# HOW TO MAKE HIGH-PRESSURE TRANSFORMERS



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# Directions for Designing, Making, and Operating High-Pressure Transformers

BY

**PROFESSOR F. E. AUSTIN**



Professor and Head of the Department of Electrical Engineering in the Thayer School of Engineering, connected with Dartmouth College, Hanover, N. H.

Author of "Examples in Magnetism."
"Examples in Alternating-Currents."
"How to Make a Transformer for Low Pressures."



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## TABLE OF EQUIVALENTS OF LENGTH, AREA AND VOLUME.

1 INCH = 2.54 CENTIMETERS.
1 centimeter = $\frac{1}{2.54}$ = 0.393 inch.

1 SQUARE INCH = $\overline{2.54}^2$ = 6.45 SQUARE CENTIMETERS.
1 square centimeter = $\frac{1}{6.45}$ = 0.155 square inch.

1 CUBIC INCH = $\overline{2.54}^3$ = 16.38 CUBIC CENTIMETERS.
1 cubic centimeter = $\frac{1}{16.38}$ = 0.06105 cubic inch.

1 MIL = $\frac{1}{1000}$ of an inch.
1 square mil = area of a square, 1 mil on a side.

1 *circular mil* = area of a circle, 1 mil in diameter.
= area of a circle $\frac{1}{1000}$ of an inch in diameter.

A square mil is greater than a circular mil, because the area of a square is more than the area of an *inscribed* circle.

1 square inch = 1000 × 1000 = 1,000,000 square mils.

1 SQUARE INCH = $\frac{4 \times 1000000}{\pi}$ = 1,274,500 CIRCULAR MILS.

$\pi$ = 3.14159 = ratio of the circumference of any circle to its diameter. The diameter of any circle multiplied by 3.14159 = its circumference.

Square root of 2 = $\sqrt{2}$ = 1.414.

**1 Horse-power** = 33000 foot-pounds per minute = $\frac{33000}{60}$ = 550 foot-pounds per second.
= **746 watts.**

**1 Foot-pound = 1.3562 × $\overline{10}^7$ ergs.**
**Volts × Amperes = Watts.**

## DIRECTIONS FOR DESIGNING, MAKING, AND OPERATING A HIGH-PRESSURE TRANSFORMER.

### *Introductory.*

Electric power, at a high pressure, is at present a commercial demand and necessity; the considerations in favor of direct-current power at high pressure are, with the present forms of construction, fewer than those favoring alternating high pressure power. The one consideration above all others in favor of "*alternating-current*" power, is the simplicity, and economy with which the alternating-pressure, (constituting one factor of the power) may be increased or decreased in magnitude; or in common engineering parlance:—"*stepped up*" or "*stepped down*", from a low to a high or from a high to a low value respectively.

The device employed to accomplish the stepping up or stepping down process is the so-called *transformer,* which is a really wonderful piece of apparatus, when considered as an energy device.

It should be remembered that a transformer cannot be operated on direct-current circuits; but only by being connected with circuits in which the current is continuously undergoing *regular* changes in value; that is, by alternating-currents.

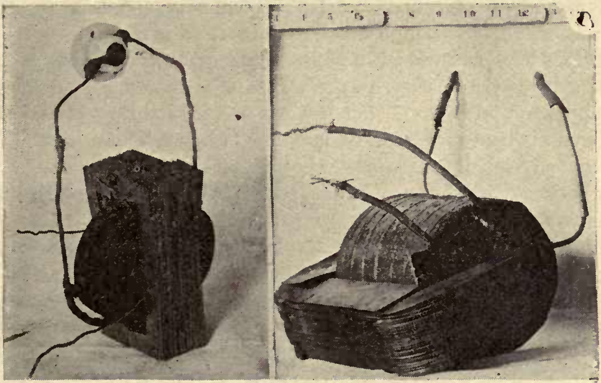
The term "*transformer*" is perhaps a misnomer when used in connection with the now common device; since energy is not transformed by the device from one *form* into another *form*; but a certain percent of the electrical energy supplied to the device is given out by it with simply a change in the magnitude of the two factors of electrical power:—pressure and current. The device might more aptly be called a *transmuter*; from the Latin *trans* (meaning across) and *mutare*, (meaning to change across or to carry over).

The electric power is simply carried across, through the medium of the so-called transformer, from one electric circuit to another.

A transformer might then be defined as a device for the exchange of electric power from one alternating-current circuit to another, with a desired change in electric pressure.

As will be evident later, a transformer consists essentially of two electric circuits interlinked by a magnetic circuit. A chain consisting of three links, the middle link representing the magnetic *circuit,* and the two outer links representing the two electrical circuits; one the primary and the other the secondary. Since a chain is no stronger than its *weakest* link, so the commercial value of a transformer is determined by its weakest part.

The mechanical simplicity of a transformer is remarkable; containing no *moving parts*; and although at times receiving and delivering energy at the rate of thousands of horse-power, it requires very little care and maintenance.



a. **Fig. 1.** b.

There are two general types of transformers in use at present, classified according to their construction. One is called the "shell" type the other the "core" type.

The shell type is shown at (a) figure 1, page 5, and the core type is shown at (b) same figure. In the shell type the iron core surrounds the copper circuit; while in the core type the copper circuit surrounds the iron core.

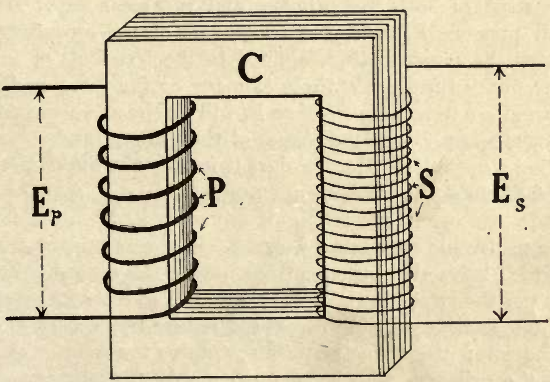



**Fig. 2.**

The analysis of the physical phenomena involved in the operation of a transformer, is as complex as the device itself is simple.

A brief explanation of the physical principles involved in the operation of a transformer may be useful.

Suppose C, in figure 2, denotes a number of thin iron plates, placed one above another to form a rectangular "*core*". These thin plates may be electrically insulated from each other by insulating paint, varnish, or simply by a coating of iron rust that readily forms after the plates have been covered with moisture.

Next suppose a number of turns of large size, cotton covered, copper magnet wire, denoted by P, are wound around one limb of the core, and a larger number of turns of smaller cotton covered copper magnet wire, denoted by S, are wound around the opposite limb of the core. There is then no *electrical* connection of any kind between the two coils and the iron core, or between the two coils themselves

The few turns of large wire, P, may be designated as the "*primary*" while the coil consisting of many turns of small wire, denoted by S, may be designated as the "*secondary*".

The primary in this case has a low resistance, while the secondary has a much greater resistance.

Suppose an alternating-pressure denoted by $E_p$ is applied to the terminals of the primary. An "*alternating-current*" then exists in the primary which sets up an alternating magnetic flux or magnetic field in the iron core. This alternating magnetic flux *induces* a counter electromotive force in the primary and also induces an electromotive force in the secondary windings. The *induced* electromotive force *per turn* of wire is practically the same in both the primary and the secondary. However the (induced) pressure $E_s$ *between the terminals* of the secondary is *n* times as great as the pressure ($E_p$), applied to the terminals of the primary, if the secondary turns are *n* times as many as the turns on the primary. If $E_p$ is an alternating pressure, then $E_s$ will also be an alternating pressure. This does not imply that the *shapes* of the primary and secondary pressure curves are similar. Neither does it follow that the *shapes* of the primary and secondary *currents* are the same.

If now the secondary terminals are connected with a straight wire having considerable resistance, a current in the secondary windings will result, which is an alternating-current having the same frequency as the frequency of the applied primary pressure. The secondary current existing in the secondary windings, reacts to reduce *very slightly* the magnetic flux in the core; this reduction of flux reduces the counter electromotive force in the primary, allowing an increase in the primary current. If the resistance connected with the secondary is *reduced*, an *increase* of secondary current results, with a corresponding increase of primary current.

The operation as described, constitutes inherent regulation of supply and demand, performed without the movement of a material substance or of *mass*.

The primary acts as a "*choke*" coil, the value of the current in it being expressed by:

$$I_p = \frac{E_p}{\sqrt{R^2_p + (2\pi f L)^2}} \quad (1.)$$

In this equation $E_p$ denotes the applied primary pressure, in volts; $I_p$ the primary current, in amperes; $f$ denotes the frequency, in complete cycles per second, of the applied pressure, and of the primary current; $R_p$ denotes the resistance of the primary winding, in ohms, and L denotes the so-called "*coefficient of induction*," expressed in "*henrys*"; which is the only variable in the equation.

To show the effect the value of L has on the primary current, suppose the following data are given, to find $I_p$.

**DATA.**

$E_p = 110$ volts
$f = 60$ cycles.
$R_p = \frac{1}{10}$ ohm.

$L = 1$ henry.

$\pi = 3.14159$
$R^2_p = \frac{1}{100}$
$2\pi f L = 377$ (very nearly).

$$\text{Then } I_p = \frac{110}{\sqrt{\frac{1}{100} + 377^2}} = \frac{110}{\sqrt{142129.01}}$$

$$= \mathbf{0.29 \text{ ampere.}}$$

If to this primary winding a direct-current pressure of 110 volts should be applied, the resulting current would be: $I_p = \frac{110}{\frac{1}{10}} =$ **1100 AMPERES,**

which would have been the same with the alternating-pressure of 110 volts, if the primary wire had been laid out straight with no iron near it.

This shows the "choking" effect, on *alternating-currents*, of coiling a wire around an iron core, and the primary of a transformer is said to act as a "choke" coil.

To explain somewhat differently a few of the important functional phenomena occurring during the operation of a transformer, a brief outline treating of a particular case in designing, is included in the following discussion applying to transformers.

While it is possible the mathematical discussion may not be completely comprehended by one who has had only a limited training in "mathematics", it is hoped that everyone may obtain valuable information regarding the *general principles* of transformer operation by carefully studying this portion of the text.

For the benefit of those desiring to build a high pressure transformer for experimental use, such as for wireless telegraphy, for the production of "ozone" or for vacuum tube lighting, data applying to specific cases are given.

If however, one studies carefully the *general principles*, many variations from the given conditions may be readily effected, to meet a large range of requirements.

The matter headed "CAUTION" and "PRECAUTION" should be very carefully read by everyone who builds or who operates a high-pressure transformer.

## SYMBOLS AND NOTATION.

Since electric *power is* often expressed in terms of the two factors, pressure and current, **denoted by $\mathbf{E \times I}$,** (meaning the product of a pressure, in volts, by a current, in amperes) if that portion (or link) of the transformer to which the electric energy is supplied is designated as the "*primary*", while that portion (or link) from which electric energy is delivered is called the "*secondary*", the following symbols and notation will be adopted.

$\mathbf{E_p}$ denotes the pressure, in volts, applied to the primary circuit.

$\mathbf{E_s}$ denotes the pressure, in volts, available from the secondary circuit.

$\mathbf{I_p}$ denotes the current, in amperes, in the *primary* circuit.

$\mathbf{I_s}$ denotes the current, in amperes, in the secondary circuit.

$\mathbf{R_p}$ denotes the resistance, in ohms, of the primary circuit.

$\mathbf{R_s}$ denotes the resistance, in ohms, of the secondary circuit.

$\mathbf{W_p}$ denotes the power input, in watts, to primary circuit.

$\mathbf{W_u}$ denotes the *useful power output*, in watts, from secondary.

$\eta$ (Greek letter *eta*) denotes the so-called *commercial efficiency* of a transformer.

Then: $\eta = \frac{W_u}{W_p}$; (2): being a symbolic expression for the commercial power efficiency of any transformer.

The commercial **power efficiency** of a transformer **is the ratio of the useful power output to the total power input.**

If a transformer is operating a load consisting of incandescent lamps, as is common practice, then the commercial efficiency of the transformer might be expressed by:

$$\eta = \frac{E_s I_s}{W_p}; \ (3).$$

If the *output* from a transformer is increased, the input must also be increased. The input has always to supply the output *plus all the losses.*

## LOSSES IN A TRANSFORMER.

The losses in a transformer may be divided into the "*copper losses*" and the "*core losses*". The copper losses may be still further divided into the loss in the primary windings and the loss in the secondary windings. These are the so-called $\mathbf{R\bar{I}^2}$ losses, in watts. The primary loss would be expressed by $\mathbf{R_p\bar{I}_p^2}$ and the secondary loss by $\mathbf{R_s\bar{I}_s^2}$. The resistances $\mathbf{R_p}$ and $\mathbf{R_s}$ of the primary and secondary coils respectively, are *constants**; while the currents denoted by $\mathbf{I_p}$ and $\mathbf{I_s}$ are *variables*. The copper losses are therefore variables, depending upon the load output. If there is no load output, then $I_s$ is zero and $R_s\bar{I}_s^2$ is also zero. If the transformer has its primary connected with service mains, even with no load output, there will be some $R_p\bar{I}_p^2$ loss in the primary. However under this condition, the primary current $I_p$ is very small; less than unity, so that the *square* of the current will be still less,† numerically, and $R_p$ being not much greater than unity, (usually *less* than unity) the $R_p\bar{I}_p^2$ loss for small transformers, is usually less than one watt at no load secondary. When however a load is applied to the secondary, then the $R_s\bar{I}_s^2$ loss in the secondary becomes appreciable, the $R_p\bar{I}_p^2$ loss in the primary increases, and the total copper loss becomes large enough to be a considerable proportion of the total power input. It is evident then as the load output increases, the primary and secondary currents increase, causing the *total copper loss*, expressed by $R_p\bar{I}_p^2 + R_s\bar{I}_s^2$ to increase.

## CORE LOSSES IN A TRANSFORMER.

The so-called "*core loss*" in a transformer may be divided into the "*eddy current*" loss and the "*hysteresis*" loss. The eddy current loss is an $R\ \bar{I}^2$ loss, produced by currents induced in the iron core by the primary input. To reduce the eddy currents, and the eddy current loss, the core is

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*So long as the temperature of the coils remains constant.

†For example, $\frac{1}{2}$ is less than unity, and the square of $\frac{1}{2}$ is $\frac{1}{4}$; less than $\frac{1}{2}$. Likewise the square of $\frac{3}{4}$ is $\frac{9}{16}$; which is less than $\frac{3}{4}$.

made "*laminated*", built up of thin plates of iron, insulated from each other; usually by varnish.

The hysteresis loss is a heat loss produced by the reversals of the molecules of the iron in the core when the magnetism of the core is reversed; which happens every time the current in the primary is reversed; for a 60 cycle circuit, this happens 120 times every second. That is, the molecules are turned end for end 120 times every second. Such rapid movement of molecules produces heat, as though the iron were hammered rapidly with a hammer; as may be done by placing an iron nail on a rock or on an anvil and hammering it rapidly. The only method adopted to reduce the hysteresis loss, is to use a "soft" iron, or one having a small hysteretic coefficient.

## LOSS DUE TO HYSTERESIS.

The numerical values of hysteretic loss, per *cubic inch* of iron in the core, as well as for any frequency $f$, or flux density $\mathfrak{B}$, may be calculated from the equation:

$\overline{W_h} = \frac{16.38}{10^7} K f + \mathfrak{B}^{1.6}$; (4) in which $\overline{W_h}$ denotes the loss in watts; $f$ the frequency of the supply pressure, in cycles per second; $\mathfrak{B}$ the flux density in gausses, or maxwells per square centimeter, and K denotes what is called a hysteretic coefficient, which varies for different kinds or qualities of iron. For ordinary transformer steel, K = .0021.

| Maximum Induction per Square Inch | Maximum Induction per Square Centimeter in Gausses | Loss in Ergs per Cycle per Cubic Inch of Iron | Loss in Watts, at $f$=15 Cycles per Second, per Cubic Inch of Iron | Loss in Watts, at $f$=25 Cycles per Second, per Cubic Inch of Iron | Loss in Watts, at $f$=60 Cycles per Second, per Cubic Inch of Iron | Loss in Watts, at $f$=100 Cycles per Second, per Cubic Inch of Iron |
|---|---|---|---|---|---|---|
| 6451.6 | 1000 | 2170. | .003255 | .00542 | .01402 | .0217 |
| 12903.2 | 2000 | 6879. | .01031 | .01719 | .04127 | .0688 |
| 19354.8 | 3000 | 13104. | .01965 | .03276 | .07862 | .1310 |
| 25806.4 | 4000 | 20147. | .03022 | .05038 | .1208 | .2015 |
| 32258.0 | 5000 | 27846. | .04176 | .06961 | .1670 | .2784 |
| 38709.6 | 6000 | 36036. | .05716 | .09528 | .2286 | .3811 |
| 45161.2 | 7000 | 45208. | .07311 | .1218 | .2924 | .4864 |
| 51612.8 | 8000 | 56511. | .09070 | .1511 | .3628 | .6047 |
| 58064.4 | 9000 | 68796. | .1094 | .1724 | .4379 | .6899 |
| 64516 | 10000 | 81900 | .1296 | .2160 | .5184 | .864 |

From inspection of the equation and the values in the table it may be seen that the loss due to hysteresis increases in proportion to the increase in frequency, but not in proportion to the increase in flux density. $\mathfrak{B}$ is raised to the 1.6 power, which may be done by the use of logarithms, as shown on page 25.

All of the losses in a transformer are in reality *heat* losses; a certain portion of the energy supplied to the transformer in the form of electrical energy, is effective in doing useful or desired work, while a certain portion is unavoidably changed into non-useful heat.

In designing transformers, the aim is to keep the losses as small as possible consistent with the cost of construction.

The efficiency $\eta$ does not vary in direct proportion with the output, since the copper *losses* in a transformer are not *constant* for all loads.

If the input and the output of any given transformer be measured simultaneously by the proper instruments, connected as indicated in figure 3, page 12, and the output, in watts, be plotted horizontally, while the corresponding values of the commercial efficiency, calculated from equation (3), page 9, are plotted vertically as indicated in figure 4, page 13; the result, shows the *variation* in the efficiency for different outputs. The curve in figure 4 shows the result of a test of a $\frac{1}{10}$ kilowatt (about $\frac{1}{7}$ horse-power) transformer designed to transform from 110 volts, 60 cycles, to about 60 volts, 60 cycles. This transformer is shown at d and at e in figure 5.

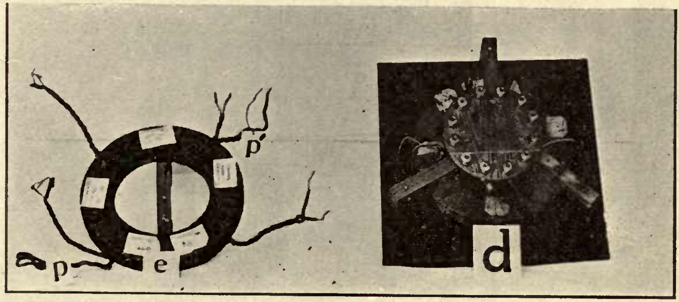



**Fig. 5.**

The condition expressed by: $W_u = E_s I_s$, exists only for a *noninductive load,* such as lamps or a liquid resistance, or any wire resistance not wound in the form of *coils*.

The condition is changed if the load consists of motors, these being highly *inductive*.

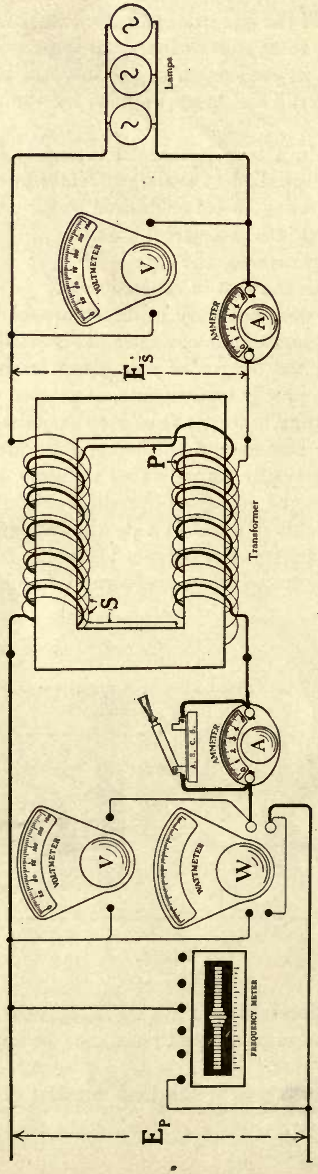
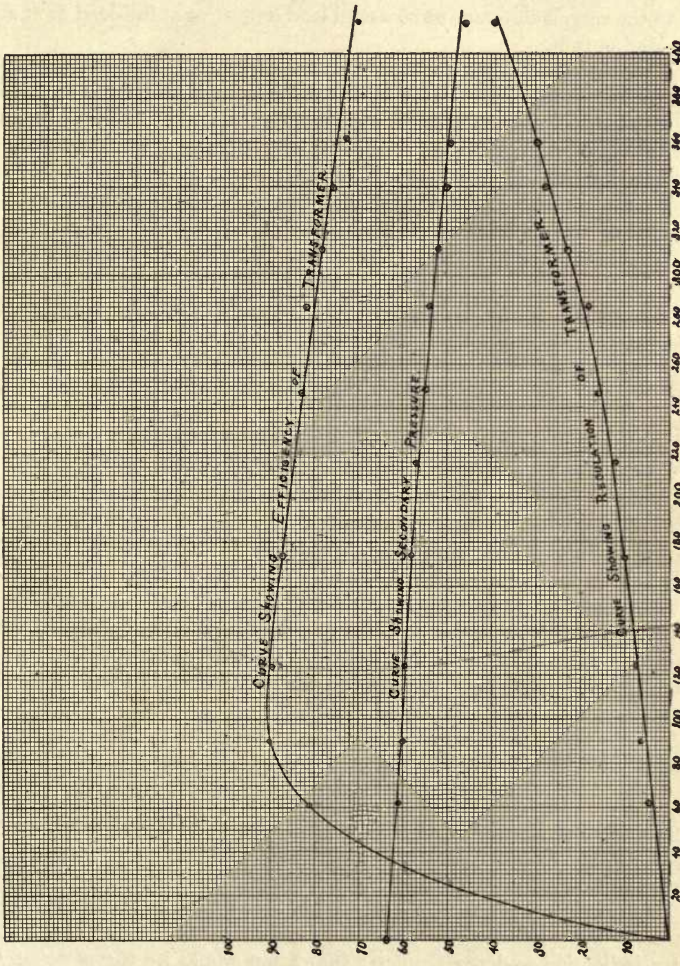

Lamps
VOLTMETER
V
AMMETER
A
$E_s$
P
S
Transformer
A. S. C. S.
AMMETER
A
VOLTMETER
V
WATTMETER
W
FREQUENCY METER
$E_p$

Fig. 3.

**Output in Per Cent, and Pressure in Volts.**




**Output in Watts.**

**Fig. 4.**

When there is no useful output from a transformer, there may be some input, to supply the *core losses,* which are however not large, and moreover are to be considered constant irrespective of loads. That is, the power loss due to the core, is the same at *no* useful load output as at full-load or at any over-load output.

This core-loss means a constant source of expense, if a transformer is kept connected to service mains when not supplying power output. While the core-loss, expressed *in watts*, may not be large, the *watt-hour* expense may be considerable if the transformer is connected with the service mains during a long time. The expense incurred in using electrical power depends upon two conditions, the RATE at which electricity is used, and the **interval of time** during which it is used.

To illustrate this feature, suppose the core-loss of a transformer is found by measurement to be 65 watts. If the transformer is connected with the service mains for 10 hours while furnishing no useful output, the total energy used will be $65 \times 10 = 650$ watt hours, which at a price of 15 cents per KILOWATT HOUR (per 1000 watt-hours) will cost $\frac{650}{1000} \times 15 = 9\frac{3}{4}$ cents. If the transformer is connected all day, (24 hours) the cost of the core-loss will be $\frac{65 \times 24}{1000} \times 15 = 23.4$ cents.

This is an important consideration for the experimenter who uses transformers, when the energy he uses is registered by meter, and shows the value of a switch, to throw the *primary* out of circuit except when actually needed to produce a useful output.

In almost all experimental work with high pressure (step-up) transformers, it will be advisable to connect a double-pole "knife" switch with the primary, so that when this switch is opened, the useful load is disconnected without danger of shocks to the operator and at the same time the no-load core-loss is eliminated.

## POWER FACTOR.

Consulting figure 3, page 2, again, to note the arrangement of the voltmeter, the ammeter, and the wattmeter in the primary circuit, a few words explaining the meaning of *"power factor"* may not be amiss.

If the primary pressure, $E_p$, applied to the primary coils of a transformer were a direct-pressure (direct-current pressure) the product of the voltmeter indication and the ammeter indication would be the same as the indication of the wattmeter; if all the instruments gave correct indications. The current in the primary coils would then be expressed by:

$I_p = \frac{E_p}{R_p}$ according to Ohm's law, and the indication of the wattmeter by: $W_p = E_pI_p$. The direct-current in the primary coil would however have no effect on the secondary coil.

When however the pressure applied to the primary is an alternating-pressure, the indication* of the wattmeter is no longer the same as the product of the voltmeter and ammeter indications, but is found to be *less.*

In such a case the *true input in watts* is indicated by the wattmeter, and the relation would be expressed by:

$W_p = E_pI_p \times$ *power factor*; or as is sometimes expressed: $W_p = E_pI_p \times$ P. F. (5) (P. F. stands for power factor). From either of these expressions is obtained:

**Power Factor** $= \frac{W_p}{E_pI_p}$. (6) Since the product $E_pI_p$ is usually *greater* than $W_p$, **the power factor is usually less than unity.** The product $E_pI_p$ can never be greater than $W_p$, and **the power factor can never be greater than unity.**

The power factor may vary as the load varies.

Returning to the consideration of efficiency as expressed by equation (2) page 9, this may be expressed by: $\eta = \frac{E_sI_s}{E_pI_p \times \text{P. F.}}$; (7).

Now suppose that the *secondary pressure is* exactly *equal to the primary pressure,* then the efficiency may be expressed by $\eta = \frac{I_s}{I_p \times \text{P. F.}}$; (7a).

It is a well known and commonly accepted fact that the EFFICIENCY of any electrical device IS ALWAYS LESS THAN UNITY; that is the *per cent* efficiency is always less than 100%.

Since the P. F. is never *greater* than unity and since $\eta$ must always be *less* than unity it is evident from the last equation that in a transformer, when the primary and secondary pressures are *equal,* the secondary current will always be less than the primary current.

Furthermore it may be noted that although the primary pressure and secondary pressure bear a certain definite relation to one another the *same*

*When dealing with instrument indications as in this discussion the indications must be noted *simultaneously;* all taken at the same instant.

proportionate relation cannot exist between the secondary and primary currents, even if the power factor is unity.

If the efficiency is high; nearly unity or *nearly* 100%, the proportionality of currents and pressures is more nearly the same. For many practical considerations the proportionality is assumed to be the same. This will be made clearer by consideration of the following:

**RATIO OF TRANSFORMATION:** The so-called ratio of transformation has reference to the ratio of the secondary to the primary pressure. The *primary* is that portion of a transformer to which the primary pressure is applied, and the *secondary* is that portion of the transformer producing the secondary pressure. It should be noted that the primary pressure *may be greater* (as in a step-down transformer) than the secondary pressure. The best definition of the *primary* of a transformer is, *that portion of a transformer* **receiving** *energy*; this having no reference to pressures.

In any case the ratio of transformation may be expressed as:

**RATIO OF TRANSFORMATION =**

$$\frac{\text{SECONDARY PRESSURE, IN VOLTS}}{\text{PRIMARY PRESSURE, IN VOLTS}} = \frac{E_s}{E_p}$$

As an example, suppose it is desired to find the ratio of transformation of a transformer, if the applied primary pressure is 2200 volts and the secondary pressure is 110 volts.

RATIO OF TRANSFORMATION $= \frac{110}{2200} = \frac{1}{20} = 0.5$; or the transformation is a 20 to 1 (step-down) transformation.

Again, suppose the primary pressure is 110 volts and the secondary pressure is 20,000 volts, then the RATIO OF TRANSFORMATION = $\frac{20000}{110} = \frac{2000}{11} = 181.81$; or the transformation is an 11 to 2000 transformation.

When the *ratio of transformation* is **greater than unity,** the transformer is called a "*step-up*" *transformer*; when less than unity, it is called a "step-down" transformer.

If there were no losses in a transformer, then the currents in the primary and secondary coils would be in exact *inverse* ratio to each other as compared with their corresponding primary and secondary *pressures.* But as indicated by equations (7) and (7a), page 15, such exact relation cannot exist.

Let it be supposed that $E_s$ = n times $E_p$, then equation (7), page 15 may be written:

$$\text{Efficiency,} \quad \eta = \frac{(nE_p)I_s}{E_pI_p \times P.F.} \; (9); \; (E_s = nE_p.)$$

$$\text{or} \; \frac{I_s}{I_p} = \frac{\eta \times P.F.}{n}; \; \text{or} \; I_s = \frac{I_p}{n} \eta \times P.F. \; (10).$$

That is, when the secondary pressure is n times the primary pressure, the secondary current is not exactly ($\frac{1}{n}$) one nth. of the primary current; since $\eta \times$ P. F. is *always less than unity.*

For ordinary purposes, however, the proportional relations; if $E_s = nE_p$ then $I_s = (\frac{1}{n})I_p$; may be used without great error. It should be remembered however that if $E_s$ is exactly n times $E_p$, $I_s$ is always slightly *more* than $\frac{1}{n}$ of $I_p$, in actual practice.

It is evident at this point in the discussion, just why the transformer is so valuable as an intermediate device in the process of power transmission. By stepping the pressure *up*, the current may be stepped *down*, so that for transmitting a given power, much *less* line copper is necessary, when the power is delivered at a high pressure, (small current) than when the same power is delivered at a low pressure. With the smaller current the $R\bar{I}^2$ line loss is greatly reduced. Interest on investment of copper is rendered much less by using the transformer.

## DESIGNING A 20,000 VOLT TRANSFORMER.

In designing a transformer as in designing many electrical devices, different requirements as to the operative conditions will necessitate different methods in designing.

A brief outline applying to the design of a transformer will be presented herewith that may serve as a guide in varying the manufacture of the transformer, for which working directions are given, beginning on page 26. The method here adopted is not a rigorous mathematical treatment, but one designed to emphasize practical applications. As a matter of fact designs are usually figured out on the assumption that the alternating-pressures and currents are *sine-waves*, while they are seldom such shapes in practice. Deviation from a sine-wave form affects the whole matter of transformer design and operation. The considerations in this book will be on the assumption of sine-wave forms.

The following outline will apply to a 1 K. W. or 1000 watt output, "*step-up*" transformer, transforming 110 volts, at 60 cycles, to 20,000 volts, necessarily at the same frequency.

The ratio of transformation is $\frac{20000}{110} = 181.8$. See page 16.

The primary current will be assumed as 10 amperes, and the secondary current as .05 ampere.

The core losses and the full-load copper losses in the transformer will be assumed to be equal to a *total* of 75 watts, and the copper losses to be equal to 50 watts. This means that the efficiency of the transformer is to be 93%. The output being 1000 watts and the input being $\frac{1000}{.93}$ = 1075.1 watts. The core losses will evidently be 25 watts total. The core losses consist of the so-called eddy-current loss and the hysteresis loss; while the copper losses are the $R\bar{I}^2$ losses in both the primary and the secondary coils.

The resistances of the primary and secondary may be readily calculated, for any assumed current, if the loss in the primary and in the secondary coils is given.

The primary loss in watts is denoted by $R_p\bar{I}_p^2$.

The secondary loss in watts is denoted by $R_s\bar{I}_s^2$.

Under the given conditions $R_p\bar{I}_p^2 + R_s\bar{I}_s^2 = 50$ watts.

## RESISTANCE OF PRIMARY WINDINGS.

Although the sum of the primary and the secondary losses is to be 50 watts, the two losses are not necessarily equal to each other. It will be advisable to allow a *less* loss for the primary than for the secondary.

For the case under consideration the loss for the primary will be assumed as 20 watts; while that for the secondary will be assumed as 30 watts.

Since the loss in the primary windings is to be 20 watts, then:

$R_p\bar{I}_p^2 = 20$, and $R_p = \frac{20}{10^2} = \frac{2}{10} =$ **0.2 ohm,** the required resistance of the primary windings.

## NUMBER OF TURNS IN THE PRIMARY WINDINGS.

At this point it will be necessary to present what is called the fundamental equation of the transformer. Expressed in symbols this is:

$$\mathbf{E_p} = \frac{A_c N_p \times 2\pi f \mathfrak{B}}{\sqrt{2}\, 10^8}; \quad (11)$$

in which $\mathbf{E_p}$ denotes the alternating-pressure, expressed in *volts*, applied to the primary; $\mathbf{A_c}$ denotes the area, expressed in square centimeters, of the cross section of the iron core; $\mathbf{N_p}$ denotes the number of turns in the primary windings; $f$ denotes the frequency, in cycles per second, of the applied pressure, and $\mathfrak{B}$ denotes the number of magnetic lines of force set up in the core *per square centimeter* of cross section of the iron core.

So far as the assumptions already made are concerned, there are three *unknowns* in this equation; $A_c$, $N_p$, and $\mathfrak{B}$. $E_p = 110$ volts, $f = 60$, and $2\pi = 2 \times 3.1416$.

If values are assumed for $A_c$ and $\mathfrak{B}$ the equation may be solved for the value of $N_p$; the number of turns of wire in the primary windings.

It is not advisable to allow the value of $\mathfrak{B}$ to exceed 5000 gausses (magnetic lines per square centimeter) in transformer operation.

It is plain that the greater the value assumed for $\mathfrak{B}$, the less number of turns will be required, and the less iron required for the core.

Let $\mathfrak{B} = 3000$ and $A_c = 44.4$ centimeters. Then:

$$N_p = \frac{10^8 \times E_p}{\sqrt{2}\pi f \mathfrak{B} A_c} = \frac{11{,}000{,}000{,}000}{1.414 \times 3.1416 \times 60 \times 3000 \times 44.4}$$

$=$ **300 TURNS.**

### DATA.

$10^8 = 100{,}000{,}000.$

$E_p = 110$ volts.

$f = 60$ cycles per second.

$\sqrt{2} = 1.414$; $\sqrt{2}\pi = 4.44$; $\sqrt{2}\pi f = 266.53.$

### LENGTH OF THE PRIMARY WINDINGS.

If the cross section of the iron core is to be 44.4 square centimeters it will be $\frac{44.4}{6.45} = 6.89$ square inches.

If the core is to be *square* in cross section, the length of one side must be $\sqrt{6.89} = 2.6$ inches. The distance around the core will be $4 \times 2.6 = 10.4$ inches.

The length of a *mean* turn of the primary must be more than this, say 11 inches. If there are 300 turns in the primary windings the total length will be $300 \times 11 = 3300$ inches or $\frac{3300}{12} = 275$ feet.

### SIZE OF THE PRIMARY WIRE.

If the resistance of the primary is to be $\frac{2}{10}$ ohm, (page 18) and its length 275 feet, the resistance per foot must be $\frac{0.2}{275} = 0.000727$ ohm.

Consulting the table on page 21 column headed **I**, the nearest size of Brown & Sharp gauge wire is found to be a No. 9 wire.

### WEIGHT OF THE PRIMARY WINDINGS.

Since No. 9 B. & S. gauge double cotton covered round copper wire weighs 0.0404 pound per foot in length, the weight of the complete primary winding will be $0.0404 \times 275 =$ **11.1 pounds.**

## DATA APPLYING TO THE SECONDARY.
## NUMBER OF TURNS IN SECONDARY WINDINGS.

The ratio of transformation being 181.8 and the number of primary turns being 300, the minimum number of turns required for the secondary would be 181.8 × 300; but if the ratio of currents is assumed *inversely* as the pressure ratios, then there must be *more* than the proportionate ratio of turns. At least $\frac{181.8 \times 300}{.93}$ = 58645 TURNS. 58650 MAY BE ALLOWED.

## RESISTANCE OF SECONDARY WINDINGS.

Since the loss in the secondary has been assumed at 30 watts, then the resistance, in ohms, of the complete secondary windings will be:

$$R_s = \frac{30}{.05^2} = \frac{30}{.0025} = \textbf{12,000 ohms.}$$

## LENGTH OF THE SECONDARY WINDINGS.

The current density assumed for the secondary wire being 1032 amperes per square inch, which has been found to be a safe value, from the relation,

$\frac{I_s}{A_s}$ = 1032, the area of the secondary wire will be $A_s = \frac{.05}{1032}$ or .00004845 square inch.

The area of this wire, in circular mils, will be, .00004845 × 1,274,500 = 61.7 CIRCULAR MILS. (See page 3.)

The nearest B. & S. gauge wire is a No. 32, (see table page 21, column D.) which will be used.

If No. 32 B. & S. gauge is used and the total resistance of the secondary is to be 12000 ohms, the possible number of feet will be:

$\frac{12000}{.1618}$ = 74165 FEET. (From column I page 21, No. 32 wire has a resistance of .1618 ohm per foot.)

## WEIGHT OF SECONDARY WINDINGS.

Consulting table on page 21, column headed G, the weight of double cotton covered, 32 B. & S. is seen to be .222 pound per 1000 feet. The total weight required in the present case is .222 × 74.16 = **16½ POUNDS.**

## DATA APPLYING TO COPPER MAGNET WIRE.

Those desiring to design transformers for outputs different from those given in this book, will find the data, applying to the more common sizes of round Double Cotton Covered (D. C. C.) copper magnet wire, of considerable help to them.

| A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|
| No. B.&S. Ga'ge | Diameter of Bare Wire in Inches | Diameter in Mils | Area in Circular Mils | Area in Square Inches | Diameter of D. C. C. Wire over all in in. | Weight per 1000 feet of D. C. C. Wire | Feet per Pound of D. C. C. Wire | Ohms per Foot at 68 degrees F. | Ohms per Foot at 122 degrees F. |
| 6 | .1620 | 162 | 26,244 | .020612 | .176 | 80.1 | 12.4 | .0003944 | .0004406 |
| 8 | .1285 | 128.5 | 16,512 | .012969 | .142 | 50.4 | 19.6 | .0006271 | .0007007 |
| 9 | .1144 | 114.4 | 13,087 | .010279 | .125 | 40.4 | 24.7 | .0007908 | .0008835 |
| 10 | .1019 | 101.9 | 10,384 | .0081553 | .113 | 31.9 | 31.1 | .0009972 | .001114 |
| 12 | .0808 | 80.8 | 6,528 | .0051276 | .092 | 20.1 | 49.2 | .001586 | .001771 |
| 14 | .06408 | 64.08 | 4,106 | .0032271 | .075 | 12.7 | 77.5 | .002521 | .002817 |
| 16 | .05082 | 50.82 | 2,583 | .0020268 | .060 | 7.99 | 122 | .004009 | .004964 |
| 18 | .0403 | 40.3 | 1,624 | .0012756 | .050 | 5.05 | 192 | .006374 | .007122 |
| 20 | .03196 | 31.96 | 1,022 | .00080425 | .041 | 3.22 | 300 | .01014 | .01132 |
| 22 | .02535 | 25.35 | 642.4 | .00050273 | .0343 | 2.03 | 473 | .01612 | .01801 |
| 24 | .02010 | 20.1 | 404.0 | .00031731 | .0291 | 1.30 | 729 | .02563 | .02863 |
| 26 | .01594 | 15.94 | 254.1 | .00019856 | .0249 | .822 | 1,114 | .04075 | .04552 |
| 28 | .01264 | 12.64 | 159.8 | .00012469 | .0216 | .526 | 1,700 | .06479 | .07239 |
| 30 | .01003 | 10.03 | 100.5 | .000078540 | .0190 | .337 | 2,611 | .1030 | .1151 |
| 32 | .00795 | 7.95 | 63.2 | .000049639 | .0169 | .222 | 3,788 | .1618 | .1830 |
| 34 | .0063 | 6.3 | 39.69 | .000031173 | .0153 | .148 | 5,376 | .2605 | .2910 |
| 36 | .0050 | 5.0 | 25.00 | .000019635 | .0135 | .101 | 7,937 | .4142 | .4627 |
| 38 | .00396 | 3.96 | 15.72 | .000012316 | .0119 | .066 | 11,310 | .6585 | .7357 |
| 40 | .00314 | 3.14 | 9.88 | .0000077437 | .0111 | .048 | 15,037 | 1.047 | 1.296 |

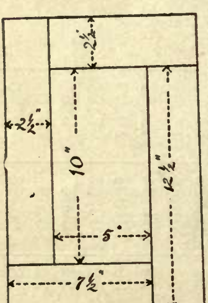
## DESIGNING THE IRON CIRCUIT.

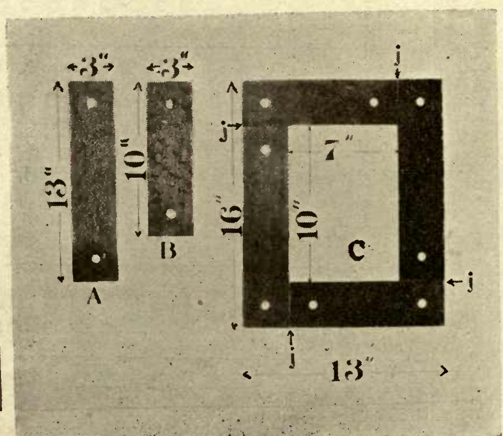
The iron circuit of a modern transformer consists of thin plates of soft steel, sometimes called "transformer steel", laid one upon another to form an iron core of the desired thickness; denoted by C in figure 2, page 5 and figure 17, page 37. The plates are usually coated all over with some kind of insulating varnish, to insulate each plate from the ones next to it; thus reducing the loss due to so-called *"eddy-currents"*; (also called "foucault currents").

While joints are undesirable, so far as losses in the iron magnetic circuit are concerned, it is very difficult to construct a high-pressure transformer without joints, and a magnetic circuit without joints increases the first cost of material, because of the waste material in stamping the plates, and increases the cost of labor in assembling.

The softer the iron or steel that is used for the core, the less the loss due to "hysteresis". Ordinary iron plates may have their magnetic qualities improved by "annealing"; heating them to a red heat and allowing them to cool very slowly while protected from the air by being covered with ashes. Hysteresis loss being due to the reversal of the molecules of the iron when the current in the primary coils is reversed, if the frequency of the primary current is increased, the molecules of iron have their position reversed more times each second, and the more rapid motion of the molecules has the effect of increasing the heating of the iron core; as more rapid hammering would have. The higher the frequency the greater the "hysteric" loss.

The heating of the core means the appropriation of a portion of the energy input to the transformer that is therefore not available for useful output, and which should be kept down to as small an amount as possible.



### NUMBER OF IRON PLATES FOR CORE.

If the core is built up of plates $2\frac{1}{2}$ inches wide; one set being $12\frac{1}{2}$ inches long and the other set $7\frac{1}{2}$ inches long as indicated in figure 6, the plates being $\frac{15}{1000}$ of an inch (15 mils) thick, it would require about 168 sheets placed together flatwise to build up to a thickness of $2\frac{1}{2}$ inches. With a width of $2\frac{1}{2}$ inches the thickness should be slightly over $2\frac{1}{2}$ inches ($2\frac{3}{4}$ inches) to make the cross section of the core 6.89 square inches as stated on page 19.

As will be shown later, on page 25, this cross section is slightly less than is necessary to give the volume of iron for continuous operation at full-load under the assumed conditions.

There will be needed, $2 \times 183 = 376$ sheets $12\frac{1}{2}''$ by $2\frac{1}{2}''$ by 15 mils thick, and the same number of sheets $7\frac{1}{2}''$ by $2\frac{1}{2}''$ by 15 mils thick, to build up the core. If thicker material is employed a less number of sheets will be needed. Also the sheets might be wider as shown in figure 7, page 22.

### WEIGHT OF THE IRON CORE.

The total volume of the iron core as given above will be $2\frac{1}{2} \times 2\frac{3}{4} \times 40 = 275$ cubic inches. The *mean* length of the magnetic circuit is 40 inches. If the iron weighs 0.27 pound per cubic inch, the weight of the core is $275 \times 0.27 = 74$ pounds.

## DESIGNING THE IRON CIRCUIT.

### CORE LOSSES.

A consideration of the core losses from the application of the results of experimental practice will be in order.

The total volume, in cubic inches, of the iron constituting the core of a transformer is found by multiplying the mean length, in inches, of the magnetic circuit, by its cross sectional area, in square inches. The volume of the core will be expressed by:

$V = A_c l$ (cubic inches). V denoting volume in cubic inches; $A_c$ area of cross section of iron core in square inches, and $l$ the mean length of the magnetic circuit, in inches. The mean length of the magnetic circuit shown at C figure 7, page 22 is 46 inches. This shows holes punched in the core sheets to allow bolts to be passed through, to bolt the sheets firmly together.

The *eddy-current loss per* CUBIC INCH of core, when made of thin plates, as found by careful experimentation, may be expressed by:

$$W_e = 16.38 \frac{\bar{b}^2 \bar{f}^2 \bar{\mathfrak{B}}^2}{10^{16}} \qquad (12)$$

in which equation, $W_e$ denotes *watts*, b denotes the thickness of the iron plates, IN MILS; that is in thousandths of an inch; $f$ denotes the frequency of the primary current, and necessarily of the magnetic flux in the iron core; $\mathfrak{B}$ denotes the flux density, in gausses; that is in maxwells per SQUARE CENTIMETER. The flux density per square inch in the present case is 3000 × 6.45* = 19350 maxwells. Substituting the proper numerical values in the above equation gives:

$$W_e = 16.38 \frac{225 \times 3600 \times 9{,}000{,}000}{10{,}000{,}000{,}000{,}000{,}000}$$

$$= \frac{1.638 \times 2.25 \times 3.6 \times 9}{10{,}000} = \frac{119.4}{10{,}000}$$

= **.01194** WATT.

**DATA.**

$b = \frac{15}{1000}$ inch.
$= 15$ mils.
$b^2 = 225.$
$f = 60.$
$f^2 = 3600.$
$\mathfrak{B} = 3000$ GAUSSES.
$\mathfrak{B}^2 = 9{,}000{,}000.$

It may be noted that 10 raised to the 16th. power, is expressed by writing 1 with sixteen ciphers after it. Multiplying 10 by itself 16 times will prove the result.

The loss per cubic inch expressed in watts, due to hysteresis, may be expressed by:

$$W_h = \frac{16.38 K f \bar{\mathfrak{B}}^{1.6}}{10^7}$$; in which equation $f$ and $\mathfrak{B}$ have the same meaning as previously; (see equation (11) page 18.) while K denotes a so-called hysteretic constant; equal to about 0.0021 for ordinary thin transformer-steel sheets.

---

*6.45 square centimeters equal one square inch. (See page 3.)

Substituting the proper numerical values gives:

$$W_h = \frac{16.38 \times .0021 \times 60 \times \overline{3000}^{1.6}}{10,000,000}$$

$$= 1.638 \times .0021 \times 6 \times 3.65 = \mathbf{.07533\ WATT.}$$

**DATA.**

$$\begin{aligned} K &= .0021. \\ f &= 60. \\ \mathfrak{B} &= 3000. \\ \log \overline{\mathfrak{B}}^{1.6} &= 1.6 \times \log 3000. \\ \log 3000 &= 3.477121 \\ & \quad\ \ 1.6 \\ \hline & \quad 20862726 \\ & \quad 3477121 \\ \hline \text{Therefore } \log \overline{\mathfrak{B}}^{1.6} &= 5.5633936 \\ \text{and } \overline{3000}^{1.6} &= 365000. \end{aligned}$$

The total CORE LOSS IN WATTS PER CUBIC INCH is therefore:
$W_e + W_h = 0.01194 + 0.07533 = .08721$ watt.

If the assumed core loss is to be 25 watts the necessary volume of iron will be: $\frac{25}{.08721}$ = 286 CUBIC INCHES.

This is the minimum allowable volume for continuous operation at the assumed core loss.

It may be noted that the *length* of the core must be proper to accommodate the requisite number of turns of wire, both primary and secondary, as well as the necessary amount of insulating material, separating the primary from the secondary, and separating the sections or so-called "*pies*" of the secondary winding.

The so-called "*core type*" of transformer is always adopted for high-pressure work; see b, figure 1, page 5.

To obtain an idea of the *necessary space* required for the windings of the transformer being designed, again consulting the table on page 21, the diameter of No. 9 covered wire, (column F) being .125 inch, and there being 300 turns, the cross sectional area required by the primary windings is $0.125 \times 0.125 \times 300 = 4.68$ square inches.

For the secondary the required area is $0.0169 \times 0.0169 \times 58650 = 16\frac{3}{4}$ square inches.

A total of about $21\frac{1}{2}$ square inches is required for both windings. If the primary is wound in two layers, and one section for each limb of the core, the necessary *length* of core to accommodate one section of two layers will be $\frac{300}{4} \times 0.125 = 9.4$ inches. The distance may be made 10 inches as indicated in figure 6, page 22.

Allowing 50% of area for cross-section of insulation, the area included by the core will need to be about 42 square inches. If the opening through the core, is 10 inches in one direction, the other dimension of the opening (or the width) will need to be 4.2 inches. This should be taken as 5 inches, when building the core; see figure 6, page 22.

## DIRECTIONS AND DATA FOR CONSTRUCTING A 3 KILOWATT, 20,000 VOLT TRANSFORMER.

The following directions and data will enable anyone to construct a transformer for use on a 60 cycle alternating-current circuit, that will give an output of about 3 kilowatts continuously without overheating, or a 50% greater output for short intervals, with a pressure of 110 volts applied to its primary, while delivering the output at about 20,000 volts.

### IRON CORE.

196 strips of soft iron (so-called Russia iron that stove pipe is made of will serve well; or so-called "transformer steel" may be used) 9½ inches long by 2½ inches wide, and 196 strips of the same material 15½ inches long by 2½ inches wide; all $\frac{1}{40}$ of an inch thick.

The data applying to the iron core is here given differently than that given under the "Design of a 20,000 Volt Transformer" for the reason that many who desire to construct a transformer cannot readily obtain the *thin* "transformer steel", but are able to obtain the "Russia" iron from local hardware dealers. This iron comes usually about $\frac{1}{40}$ of an inch thick in large sheets, from which, strips of the desired size may be cut. The strip should be kept as flat as possible.

1. Carefully remove all burrs and sharp edges from the iron strips by means of sand paper (No. 0), or by means of a fine file.
2. Coat both sides and edges of each strip with shellac varnish.
3. Stand strips on end as soon as varnished and allow the varnish to dry for several hours. One side of each strip may be varnished and allowed to dry thoroughly, and then the other side may be treated likewise. The drying process should take place in a warm dry room.
4. Do not allow one freshly varnished strip to come into contact with another strip while drying.
5. While the strips are drying, prepare the wooden supporting structure according to the following:

A base consisting of soft pine, made of planks 22 inches long, 2 inches thick and of sufficient number (depending upon their width) to form a base 22 inches × 22 inches. These planks to be cleated together by screwing to their under sides two cleats of the same material, 2 inches thick, 22 inches long and 4 inches wide. See figure 8.

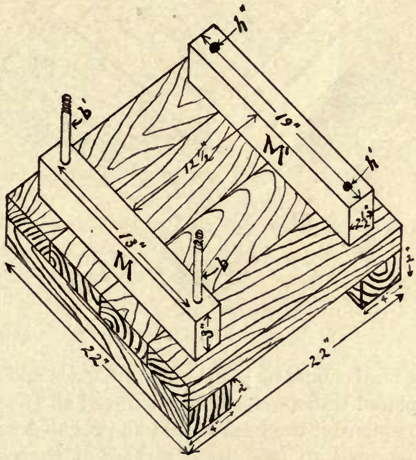



Fig. 8.

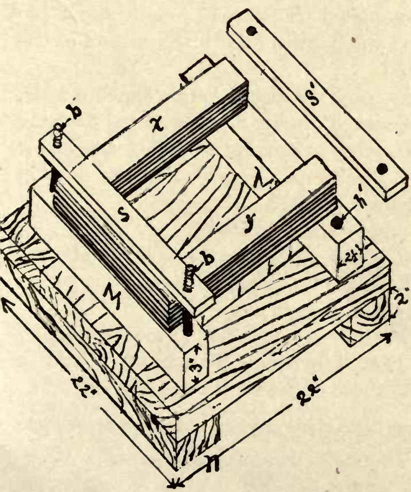



Fig. 9.

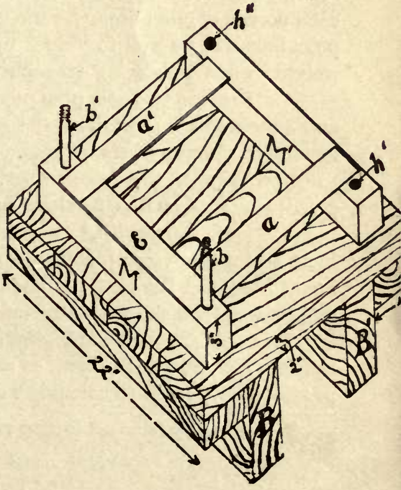



Fig. 10.

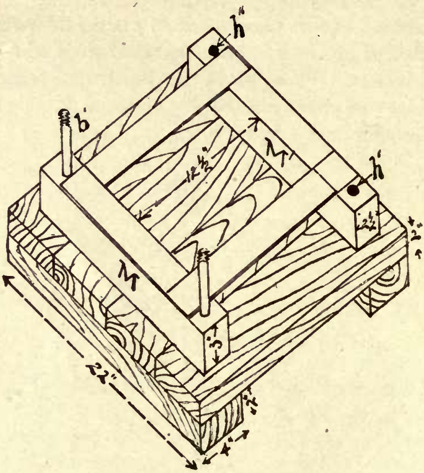


**Fig. 11.**

The lumber used should be planed on both sides and edges.

If the completed transformer is to be moved about, from one place to another, very frequently, the base should be provided with heavy casters, which may be secured to the under surface of the cleats. "Feltoid" casters, made by the Burns and Bassick Co., Bridgeport, Conn., have been found to give the best satisfaction. Four of these are sufficient: one for each corner of the base. As the completed transformer weighs about 140 pounds it will be well to "block up" the base to relieve the casters of the weight, when not being transported.

6. Provide two soft pine pieces, each 19 inches long, $2\frac{1}{2}$ inches wide, and 3 inches high as indicated at M and M′, figure 8, which when properly located on the top of the plank base, serve to provide a bearing surface for the iron core of the transformer. The proper position for the bearing pieces may be seen by consulting figure 8, page 27.

7. Bore four holes,* two of which are indicated by h′, and h″, $\frac{9}{16}$ inch in diameter, completely through the supporting blocks, M, M′, the board base and the cleats. The distances between the supporting pieces and between the centers of the holes are given in figure 8.

8. Two strips of hard wood, (oak or maple) each 16 inches long, $2\frac{1}{4}$ inches wide and 1 inch thick, as indicated by S, and S′, figure 9, should be provided with holes to coincide with those in the supporting blocks.

*Care should be taken not to put screws in the cleats and base where it is necessary to bore the holes.

These strips serve to bind the iron strips firmly together by means of four bolts, 12 inches long and ½ inch in diameter, which pass down on either side of the iron core, through the supporting pieces, and the base, two of which are shown in figure 9, at b and b′.

9. If desired, sand paper the surfaces of the wooden structure, and stain with cherry or oak stain as preferred. Apply with a brush a "filler" consisting of ½ pint of linseed oil, ¼ pint turpentine and about two tablespoonfuls of corn starch thoroughly mixed together. After the two applications have dried for 24 hours, rub the surface with a handful of excelsior, to remove lumps and excess of corn starch, and apply a coat of shellac varnish. After this has dried for 10 hours, sand paper the surface with No. 00 sand paper, and apply a second coat of varnish. Let this dry for 10 hours.

10. During the Periods necessary for drying processes, the work of winding the coils may be performed. See page 33.

11. Place the supporting pieces M and M′ in position, and insert the bolts b and b′ in M. During this stage of the construction the structure should be supported on a box or by blocks as indicated by B and B′, figure 10, high enough to allow the 12 inch bolts to be inserted from below. The bolts may be inserted from the top, in the piece M′, to simply hold it temporarily in position.

12. Proceed to lay the iron core strips in position as shown in figure 10. Consult figure 6, page 22, and figure 7, page 22. The two long strips a, a′, should be parallel with each other and at right angles with the shorter end strip, e. Directly on top of the strips already laid in place, apply another layer of strips as indicated in figure 11, page 28.

Continue piling the strips, alternating the joints, until all of the longer strips and *one half* of the shorter strips have been used.

13. Place the strip S in position and bolt down firmly by means of the bolts b and b′. Just before the final turns are given to the nuts on b and b′, the strips may be carefully lined up, by means of a small block and hammer, or by using a wooden mallet. The arrangement now appears as in figure 9, page 27.

14. If now the structure is tipped up on its end, n, n′, figure 9, the piece M′ may be removed, to allow the primary and the secondary coils to be slipped on over the limbs x and y of the iron core.

It is very essential that both primary and secondary coils be well insulated from the connecting end yokes of the iron core. This may be accomplished by *building up* an insulating sheet using the scrap pieces of Empire Cloth, sticking them together with shellac varnish, and compressing the sheet between two flat boards under a heavy weight, while the shellac varnish hardens. The built up sheet may be about ½ inch thick shown at a, figure 12, page 31, and in figure 14, page 33; also in position on the transformer at a, figure 12. A sheet in the process of construction is shown at b, figure 14, and a finished one at a, same figure. Two such sheets are needed for each transformer, as shown in figure 16, page 35.

To build up such a sheet, place a square piece of Empire Cloth, the desired size, on a flat board, and apply a coat of shellac varnish to its upper surface. Immediately place scrap pieces of the cloth on the varnished surface and apply a coat of varnish to their upper surface. Continue this process until the desired thickness is attained. Place another whole sheet of Empire Cloth over the top of the built up sheet, place a flat board on the completed built up sheet, and apply a weight of about 50 or 75 pounds. Allow the sheet to dry for twenty-four hours and then trim to the desired shape, with a sharp knife. By this process there is no waste of Empire Cloth, and a sheet of material having insulating qualities approaching those of mica is obtained at a small cost.

15. Slip each tube, containing each section of the "primary" windings, over each leg of the core, bending the terminals to allow the tubes separating the primary from the secondary windings to be slipped over the primary coils, after adjusting one of the insulating discs to the lower *end* of each separating tube, about 2 inches from the end.

An excellent insulating separating tube may be constructed or "built up" by first gluing two layers of cardboard to form a tube of sufficient size to slip over the primary windings easily; applying a coat of shellac varnish to the outer surface, and immediately winding thereon in a spiral fashion, strips of Empire Cloth, about 1 inch wide, and about 5 feet in length. The winding should lap each other about ½ inch, and after one complete winding has been finished, its surface may be coated with shellac varnish and another spiral wound on. The process may be continued until a tube of the proper thickness has been built up. After such a tube has been allowed to thoroughly dry, a strong tube having excellent insulating qualities is the result.

The *outside* diameter of this separating tube should be slightly less than the inside diameter of the secondary pies.

These separating tubes are shown at t, t′, figure 12, page 31.

16. Next slip on over the separating tube a pair of "*pies*" of the secondary winding, being arranged as explained under winding of secondary coils, page 33, until they rest against the end insulating disc.

17. Proceed to add the secondary "pies", to both limbs of the transformer putting 16 single pies or 8 "units" on each limb. The units should be placed so that their terminals are all on the same line, to facilitate in joining them together.

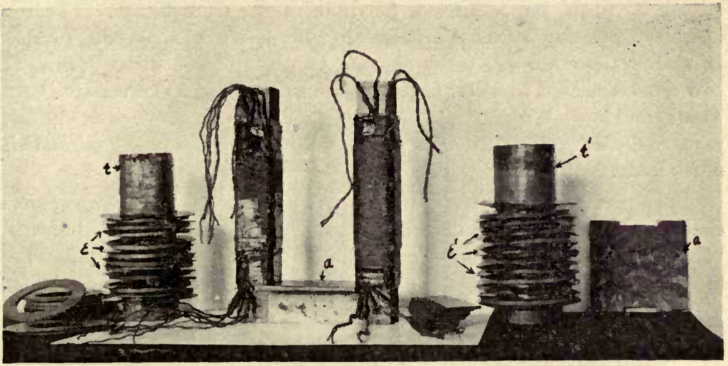


**Fig. 12.**

18. The units or pairs of pies should be placed relatively with each other so that when their terminals are connected with each other there will be a continuous winding, *in the same direction*, from one end of each limb to the other end of the same limb. That is, so that each half of the secondary winding shall consist of turns of wire all in the same direction of winding, and the two half sections of the complete secondary must be so connected with each other as to work properly together and not in "opposition".

Figure 3, page 12, will give an idea of the relation of the turns in the windings.

19. The free ends of the "units" should be carefully cleaned, twisted together, and soldered by use of a small soldering iron. Do not use a lamp in soldering small wires. The heat of the flame tends to "burn" the wire, making a very poor joint and doing permanent injury to the wire.

20. Properly connect the half-sections of the secondary with each other and bring the two end terminals to the top of hard rubber posts each ½ inch in diameter, 3 inches high, located as shown in figure 16, page 35. These hard rubber posts may be inserted in ½ inch holes about 1 inch deep.

21. The primary terminals may have flexible leads, soldered to them and brought out to four binding-posts, to allow various arrangements of connections. See figure 12.

## WINDING THE PRIMARY COILS.

The primary windings require 18 pounds of No. 12 Double cotton covered (D. C. C.) B. & S. gauge, copper wire, wound double, two wires being wound side by side to form two layers, one having 40 turns, the other having 60 turns, per section or per limb of the transformer. The total operative primary turns are therefore (40 + 60) x 2 = 200 TURNS. In reality there are 400 turns of wire; two sets of 200 turns each. The two sets connected together in parallel constitute the 200 operative turns. This shows how an *equivalent* number of smaller wires may act as one large wire, and also renders winding much easier; the two smaller wires being much more flexible than the equivalent single wire.

The primary in one transformer was wound directly on the iron core, as shown in figure 12, being insulated from the iron core by several layers of "Empire Cloth"; having a thickness of about $\frac{1}{20}$ of an inch. It might have been wound on a form such as shown in figure 13, taken from the form, and

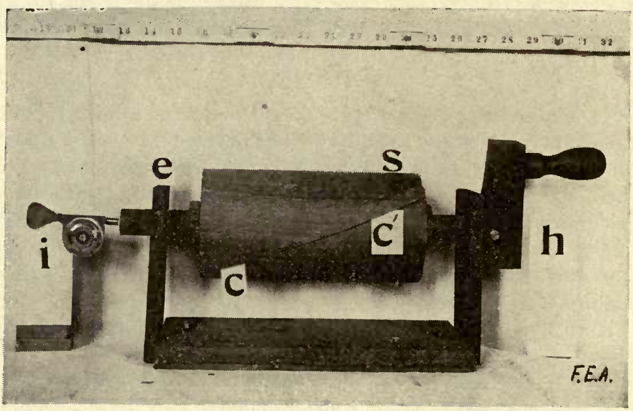



**Fig. 13.**

slipped on over the limb of the core. If wound in circular form, it allows the air to circulate through the spaces between the coil and the core, tending to keep the temperature of the transformer, when in operation, at a low value. This however requires a greater length of wire. The arrangement of the winding form should be noted. The cylinder is mounted to be turned by the handle h, is provided with a speed-counter at i, for registering the number of turns, and has a diagonal cut cc′ through it, so that its thinner ends may be screwed (screw at S) to the thicker ends thus holding the sections together. After a coil is wound, the screws at the ends may be removed, allowing the form to be easily withdrawn from the coil. The end bearing e and the handle h are removed by removing screws.

## DIRECTIONS FOR WINDING THE SECONDARY COILS.

The secondary of the transformer requires 20 pounds of No. 26 B. & S. gauge, double cotton covered copper magnet wire.


**Fig. 14.**

This secondary is wound in "pies" or thin sections shown at e and f in figure 14, 4½ inches, internal diameter, 6¾ inches over all diameter, and ⅜ inch thick. Each pie is first wound on a form as shown in figure 15, carefully bound together with pieces of the No. 26 wire, to enable it to be removed from the winding form, and then soaked in melted paraffin, in a proper sized dish. When removed from the melted paraffin, and allowed to cool, the pie may be easily manipulated. Each pie should contain 800 turns of the No. 26 wire, and 32 pies are needed for the finished transformer, if 20,000 volts are to be obtained. A set of finished pies is shown in process of being assembled on the separating tube, at e and e′, figure 12, page 31.

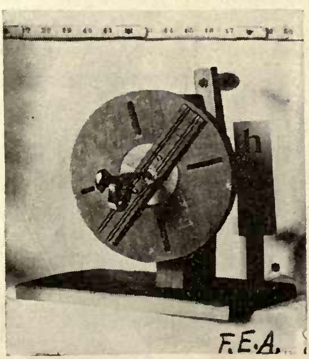



**Fig. 15.**

The winding will be greatly facilitated if done in a lathe.

A proper tension should be maintained on the wire while winding it and the wire should be continually guided from one side of the form to the other while winding, to prevent humps in the winding, or the slipping down of a turn between the turns already wound, and the side of the form.

It should be noted that the tension on the wire while it is being wound, determines whether the number of turns stated may be wound in the given space. It is not considered advisable to wind the pies too tightly as this does not allow the hot paraffin to soak into their interior.

A tube, t, figure 12, page 31, made of about 10 layers of Empire Cloth separates the primary from the secondary windings; while each secondary pie is separated from its neighbor by five discs put side by side to form an insulating separator about $\frac{1}{16}$ inch thick, shown at c, figure 14, page 33 and in figure 12, page 31, cut from a sheet of the Empire Cloth. These discs are cut to fit closely to the tube separating the primary and secondary, and having an outside diameter about one inch larger than the over all diameter of the secondary pies. The over all diameter of the separating discs may be 8 inches. A card board pattern used in cutting out the separating discs is shown at d, figure 14. If the transformer is to be immersed in oil, ordinary card board may be used in place of the Empire Cloth.

## APPROXIMATE COST OF MATERIALS.

The following is an itemized account showing the approximate cost of the transformer just described.

| | |
|---|---|
| Wood for base | $ 1.00 |
| Casters | 1.34 |
| 4 bolts, 12″ x ½″ | .20 |
| Iron strips for core, 82½ lbs. | 9.00 |
| Wire for primary, 18 lbs., No. 12 | 3.00 |
| Wire for secondary, 20 lbs., No. 26 | 10.00 |
| Linseed oil, turpentine, and shellac | 1.00 |
| Paraffin wax | 1.20 |
| Binding posts | .40 |
| 10 yards of Empire Cloth | 4.00 |
| | $31.14 |

The completed transformer is shown in figure 16, the secondary spark gap being made of copper wire bent into the shape of horns, arranged on sliding brass rods, supported by hard rubber posts. Flexible "drop cord" wires are used for primary connections.

The purchase price of a transformer such as the one described, would probably be not less than $100.00.

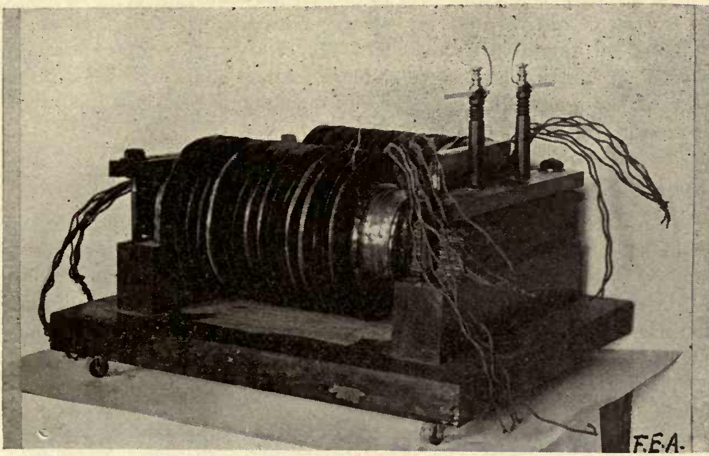



**Fig. 16.**

## OIL IMMERSED TRANSFORMERS.

All high-pressure transformers will operate much more satisfactorily if surrounded with oil, such as paraffin oil, which belongs to the kerosene family. The oil is a *liquid* insulator that is self mending after a spark discharges through it, and acts to convey the heat away from the hottest portions of the transformer; preventing excessive heating.

Good insulating oil called "transil" or transformer oil may be purchased for about 50 cents per gallon.

To make an oil containing tank for a transformer, construct a box using soft pine boards about $\frac{7}{8}$ inch thick, large enough to allow the completed transformer to be inserted with an all around clearance of about 1 inch. Cover the *outside* of the box with thin sheet copper or ordinary "roofing" tin, carefully soldering all joints to prevent leaking of oil. A faucet may be soldered to one side near the bottom of the box to allow the oil to be drawn off when desirable. The oil may however be syphoned from the box when necessary, by means of a flexible rubber tube or hose, doing away with a faucet, and preventing loss of oil by accidental opening of a faucet.

If oil is employed as an insulator, cheaper separating insulation may be used, and much labor saved in constructing a transformer, as there will then be no need of soaking coils in melted paraffin.

A word of caution may be valuable regarding the first trial of the completed oil immersed transformer. Never attempt to operate a high-pressure oil immersed transformer, for at least 24 hours after being placed in the oil. It requires time for the oil to completely soak into the interior of coils which contain many turns of wire.

## PRECAUTIONS.

All material used in the construction of high pressure transformers should be carefully inspected for defects. The greatest care should be exercised in the various processes of construction to obtain the best possible insulation of the various portions, the iron plates of the core, and the windings. The insulation of the different portions from one another may be tested by use of a telephone receiver and a single dry cell.

The several coils should be individually tested to determine any broken wire that may exist.

All coils should be carefully *inspected* and *tested individually* before assembling.

Never use *enameled* wire in high-pressure transformer construction.

Particular care in insulating is necessary, since it is the *maximum* value of an alternating-pressure that tends to puncture and break down insulation.

For example, if the pressure wave is a *sine-wave* having a working value (effective) of 20,000 volts, the maximum value of this pressure is 20,000 x 1.414; which is 28,280 VOLTS.

The maximum value of a sine-curve is equal to the $\sqrt{2}$ (square root of 2 = 1.414) times its *effective* value.

## CAUTIONS.

The experimenter using high-pressure apparatus that is connected with service mains, should keep in mind that the source of energy is capable of supplying a considerable amount; meaning that personal contact with the high pressure side of the apparatus does not cause the input to the apparatus (and to the individual) to cease. The discharge of a Leyden jar or of a condenser through the body does not prove fatal, because the supply of energy is not only limited, but is very quickly exhausted; so quickly in fact that the effect is not perhaps even harmful. The *pressure* in such a case may be much greater than that produced by an apparatus, which furnishing a much lower pressure continuously, is dangerous. Contact with the high-pressure terminals of a transformer should be guarded against. The ordinary *frequencies* offer no protection to the individual. A CONTINUOUS CURRENT OF $\frac{3}{100}$ (.03) OF AN AMPERE, IN A VITAL ORGAN, IS FATAL.

Even though the resistance of contact through the two hands may be 50,000 ohms, it is evident that 20,000 volts will send a current of $\frac{20000}{50000} = \frac{2}{5}$ of an ampere through the body:—*enough to kill a person several times.*

Always disconnect the double pole knife switch, connected with the primary, before touching any part of the secondary, with even one hand or with a stick.

The secondary should be provided with fuses of small current capacity in addition to the primary fuses.

In case of accidental short-circuit of the secondary, or in case of accidental contact with the secondary, the small secondary fuses will blow out very quickly, offering better protection than offered by the larger primary fuses.

Never attempt to adjust a high pressure wire with a screw driver, with the apparatus operating.

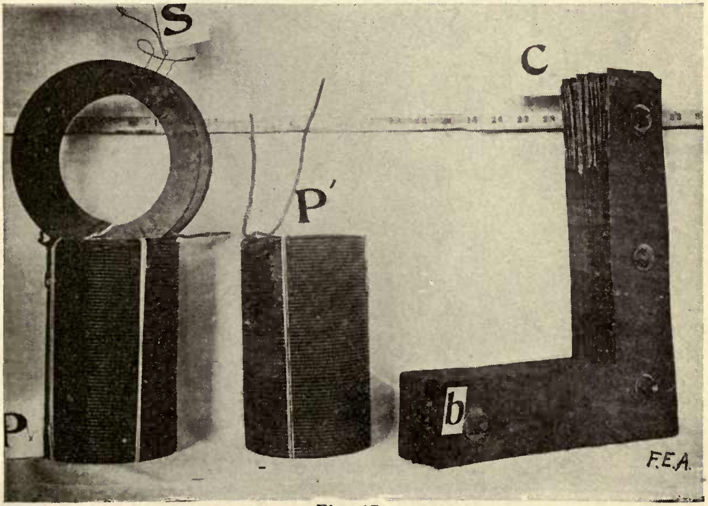



**Fig. 17.**

## DATA APPLYING TO A 4,000 VOLT TRANSFORMER.

A 1 K. W. transformer to transform from 110 volts at 60 cycles, to about 4,000 volts, is shown, in the process of construction in figures 17, and 18, pages 37 and 38. The ratio of transformation is 36.3.

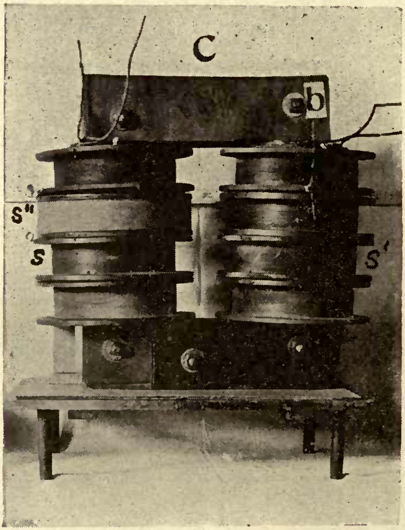



**Fig. 18.**

The core consists of angle strips of Russia iron, $2\frac{3}{4}$ inches wide, bolted together as shown at b, figure 17, page 37 and in figure 18, to make a thickness of core of $2\frac{1}{2}$ inches. The angle strips are cut from the sheet of iron as indicated in figure 19, to minimize waste of material. The longer leg of the larger angle piece is $10\frac{1}{2}$ inches, and the shorter leg is $7\frac{3}{4}$ inches long or $13\frac{1}{4}$ inches and $10\frac{1}{2}$ inches over all. This method of construction allows only *two* magnetic joints, and facilitates the taking apart of the device and the removal of the coils. One *section* of the core is shown at C, figure 17, page 37. The complete iron core weighs about 55 pounds. The primary consists of two coils, of No. 9 B. & S. gauge D. C. C. copper magnet wire, P and P′, figure 17, page 37, each wound in two layers, 61 turns, per

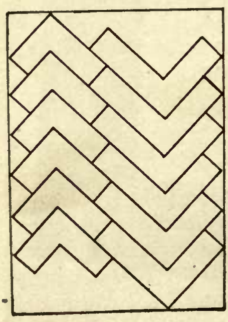


**Fig. 19.**

layer, making a total of 244 primary turns, all weighing about 9 pounds. The primary was wound on the winding form shown in figure 13, page 32, the form being 4 inches in diameter. Two layers of ordinary card board were first wound on the form and glued together, the wire being then wound on over the cardboard, tied together with tape, and the winding form removed. The inner diameter of the primary coils was $4\frac{1}{8}$ inches, and the over all diameter, $4\frac{5}{8}$ inches. The coils were given three coats of shellac varnish.

The secondary consists of eight coils of No. 26 B. & S. gauge, D. C. C. copper magnet wire, wound on wooden* spools as shown at S in figure 17, page 37, and at S, S′, figure 18; each spool containing about 1,100 turns of wire. As can be noticed in figure 17 and in figure 18 the wire was very

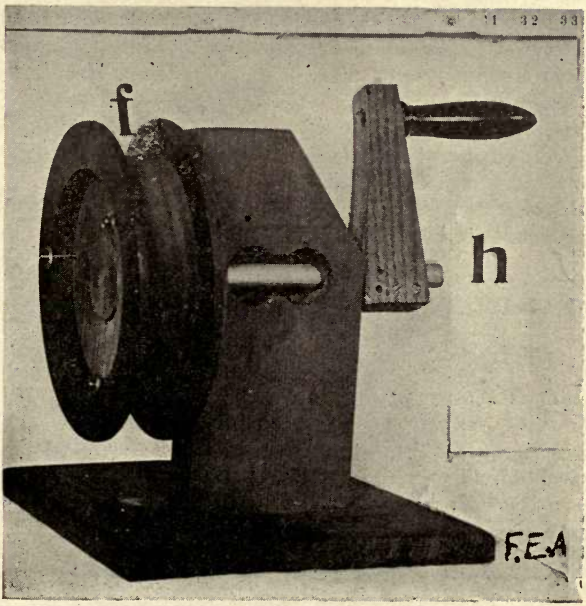



**Fig. 20.**

carefully wound, in even layers, which renders it possible to wind more turns in any given space. This transformer was designed for use without oil immersion, and without soaking the secondary coils in melted paraffin; being simply varnished over with shellac varnish.

***Dry soft pine is the best wood to use; dry white-wood being the next in desirability.**

The spools for the secondary were turned out in a wood-turning lathe, and had the following dimensions:—

Over all, $6\frac{7}{8}$ inches.
Inner hole, $4\frac{1}{16}$ inches.
Width over all, $1\frac{13}{16}$ inches.
Width of winding space, $1\frac{3}{8}$ inches.
Depth of winding space, $1\frac{3}{16}$ inches.

The wooden *spools* were thoroughly soaked in hot paraffin and cooled before the secondary was wound onto them. The application of two coats of shellac varnish would answer in place of paraffin.

Figure 18 shows one spool S″, wound with wire, and seven empty spools. Figure 20 shows an arrangement for winding the wire on to a spool f by means of the handle h.

The spools are so wound that two may be placed adjacent to each other, the inner ends of the windings on the two spools coming together, so that when joined the two spools constitute *one unit*, of continuous winding in the same direction. This allows the inner ends and the outer ends of wires from *two units* (or all the units) to be directly joined together, constituting a continuous winding, in the same direction, if any number of *units* are connected together.

If taps are brought out from any single spool, a pressure of $\frac{1}{8}$ the total, or about 500 volts may be obtained. One *unit*, two spools will give about 1000 volts.

Values of pressure of 500, 1000, 1500, 2000, 2500, 3000, 3500 and 4000 volts may be obtained by making taps to proper points.

## POSSIBILITIES OF A TRANSFORMER AS A FREQUENCY CHANGER.

All alternating-current waves are not true "SINE-CURVE" waves. When *not* sine-curve waves they are made up of the sum of a number of sine-curves, having different amplitudes and different *frequencies* from that of the so-called fundamental or resultant curve.

Figure 21 shows an alternating-wave:—either an alterating-pressure or an alternating-current—that is made up of the sum of *three* sine-waves. Each point, (designated by being surrounded with a small circle) on the fundamental or *resultant curve* was located by adding, *algebraically* the corresponding vertical heights of the three component sine-curves.

Irregular shaped alternating-curves found in practice are made up of sine-waves having frequencies that are an *odd number* of times the frequency of their fundamental. An alternating-current wave having a frequency of 60 cycles per second, may be made up of four separate sine-waves, having frequencies of 1, 3, 5, and 7 times 60: namely, 60, 180, 300

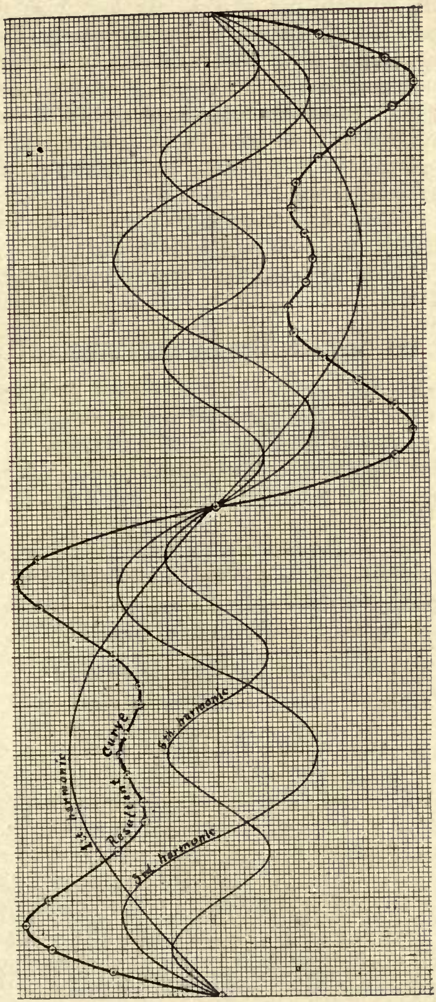



**Fig. 21.**

and 420 cycles respectively per second. By low values of magnetic flux in the iron core of a transformer, by a small primary current, *one* of the component frequencies of the fundamental may be brought into prominence, and thus the transformer, in a degree, can be made to act as a frequency changer; the changes of course being limited in number. Many current-curves in practice have been found to consist of as many as 27 component sine-curves, the frequency of each being an *"odd"* number of times that of the fundamental.

Transformers arranged on three-phase circuits may be well adapted for frequency changers, acting on the principle of magnetic supersaturation. The *"efficiency"* of frequency changers based upon the foregoing principle will not be high.

## HOW TO OBTAIN UNITY POWER FACTOR.

It is undesirable that any alternating-current device should operate at a low power factor, since this condition means increased losses, a greater first cost, and an attendant increased operating expense.

Any method of keeping the power factor at a high value, (the greatest value being unity) is valuable so far as increase in *operating* efficiency is concerned.

A *"condenser"* connected with any coil which has inductance, will tend to increase the power factor, and if the proper numerical relation exists between the "capacity" of the condenser and the coefficient of inductance of the coil, a power factor of unity may be expressed by:

$2\pi f C = \frac{1}{2\pi f L}$; (13) from which may be obtained:

$C = \frac{1}{4\pi^2 f^2 L}$. Here C denotes the capacity of a condenser, expressed in *farads*: $f$ denotes the frequency of the applied pressure; L denotes the coefficient of inductance, expressed in *henrys*, and $\pi$ as usual, denotes the number 3.1416. See page 3.

It should be observed that the larger the value of L the *less* the required value of C, to produce unity power factor at any fixed frequency. This means that for a large coil of many turns with a large iron core, a condenser having a small capacity is needed to produce a power factor of unity. A condenser connected in series or in parallel with the primary of a transformer, improves the power factor.

Likewise a condenser connected with the *secondary* improves the power factor of the secondary, and greatly increases the sparking ability of high-pressure transformers.

A condenser used in connection with the high-pressure secondary has a much smaller capacity, and is constructed differently from a condenser which is to be connected with the low pressure primary. Any condenser that is to be used with high pressures must be made of thick metal plates, very carefully insulated with thick glass plates, and immersed in oil; while a condenser for low pressures may be made of ordinary tin foil, separated by thin paraffined paper.

The following numerical example will be given: TO FIND THE CAPACITY OF A CONDENSER THAT WILL NEUTRALIZE THE INDUCTANCE OF THE PRIMARY COIL OF A TRANSFORMER WHOSE COEFFICIENT OF INDUCTANCE L = ½ HENRY, IF THE FREQUENCY OF THE APPLIED PRESSURE IS **60** CYCLES PER SECOND.

Making the proper numerical substitutions in equation (13), page 42 gives:

$$C = \frac{.0000070362}{\frac{1}{2}} = 2 \times .0000070362$$

$$= .0000140724 \text{ farad.}$$

which is equal to $\dfrac{.0000140724}{1000000}$

$$= 14.072 \textit{ microfarads.}$$

(One farad is equal to 1000000 microfarads)

**DATA.**

$\pi = 3.14159$

$\pi^2 = 9.8696$

$f = 60$ cycles.

$f^2 = 3600$

L = ½ henry.

$$\frac{1}{(2\pi f)^2} = .0000070362$$

Next suppose the inductance of the secondary of the above transformer is 50 henrys; find the numerical value of the capacity of a condenser to give a unity power factor.

In this case:

$$C = \frac{.0000070362}{50} = .00000014072 \text{ farad: or}$$

$$= \frac{.00000014072}{1000000} = 0.1407 \text{ MICROFARAD.}$$

The greater inductance of the high-pressure circuit of a transformer is because of the greater number of turns of wire constituting this circuit.

Inductance varies directly as the *square* of the number of turns on any given coil. Doubling the number of turns increases the inductance fourfold.

Another term for unity power factor is "*resonance*".

One of a number of odd harmonics may be rendered prominent by connecting a condenser (in series) with the secondary of a transformer and producing "*resonance*" with an *odd harmonic* instead of with the fundamental itself.

Applying the foregoing principle, the value of a capacity that will produce resonance with the *third harmonic* frequency may be found. If the applied pressure has a frequency of 60 its third harmonic is 3 x 60 = 180 cycles per second. In this case:

$$C_3 = \frac{1}{4\pi^2 \times \overline{180}^2 \times \frac{1}{2}} = \frac{1}{39.478 \times 32400 \times \frac{1}{2}}$$

$$= \frac{2}{1279100} = .00000156 \text{ farad.}$$

$$= \mathbf{1.56} \text{ MICROFARAD.}$$

A condenser having this capacity, connected with the primary, would tend to bring the third harmonic frequency into prominence, causing the arrangement to act as a frequency changer, from 60 to 180.

The value of a capacity to reinforce the *fifth* harmonic would be:

$$C_5 = \frac{1}{39.478 \times \overline{300}^2 \times \frac{1}{2}} = \mathbf{0.562} \text{ MICROFARAD.}$$

A condenser having this capacity will tend to make prominent a frequency of 300 cycles per second. By using a *variable condenser* properly graduated, the different odd harmonics may be rendered prominent. For this particular primary a condenser having a capacity of 0.3 microfarad will bring out the seventh harmonic.

## METHODS OF CONNECTING PRIMARY COILS TO PRODUCE DIFFERENT SECONDARY PRESSURES.

The induced secondary pressure in any transformer depends upon the magnitude of the applied primary pressure.

If pressure is used that is supplied from so-called constant pressure mains, it is impossible, with a coil having a single winding, to *increase* the induced secondary pressure; it may however be readily *reduced* by connecting resistance, (either inductive or non-inductive) in *series* with the single coil.

With *two* primary coils, on the other hand, a method for varying the secondary pressure may be employed, by first connecting the two primary coils in series. The two coils may next be connected together in parallel, with resistance in *series* with the parallel arrangement of the two coils. By varying the amount of the resistance, the applied pressure may be varied as desired.

If the applied primary pressure is 110 volts, and the two primary coils are connected in *series*, the pressure applied to each coil is 55 volts. When the two coils are connected with 110 volt mains, each *coil* receives an applied pressure of 110 volts instead of only 55 as when the coils were in series. Much more current in the coils is the result, according to equation (1), page 7, and the flux density in the iron core is greatly increased according to equation (11), page 18.

Another way of expressing the matter would be based upon the condition that the pressure *per turn* of both primary and secondary is the same. If the pressure *per turn* of the primary is increased, then the pressure per turn of the secondary is also increased.

EXAMPLE. Suppose the primary of a transformer consists of two coils, each having 110 turns of wire, while the secondary of the same transformer consists of two sections or coils, each having 2200 turns.

If the two primary coils are connected in series and 110 volts applied, the primary *per turn* pressure will be $\frac{110}{220} = \frac{1}{2}$ volt. If the per turn pressure of the secondary is also $\frac{1}{2}$ volt, the secondary terminal pressure will be 2200 volts, provided the secondary coils are also connected in series. If the secondary coils in this case should be connected in parallel, the secondary terminal pressure would of course be 1100 volts.

Now assume that 110 volts is applied to each individual primary coil; the two coils being in parallel. The *per turn* pressure will be one volt. The induced secondary pressure will be 1 volt per turn; giving a secondary terminal pressure of 4400 volts if the two secondary coils are in series, and 2200 if they are in parallel.

With the latter arrangement, care will need be taken that the coils are not overheated.

If two similar transformers have their primarys connected with the same supply mains, and their secondaries connected in *series* with each other the combined terminal pressures will be double that of a single transformer. If ten transformers, each giving a secondary terminal pressure of 100,000 volts, have their primaries all connected together in parallel and to the same service mains, while their secondaries are all properly connected together in series, the combined terminal pressure would be 1,000,000 volts, which would produce a vigorous spark.

**PRICE OF MATERIALS FOR BUILDING THE HIGH PRESSURE TRANSFORMER DESCRIBED ON PAGE 26 OF THIS BOOK, AND FOR BUILDING THE TRANSFORMER AS PER PAGE 38.**

| | |
|---|---|
| Iron strip for Core.................................... | 20 cts per pound. |
| Wire for Primary.................................... | 25 cts per pound. |
| Wire for Secondary.................................... | 35 cts per pound. |
| Bolts and Screws.................................... | 30 cents. |
| Paraffin Wax.................................... | 15 cts per pound. |
| Binding Posts.................................... | 15 cts. each. |
| Empire Cloth.................................... | 40 cts. per yard. |

Prices subject to change without notice. Remit amount with order to

**ENGINEERING EDUCATION EXTENSION,**

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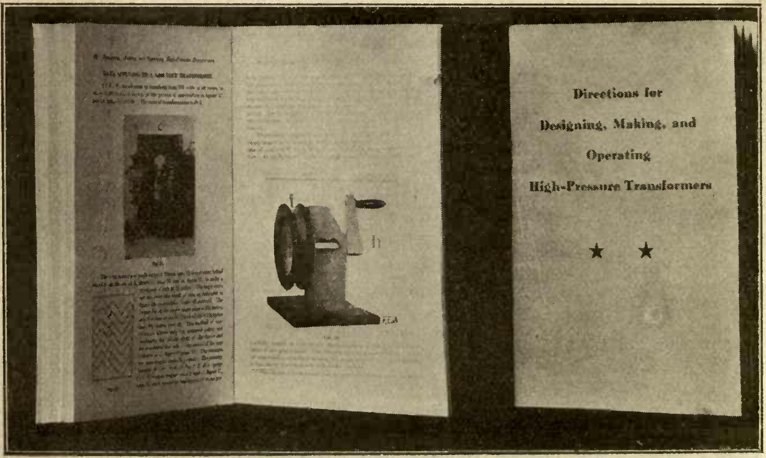
# Directions for Designing, Making and Operating

# High Pressure Transformers

Review from **"Electrical Engineering"**, July, 1915.

A new book entitled "DIRECTIONS FOR DESIGNING, MAKING AND OPERATING HIGH PRESSURE TRANSFORMERS," written for those experimenters who desire to construct their own apparatus, is also published by Prof. F. E. Austin. This book is a companion volume of "How to Make a Transformer for Low Pressures," but containing more working directions and useful talks such as loss due to Hysteresis, per cubic inch of iron core for various flux densities and frequencies; and data applying to copper magnet wire. The book is well illustrated with half-tone and line cuts showing special methods of procedure, fundamental theories, and finished apparatus. It is written in simple English, is full of technical information and new ideas relating to methods of design and construction, and will prove of great assistance to those who are pursuing correspondence courses or regular college courses. The price of the book is 65 cents.



Review from **"Machinery"**, May, 1915.

*Directions for Designing, Making and Operating High-Pressure Transformers.* By F. E. Austin, 46 pages, 4¾ by 7½ inches, 21 illustrations. Published by Prof. F. E. Austin, Hanover, N. H. Price 65 cents.

This book is a companion to the author's work on making a transformer for low pressures. It describes the making of a step-up transformer, giving 20,000 volts, for wireless telegraphs, telephones, for operating tube lamps and X-ray tubes. The mathematical matter is treated in a simple way that is well within the comprehension of the amateur who would be interested in building a high-pressure transformer for experimental purposes. All materials are specified and all calculations are worked out for the model described. Probably no exercise would give the average student a firmer grasp of electrical principles than the building of a piece of apparatus like this transformer.

From **"Telephony"**, Chicago, Sept. 4, 1915:

*Directions for Designing, Making and Operating High-Pressure Transformers,* by Prof. F. E. Austin, Hanover, N. H. 46 pages, 4½ ins. by 7½ ins. with illustrations. Price, cloth binding, 65 cents.

In this booklet, points relating to the design of a transformer are first taken up, after which the practical calculations involved are considered. Details of the construction of a three-kilowatt, 20,000-volt transformer are then presented, sketches being used to make clear the text. Estimates of the costs of materials entering into the construction of transformers according to the design presented are given.

PROF. F. E. AUSTIN,
HANOVER, N. H.,

DEAR PROF. AUSTIN:

Your two little books on transformers received. They are exceptionally well gotten up. I was pleased to get them.

Enclosed you will find check paying for books and return postage on biii.

I trust I may have an opportunity of using more of your books in the near future.

Yours very truly,

ERNEST C. CHESWELL,
Orono, Maine
(Instructor in Elec. Eng., University of Maine)
Nov. 5, 1915

## YOU MAY BE INTERESTED

in the following "reviews" of *"Examples in Alternating Currents"*

Review in **"Bulletin of the Society for the Promotion of Engineering Education"**, October, 1915:

*Examples in Alternating Currents.* Vol. I. By F. E. Austin. Published by the author at Hanover, N. H. Price, flexible leather, $2.40.

While the title of this book indicates the purpose, it by no means indicates the scope. It is almost a text-book in its treatment of alternating currents and alternating current circuits. The author very evidently had in mind the teacher, the student, and the practicing engineer while preparing the book.

For the teacher it contains a well ordered list of problems classified under the proper subheads; for the student it contains in addition to explanatory matter covering each type of problem, an example completely solved, and a review of the mathematics involved; and for the practicing engineer it furnishes a logically planned review of the whole subject of alternating quantities and the solution of alternating current circuits. Some unusual tables are included. The calculus is freely used and the fundamentals of calculus and trigonometry are reviewed as they become necessary to the solution of problems.

L. H. H.

Review in **"Electrical World"** of October 23, 1915:

*Examples in Alternating Currents.* Vol. I. By Prof. F. E. Austin. Published by the author at Hanover, N. H. 224 pages, 69 illus. Price, $2.40.

The author of this work has made a very successful attempt to help the student and practical engineer to analyze the theory underlying practical problems and work out for himself certain mathematical solutions. The problems taken up deal with fundamental principles of alternating currents and in most cases are worked out step by step. The book should be very useful to teachers as a class-room text for electrical courses and to engineers as a reference text, since it contains numerous formulas and several useful tables designed to save time in computations.

**"Telephony"**, October 16, 1915:

*Examples in Alternating Currents,* Vol. I, by F. E. Austin, Hanover, N. H.; 223 pages 4½ ins. by 7½ ins. with 70 illustrations and tables. Price $2.40.

This is the first of two volumes which take up problems relating to alternating currents such as are encountered in engineering practice. In this volume trigonometric functions, typical expressions encountered in integral calculus, and their application in the study of alternating quantities are given.

Practical examples are worked out and are immediately followed by a problem which may be solved by the application of the same methods. The first thirty examples and problems relate to sine and non-sine curves and pressures, after which inductance is taken up.

About twenty examples and problems relating to inductance are presented and these are followed by a discussion of resonance.

A feature of the book is the inclusion of tables containing values of variable quantities met with in engineering work, arranged to render evaluation convenient and rapid. One of the tables contains values of $2\pi f$ for frequencies from 1 to 151 cycles and other corresponding values.

While the book is intended to assist the college student, those following correspondence courses will find it of aid to them. It should also be of value to the practicing engineer, as he will be able to use the results of the solutions of the problems to considerable advantage.

**Some idea of the wide field covered by the subject matter of this book may be obtained from the following letters:**

F. JOS. LAMB CO.
MANUFACTURERS OF
ELECTRIC STARTERS
940 JEFFERSON AVE. EAST
TELEPHONE EAST 339

DETROIT, MICH., September 6, 1915

PROF. F. E. AUSTIN,
Hanover, N. H.,

MY DEAR SIR:—

Your letter of the 4th instant to hand, also a copy of your new book "Examples in Alternating Currents". I wish to say this is the best book on the subject that I ever saw, and I believe my library contains about all the leading books. You have matter in this book which I doubt a busy man like myself could ever "dig out" of my entire list.

I attach hereto my check to cover its cost, also for another copy I want you to send to a friend of mine, Mr ——— ————, S. C.

Yours very sincerely,

F. JOS. LAMB

ADELPHI COLLEGE
BROOKLYN, NEW YORK

September 25, 1915

PROF. F. E. AUSTIN,
Hanover, N. H.

DEAR SIR:—

I would acknowledge with thanks your Vol. I, Examples in Alternating Currents, which came today. I have already read enough to see its value, and I hope your return from it will be satisfactory. There is need of a book on this subject. Most of the texts are quite meager.

Very sincerely yours,

(Signed) W. C. PECKHAM

October 22, 1915

PROF. F. E. AUSTIN,
Hanover, N. H.

DEAR SIR:—

I have reviewed your book, and found it well worth study.

The tables in the back of the book are well worth the price of the volume, and the problems you give are all interesting and should leave a student well drilled in the mathematics of the subject.

But you excel everything in the clearness and logical order of your explanatory sections.

Very truly yours,

CLINTON C. BARNES,
Center Rutland, Vt.,
Electrical Inspector for the Vermont Marble Co,

**From a former teacher at University of Pennsylvania:**

The little volume is a *beauty* from every point of view. It is without doubt, the most useful and helpful book for use in the study of A. C. that I have come across. It is in a class by itself, without any question.

The explanation of fundamental theories, the *mathematical conception* of these theories, the useful data, tabulated formulae, etc., and the *extremely clear cuts,* all form a very "complete whole," which bespeaks the writer's familiarity with the subject, and the students' view-point.

Very sincerely,

WM. F. JOHNSON

ELECTRICAL ENGINEERING DEPARTMENT
IOWA STATE COLLEGE
AMES, IOWA

FRED A. FISH, PROFESSOR
H. C. BARTHOLOMEW, ASSOCIATE PROFESSOR
F. A. ROBBINS, ASSISTANT PROFESSOR
F. D. PAINE, ASSISTANT PROFESSOR

Sept. 16, 1915

PROF. F. E. AUSTIN,
HANOVER, N. H.,

DEAR SIR:—

I enclose check in payment for "Examples in Alternating Currents." I am very much pleased with it. I should be glad to have you send me a copy of Volume II as soon as it is ready.

Very truly yours,

F. A. FISH

**YOU CANNOT AFFORD TO BE WITHOUT THIS BOOK!**

Coast Artillery School,
Fort Monroe, Va.,
...ov. 10, 1915

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