let us consider some of the special characteristics of this attitude.

The Scientific Attitude

Every small boy, unless he is most unlucky, passes through the stage of learning, rather early in his career, that he gains nothing by lying, crookedness, or not playing fair. Seemingly men have had to go through with much the same process in their constant fight with nature. The world is a pretty decent place if we are careful to conform to nature's laws, but we are sure of defeat when we do not. The bridge that is designed to suit a present fancy, instead of being in strict conformity with the established laws of statics and the proved strength of its materials, is certain to fail. All engineering practice owes its rapid progress to the truthful observance of and strict adherence to known principles and proved facts.

There are several ways in which such a body of knowledge can be secured, and when systematized into form for use it may be called "science." If this knowledge is obtained by the slow and expensive process of trial and error in actual practice, each success provides an indication of one limiting condition and each failure shows another limit; but the method can hardly be called scientific. That is the old method by which the arts used to advance. What special features distinguish the newer method?

One of the most obvious distinctions is that science is not satisfied merely to know that such and such a thing is true—it must know *why*. That the ultimate *why* is unknowable merely adds zest to the game—it extends our horizon to the limits. Having discovered *why*, we are in a position to extend the application of the *principle* involved. Without knowing *why*, we could only repeat what had been done before. Thus the search for knowledge in the form of principles of general application is one of the chief characteristics of the scientific method. Its most obvious application in manufacturing is to know, in detail, the principles involved in the processes in use in the factory. Upon what elementary laws of nature do they depend, and what special adaptations of such laws are involved? Look around you and see how many processes there are *not*, whose true inwardness is known. Many of the oldest will be found in this class. The latest, such as those peculiar to electrical work, have been able to profit by the discoveries of the science which made them possible. Even the processes we think we know something about, still provide room for intensive study; which brings us to another characteristic of this special sort of mental attitude.

The scientist approaches his problem with humility. Constant pondering over natural phenomena can have no other effect than to make clear the huge number and vast range of the knowable things which we still have to find out about. Against such a background, what we today call knowledge seems puny indeed. In this realization lies one of the scientist's greatest sources of power. Knowing how little he knows, he makes very sure to see that his work is done with such precision that error is reduced to a minimum. He pays great attention to minute details, so that nothing shall be left out, because the answer may lie in some insignificant fact which is obscured by its very obviousness. Nothing is taken for granted, and although influenced by practical experience, he is careful to avoid its dangers by freeing his mind of traditional untruths.

The Scientific Method

However humble the scientific man's attitude in preparing his mind to attack his problems, he nevertheless goes into action with confidence of success, because he has a *method* which works. Applied with determination and guided by good judgment, the scientific method is the one method that is certain to produce results sooner or later. For its guiding principle is fidelity to truth, and in this sense the achievements of scientific research are the greatest possible vindication, in practical form, of the great moral law of honesty, in its broadest application. This is the first thought which should be driven home to every student of the engineering sciences. There is but one safe way to deal with natural phenomena, namely, to make sure, with painful accuracy, that your facts are correct and complete, also that the conclusions drawn from these facts are sound in every particular. Then, if the principles and practices thus developed are translated into action with the same fidelity to truth, really useful results are sure to follow. The success of any other method is a matter of chance.

In the effort to present in convincing form conclusions reached by the scientific method, the engineer would do well to take a leaf from the book of the lawyer, who must necessarily make very sure of the truth and completeness of his facts, and be certain that his deductions are both logical and precise. The literature on argumentation and the very practical methods for testing evidence and building briefs contain many useful hints which the engineer may adapt to his situation with profit. Not the least of these is the way in which the lawyer deals with the technical and scientific matters which arise within his purview. Realizing his own ignorance, he first makes sure to learn the story himself. Then he assumes an equal ignorance on the part of his readers and writes a clearer exposition and more convincing presentation of the technical matters involved than does the discoverer of these very phenomena.

Then again, scientific work yields high returns for constructive imagination. The latter is one of the rarest and least used of the mental processes, yet because of its forward-looking attitude it should be strongly developed. The mere statement that something is good enough as it is, or that further improvement is impossible, should be a sure sign to the engineer that right there is an opportunity. The situation may call for all his ingenuity, and surely for plenty of hard thinking. All the anticipatory and constructive imagination he possesses may well be focused on the problem; but if this follows a thorough and truthful analysis of the problem in the first place, his hard work and late hours will be amply rewarded by results of practical value.

The Place of the Engineer

The reason for inviting attention to the preceding discussion of the scientific attitude of mind and its methods, is to indicate the way in which we should go about the advancement of the arts of manufacturing. The most successful method is obvious. It remains only to select the man to direct the job, because without a definite assignment and a systematic program we shall get nowhere. "Everybody's business is nobody's business."

As already stated, the technically trained engineer is the logical co-ordinator of science and industry. Attention is directed to the phrase "technically trained," because some men go through college without achieving that result, and others acquire education without going to college at all. But the man must be an *engineer* in the truest sense, regardless of the route by which he has arrived at that specialized intellectual condition.

CHAPTER XXIII

THE METHOD OF ATTACK TO CONTROL QUALITY

The Approach to the Problem

There is a lesson for everyone contained in the Chinese philosophy which says that no theory has any value except in so far as it is translated into action or, at least, is translatable into action. Therefore if there is any merit in this theory of controlling quality, completeness requires that some plan be advanced for approaching the task of bringing quality under control.

Since quality of output is the ultimate result of technical processes in one form or another, it follows that the best way of solving problems in the control of quality is to use the scientific method. It is the best method for obtaining rapid and certain returns. But it must be applied in a strictly practical engineering way because this is a commercial application of the method rather than a purely scientific search after knowledge for its own sake. The sort of knowledge wanted in this instance must be of immediate and economic use.

Uniformity within Limits

In crystallized form, the underlying object of any manufacturing enterprise is to make more and better goods for less money—to obtain a greater output of standard quality for less effort. In planning to bring quality under control, therefore, every step is made with a view to removing obstacles to greater and better output by regulating the deviations from standard. In every instance these deviations or errors represent losses in the use of material, labor, and manufacturing plant. Perfect quality implies freedom from errors. But there is a limit to which qualitative refinement can be carried with economy. Consequently, while it is true that we seek uniformity, it is a modified and reasonable degree of uniformity—that is, *uniformity within* commercial *limits.* The economy of manufacture requires that the limits be suitable for the case in hand at the moment—they must not be too large or too small.

The scientific method is to be applied, then, to manufacturing problems with quality as the criterion, but every solution worked out in this way must be mentally projected against a background of dollars and cents, and our conclusions modified accordingly to suit the present commercial situation.

Getting the Facts

In applying any such method to a given industrial situation the first desideratum would appear to be an unbiased scrutiny of the business as it is. The art of seeing things as they really are is often a gift, but it can be cultivated also. The industrial executive is so close to the details of the business that the most obvious things escape him. Unless he recognizes this failing and stops to take stock of the situation he is very apt to get into a fix where "he can't see the woods for the trees." Yet an accurate viewing of the problem is prerequisite to any measure of success in laying out a program for constructive work.

A prominent manufacturer who has a faculty for concise expression says that industry should heed the warning of his boyhood riding-master. The latter was in the habit of concluding his advice about sitting up straight and so on, by barking out—"Get off your horse and look at yourself riding." Many a factory would be the better if its controlling executives would get off their horses and watch themselves riding—they wouldn't look so humped up to the disinterested outside observer.

But after all, isn't this just another way of starting in to practice the things we have been considering in the last chapter? As we have just observed, one of the outstanding features of the scientific method is the collection of basic data, and the testing of such data to make sure that it is correct; so that the first step is to get the facts in the case—starting with the general business situation and its trends as affecting quality, and then in all the detailed ramifications of the business itself. The first or general viewing has to do with external or commercial relationships, while the detailed study is for the most part a matter of regulating conditions within the factory.

Analysis

In securing the facts in detail it soon becomes evident that resort must be had to analysis. Manufacturing problems are too large to be solved as a whole and must be broken up into parts which are small enough to suit the limitations of our intellectual equipment. Getting the facts is often the hardest part of the entire process, and the way in which the preliminary analysis is made becomes of great importance.

Of course there is no exact and arbitrary scheme of analysis which can be rigorously applied to every case, but certain general guides should be followed, just as in the case of collecting and testing legal evidence. The first step is to make sure that we have *all* the facts and that they *are* facts—to test their truth. The next step is to exclude those which are clearly not pertinent to the problem in hand, as well as those which obviously are of such little influence as to be unworthy of consideration. Finally, the remaining data should be *measured* to determine the influence (and the relative influence) of each fact upon the problem as a whole. Thus measurement takes its place as a part of analysis, or more accurately, as a necessary accompaniment to analysis.

Tripartition or Tripartite Analysis

Since there appears to be no generally accepted scheme for making sure that an analysis is complete and that all pertinent facts have been collected, I am venturing to suggest the use of a general guide or working rule which has proved of value in personal work. This working rule is that any complete analysis should be made from three principal viewpoints (or from at least three different angles). Its practical application works in this fashion—if you have examined a question from only one or two points of view, there probably is something missing; hence at least one more division of the subject should be made. On the other hand, in ordinary practice *three* main divisions of the subject are enough.

For example, it has been fashionable for labor and capital to consider themselves as solely interested in so-called labor problems, whereas both sides to the controversy would have done well to consider the interests of the great third party—the public—which in this case holds the deciding vote. Another example more closely related to the work in hand is to be found in the common error of assuming that any cause has but one effect. The truth is that every cause has several effects. As a simple instance of this, suppose that a greater output is sought by the means of providing a high incentive in the form of a greatly increased piece rate. The cause (one element) is the higher incentive; the direct effect (the second element) is greater output, but unless the accompanying additional effects (the third element) are considered and arranged for, the quality of the output will drop. Consequently, a complete analysis would provide at the start, with tripartition as a guide, for an adequate stiffening of the provisions for inspection as a means of controlling quality to the desired standards.

It may be mentioned incidentally and as a matter of interest that I adopted this tripartite guide in analytical work after observing the frequency with which careful thinkers divide their subjects into three main sections. A little consideration will show, however, that there is a basis for the method in the physical world all about us. Thus the three physical constants generally used as a foundation for measurement are mass, time, and space, each one of which (and many other physical things) again divides into three elements.

The use of the three divisions of time (i.e., past, present, and future) will be found very useful in the analysis and subsequent solution of many factory problems. This time relationship as affecting the planning, production, and inspection groups in organization has been traced in Chapter V. It may often be utilized in the study of an individual process. For example, deviations from standard may be caused in the process itself; or they may be carried over from, or result from some cause in a previous process; or they may even be due to the influence of a subsequent process. All three possibilities should be considered. Thus, if the later processes are in need of work, the workers whose operation is in trouble may be unduly hurried; or they may be assuming that any errors they make will be corrected by subsequent and more precise operations. This third element (the possible influence of later operations) is too frequently overlooked.

The subject of color quality has been treated in Chapter XXI in accordance with the tripartite guide.

Quality Records

The basic data for analysis will be obtained from various sources. Such production and cost records as are at hand should be used as a starting point, but it generally will be found that the facts presented by such records are not sufficient nor are they arranged in the most useful form for the study of quality problems. As noted in Chapter VI, a well-organized inspection service is a very useful instrumentality for the collection of facts relating to quality. But a preliminary analysis should be made and used as a basis for the quality records.

Since quality involves uniformity within limits, the control of quality requires that quality records deal with variations from the working standards. They must show where and when these variations, or manufacturing errors, occur. This involves an analytical list of all the kinds of errors which do occur. They must show for each kind of error the relative frequency of its occurrence, and, in a general way at least, the size of the individual errors—all of which involves some form of measurement.

Quality records, then, should present a list of characteristic qualities, a list of the kinds of error for each quality, a statement of the number and sizes of each kind of error, and a notation of when and where the error occurs. The cause of the error should be added if known, but, strictly speaking, the determination of causes is a matter for subsequent treatment. And all of the data is a subject for treatment by the methods of analysis and measurement. When the character of the quality prohibits a strict application of measurement for determining the relative size of errors, then the *idea* of measurement should be utilized by comparison with standard samples graded in such a way as to provide limits.

Using the Facts—Synthesis and Adjustment

The scientific method, as we have seen, is not content to stop with a statement of facts—it must know *why*. In practical application this brings us to the determination of the causes of variations from standard. Once the reasons for the variations are known, we are a long way on the road to their correction. Again, it is a matter for analysis, for carefully thorough and logical reasoning, and for the use of constructive imagination in developing proper conclusions. For instance, errors which occur intermittently are *probably* due to the way in which processes are applied. Progressive increase in the size of an error *probably* indicates wear or change in equipment, and so on.

Skill in this part of the work as well as in the selection of the most promising points of attack is something to be acquired solely by practice. No arbitrary rule applies and the solution in each instance will differ in details, although the methods used are alike in principle.

After the problem has been analyzed and each small part treated separately, the separate parts must be put back together and adjusted. The procedure is analysis, synthesis, and adjustment (or compromise), as already discussed in several places—notably in Chapter XVI, "Repetition Manufacturing." Thus the tolerance on a given dimension is a matter for agreement between engineering, production, and inspection. Correct and complete analysis is a very large part of solving the problem, because a detailed knowledge of the truth usually suggests the cure. Synthesis and its concomitant, adjustment, ordinarily require a much shorter time to execute, but their vital importance cannot be too strongly stated—they call for all the available skill and good judgment which can be brought to bear upon them.

The Order of Procedure

When we come to the application of the method outlined in the preceding, it is very evident that the approach from the standpoint of quality must begin with an intensive study of the product itself. This is the only sure and complete way of taking the true measure of an industrial situation when quality is to be the primary guide. As suggested in Chapter II there should then follow a similarly careful study, first, of the processes used to create the product, then of the organization employed to apply these processes, and, finally, of the system used to measure the achievements and control the operation of the organization.

Admittedly the method of approach which starts with a searching analysis of the product and processes may be found to be somewhat arduous and exacting, but it soon becomes most interesting because of its great practical influence on the enterprise. Sometimes minute details are considered uninteresting, but as Gilbert K. Chesterton has remarked: "There is no such thing on earth as an uninteresting subject; the only thing that can exist is an uninterested person."

Quality is a variable. Oftentimes the variations are small, but it is the amount of attention which is paid to just such little things that determines the difference between success and mediocrity.

Begin with the Product

Starting with the *product*, the first step is to analyze it as it is, and with reference to its characteristic qualities. In what respect should the individual *articles* making up the company's output be alike? The next step is to reduce these characteristics to some basis of measurement for purposes of impersonal comparison. We can then determine to what degree of likeness it is sensible to make the individual pieces and establish tolerances and limits accordingly. This involves the determining of how far the articles may be unlike. At the same time, and by the same means, we may observe the direction which future improvement of the product should follow toward closer approximation to the ideal standard.

Proceeding next to a study of the processes used in creating the product, the investigation takes the form of studying both processes and product together. The first object sought is a uniform product conforming with the predetermined working standards. This requires that the processes used to create the product must be controllable to an equal uniformity. To bring them to this condition we must proceed to list the various kinds of errors (or differences in the product), their magnitudes, and the frequency with which each kind of error occurs. The next step involves listing the possible and probable causes of these errors, as a step toward determining their actual causes. When the last-mentioned thing has been determined, it is no very difficult problem in most cases to develop means and ways for reducing the errors—and often to eliminate them for all practical purposes.

If the solution of the problem is not so easy to find, then we must turn back to pure science—the master teacher—and develop new methods from a fresh start. If your task seems too difficult, it will reassure you, perhaps, to take a look at the obstacles others have overcome. One trip through a plant making electric light bulbs, for example, is quite cheering. The winding of wire filaments too small for the eye to see the coils without the use of a microscope, and the actual use of the latter on production machines is

Figure 89. Precision Torsion Balance—Roller-Smith

typical; as also is the weighing of these filaments to a precision of 1 per cent for weights of less than 12 milligrams (see Figure 89), and this as a regular production proposition.

Written Descriptions of Processes

Presently, as a result of this study, we shall know how to perform each process. As a matter of fact, in work where the product cannot be described by a plan (like heat treating, or weaving, or making some chemical compound), the only method of description available is to build up an aggregation of explanatory descriptions, or written instructions for doing the work. Of course these process descriptions must be in complete detail, if they are to be of use either in analyzing matters affecting quality or for use in instructing workmen. The creation of such records involves learning your business in detail, but that is a knowledge the management of any business should have if it intends to run the business, instead of letting the business run the management.

There is one great distinction, however, that you can learn the technical details of the business by the scientific method, even though you are not actually able to do the work yourself—at any rate, you need not be able to do it as well as the man who is continually engaged in production. This is a bitter pill to the extreme type of "practical" man. He is unwilling to disparage the results of years of devotion to his work—consequently he is quite likely to reject your advice for improvement by asking (of himself, at least), "How can anyone, who avowedly knows little if anything about this work, teach me how to do it better? Haven't I been working right at this same job for the last twenty-five years?"

But, as doubtless you have already observed, this attitude fails to distinguish between knowing the methods and principles used in doing the work, on the one hand (the why and how) and the skill required for their execution, on the other. One could write out the most particular instructions for shooting a rifle, but would only acquire the skill necessary for accurate shooting through continuous practice. Yet almost anyone could learn to shoot by following the written instructions exactly.

It is a safe statement that man is not capable of doing anything which cannot be analyzed by the scientific method of attack and reduced to a description written in clear and simple language. Further, such a description may be used as the basis for improvement, once the governing principles have been worked out; and it can be employed as well to start any other intelligent person toward acquiring the skill needed in its execution.

As a general rule, the oldest processes, which have not yet been subjected to such an investigation, are the most fertile field for its application. There is no mystery in any industrial process, although it may well be that great skill is required for its proper execution, and even the latter may be simplified.

The Assemblage of Processes

After the processes have been considered in detail, it is in logical order to consider them as merely the principal working parts of a great manufacturing machine—the factory as a whole. Shop arrangement (especially with a view to care of material in process) will show new values for system and order in physical form, as distinguished from mere paper systems. Consider the shop and inspection arrangements with a view to planning with material and taking full advantage of the possibilities of the principle of centralized inspection.

Organization and System

Taking up the *organization* next—is it well balanced as regards the main functions of planning, production, and inspection? For this much is fundamental in controlling quality. Is the factory personnel organized in a way to provide for bringing to the attention of the workmen, in effective form, the things they should know if quality is to be maintained as it is, and systematically improved thereafter? Also, does the organization provide a competent person, whose duty is that of directing this improvement with the idea of making progress conscious and intentional?

Usually some form of committee system will be found useful as a means of educating the rank and file in the details of quality manufacture. It is well-nigh useless to spend money in bringing valuable facts to light, unless provision is made for using them. Education is the first step toward accomplishing this, and to be effective, it should be reinforced by methods which make it clearly to the interest of the producer to put these lessons into practice.

Finally, some economical sort of *system*, or systems, should be devised to present the statistics of the business (costs, qualities, and quantities) in clear and useful form for the guidance of the organization in correcting errors and eliminating wastes. The cost system especially should locate charges for damage and waste against the responsible department rather than against the department where they occur.

In short, the whole process of controlling quality involves applying the scientific method to the industry, in a practical engineering way. Beginning with an untiring and systematic search for facts, we pass to a truthful, accurate, and sensible use of them in refining our work. The method is an invincible one for securing increased output, at less expense of effort, and with *higher quality*.

Conclusion

Whether as a part of some general trend for which the times are opportune, or as the working out of economic laws, or as a combination of both (which is the most probable), business as a whole is working toward greater truth and fidelity to accuracy. This increasing tendency toward exact definition, which is the precursor of improved and better regulated quality, has shown itself rather prominently at times. Some years ago, for example, there began a great movement for "pure food." More recently, similar action has been taken for pure advertising, and one form of truthfulness which the latter has urged is the frank and open publication of technical details. Things are being called what they really are, and the proof supplied, instead of making mere assertions about quality and performance.

This situation is encouraging, especially if you are one of those who believe that the business of the future will be built upon a sounder basis of merit, service, and worth, than ever before. If this is a correct viewpoint, then is not the control of quality the first step in that direction? Surely it is the basis for both service and the profit which follows real service. American industry has been famous for quantity production. Why should it not be distinguished also for qualities that are definite and certain? When capitalists and industrial executives regard quality in this light, the biggest step toward the qualitative improvement of industry will have been taken, because there is no serious difficulty in the way of its achievement.

Very happily, quality is like many other things which you can have if you only want them badly enough. In his essay on "The Art of Seeing Things," John Burroughs says that the secret of the successful angler's effort is no doubt due to love of the sport. "What we love to do, that we do well." Without the strong desire for quality, beginning at the very top of the organization, there is little chance for securing quality. Thus it is one of the prime responsibilities of ownership and management.

There is no danger, either, in setting our ideal standards too high, because the fact that the realized standards are lower need not be discouraging. For it does not prevent the ideal from serving a most useful purpose, by indicating the direction improvement should take. "Ideals"— said Carl Schurz—"are like stars. You cannot touch them with your hands but like the seafaring man on the desert of waters you choose them as your guides and, following them, you reach your destiny."

Granted that quality is a desirable thing to have, the way to approach the task of placing it under sure control is the simple one of seeking true facts and being guided thereby, in accordance with a definite campaign. In the main, the methods most useful in the control of quality are merely the old-fashioned, time-honored ways of engineering with perhaps a little different slant. "Engineering is the art of organizing and directing men, and of controlling the forces and materials of nature for the benefit of the human race." There is nothing especially dramatic or mysterious about engineering methods, but the results of their intelligent and earnest application are pure magic. They present the most romantic possibilities for solving the problems of the world that confronts man in his upward climb.

INDEX

THIS BOOK IS DUE ON THE LAST DATE STAMPED BELOW

AN INITIAL FINE OF 25 CENTS

WILL BE ASSESSED FOR FAILURE TO RETURN THIS BOOK ON THE DATE DUE. THE PENALTY WILL INCREASE TO 50 CENTS ON THE FOURTH DAY AND TO $1.00 ON THE SEVENTH DAY OVERDUE.

MAY 9 1938
APR 10 1941
APR 2 1942 E
APR 17 1948
MAY 25 1948
26Oct'49 I 7
25Mar'50BG
[illegible]
26May'50CD
26Nov'50RF

ALLGEYER
DEC 23 1950
15JUN'55SS
JUN 1 1955 LU
9Dec'57MH
DODDS
JAN 9 1958 n
REC'D LD
JAN 8 1958
7Jan'62JH
REC'D LD
JAN 5 1962
23MAY'62DF
REC'D LD
MAY 14 1962

LD 21-95m-7,'37

(C7097s10)476B

University of California
Berkeley