TRANSMISSION EFFICIENCIES OF BELTING

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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Transmission Efficiencies of Belting

A THESIS

PRESENTED BY

ROBERT EDWARD MARKS

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

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IN

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APPROVED

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LIST OF ILLUSTRATIONS.

Fig. 1. First completed form of the machine.

Fig. 2. Completed form of the machine.

Fig. 3. Recording apparatus.

Fig. 4. Dial reading as used in the test.

OBJECT.

The object of this thesis is the determination of belt transmission efficiencies under varying conditions of load, speed and slip.

These determinations were obtained by means of a specially designed belt testing machine, consisting of a sliding carriage belt dynamometer, a Sprague electric cradle dynamometer and a photographic recording device.

DESCRIPTION OF APPARATUS.

The machine consists essentially of three sets of apparatus:

1. Driving
2. Driven
3. Recording

1. The recording apparatus consists of a Sprague electric cradle dynamometer. A switch-board, as shown, is the means of varying the speed and the load. Attached to the casing of the dynamometer is a knife-edge. The torque of the dynamometer is transmitted through this knife-edge to both a spring and a beam scale. The readings of these two scales serve as a check on one another.

The knife-edge is located at a distance of 15.75" from the center of the dynamometer shaft, making the constant of the dynamometer, C = 4000 in the formula

$$H.P. = \frac{T\,R}{C} = \frac{T\,R}{4000}$$

Where T = torque in pounds as indicated

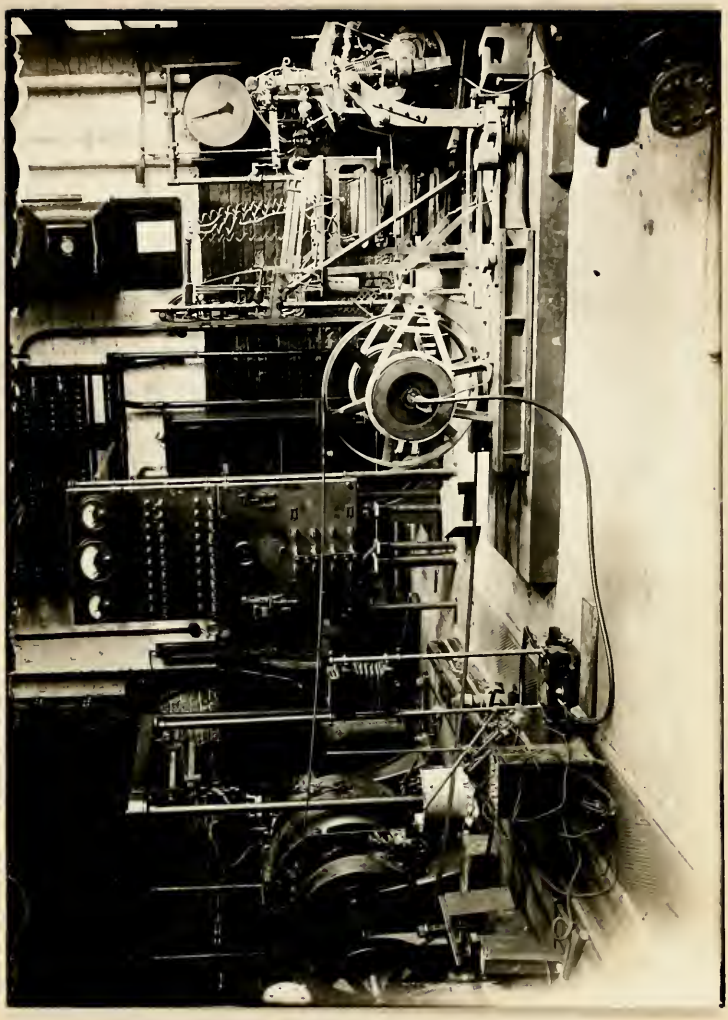
R = R.P.M.

The dynamometer shaft carries a pulley two feet in diameter and four inches wide. This pulley is the driving pulley for the belt which is to be tested.

2. The driven pulley, two Prony brakes connected together, a beam balance and a tension device comprise the driven end of the apparatus. (Reference to the accompanying cut will serve to clarify the following description).

The receiving pulley is four inches wide and two feet in diameter. It is essential that the driving and driven pulleys be the same diameter to one one-thousandth of an inch. If they are not, a difference in the total number of revolutions will be indicated which is not due to slip.

The bed of the machine consists of a single casting, three feet long, twenty-two inches wide and five inches high. Horizontal runways are planed out so as to accomodate a U.S.#308 ball-bearing.



The carriage is a casting fourteen inches wide and twenty-eight inches long to which four hubs are bolted, at the corners. These hubs carry the U.S.#308 ball-bearings, which are placed on with a fairly tight fit. Two slots are milled along the entire length of the carriage, on either side of it. Twenty three-sixteenth inch balls are placed in each of these slots; this arrangement tends to reduce the lateral friction of the machine.

To the carriage are bolted two supports which contain the bearings of the Prony brake shaft. This shaft is two and one-half inches in diameter and two feet long. Two pulleys are keyed at either end of the shaft. These pulleys are twelve inches in diameter and four inches wide. They have an outer flange which serves to contain the cooling water.

The pulleys carry two aluminum brakes, three and one-quarter inches wide and three-sixteenth inches thick. They were cast with

a one-half by one quarter inch rib running around their centers. Two lugs were cast on each band, three and one-quarter inches wide, two inches long, and three-quarters inches thick. The pulleys were cast in one piece, and afterwards split between the lugs.

The lugs were drilled to accomodate a one-half inch diameter bolt. These bolts were threaded twenty threads to the inch and are eight inches long. One and one-quarter inch diameter springs are placed on these bolts. The springs serve to spread the brake apart and produce a more uniform pressure. Hand-wheels are placed on the bolts for the purpose of regulating the load applied to the brakes.

The brakes are lined with automobile brake-band lining, four inches wide and one-eighth inch thick. This lining is fastened to the inner circumference of the bands by means of copper rivets, spaced three inches apart. Two aluminum castings, in the shape of an A are

bolted to the brakes, and serve as the brake-arms of the Prony brake. An aluminum casting connects the two brake arms. The oval shape of this casting is due to the fact that at first, the tension device extended through the straddle. A hole is drilled in this casting into which a hooked rod is fitted. This rod is threaded on one end, and fits into the counter-weight of the beam balance.

The balance rests on knife-edges which are supported by Y shaped castings. These castings, in turn, are supported by a vertical stand which is bolted to the carriage. A hole is drilled in this stand, fifteen inches above the floor of the carriage. A steel cable is attached to the support at this point and extends horizontally over a pair of grooved pulleys, which are placed in a vertical support. This support is bolted to the carriage of the machine and rides with it. Tension is provided by means of cast iron weights,

of about twenty pounds each. The grooved pulleys are mounted on ball bearings to reduce the friction. A V shaped casting carries the tension support. The whole machine rests on a cast-iron bed plate, six feet, eight inches long, and two feet, two inches wide.

The shafts of the belt-testing machine and the Sprague dynamometer are tapped with a three-sixteenth inch left-hand thread. The object of the left-hand thread is to prevent loosening of the flexible shafting, relative to the shafts of the dynamometer or the belt-testing machine.

3. The recording device consists of a camera, two odometer dials and the necessary connections. The odometer dials are mounted on a horizontal platform. Two flexible shafts connect the odometer dials with the shafts of the Sprague dynamometer and the belt machine. These shafts (the flexible shafts) are seventy-two inches long and run in casings. The ends of the flexible shafts are special fittings

made to conform to the left-hand thread of the power shafts and to the shafts of the odometer dials. Attached to the stand on which the dials rest, are two vertical rods which support a three and one-quarter by four and one-quarter camera. The camera is equipped with a Zeiss-Tessar lens, mounted in a Volute shutter. This shutter permits of any length of exposure from one second to one two-hundredth of a second. Film packs were used to make the records. The lens is quite speedy (f.6.3) and cut down the length of exposure.

Light for photographic purposes was provided by six nitrogen-filled tungsten lamps, placed in a parabolic reflector. This gave ample illumination on the odometer dials. A stop-watch and a serial number were placed on the stand so as to be photographed with the dials on the film. Water connections were made to the city mains, supplying the pulleys of the belt machine.

FUNCTIONS OF THE APPARATUS.

The Sprague electric dynamometer furnishes the power to be transmitted by the belt which is to be tested. The Prony brake serves to measure the output of the belt. The weights applied at the end of the steel cable provide the variable belt tension. The flexible shafting transmits the number of revolutions of the power shafts to the odometer dials, which, in turn, indicate the differential revolutions of the driving and driven pulleys. The camera makes an instantaneous and permanent record of the dial readings.

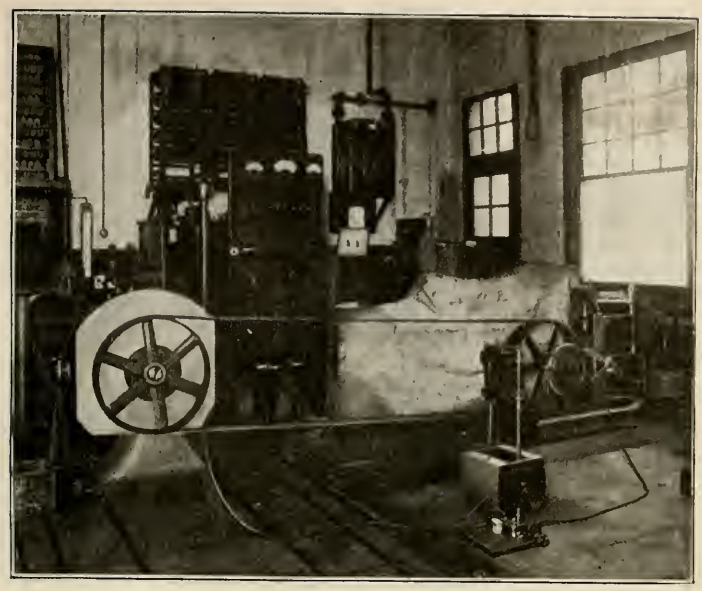


FIG. 5. BELT-TESTING MACHINE WITH PHOTOGRAPHIC SPEED MEASUREMENT DEVICES

METHOD OF PROCEEDURE.

The machine is set up and a belt laced on the pulleys. The Sprague dynamometer is started by means of the switch-board control. A speed is obtained by means of cutting out the field resistance of the dynamometer. This speed corresponds to the speed at which the test is to be made. Equal increments of load are applied to the belt, while a constant tension is applied to the cable. This run gives the result of variable slip against constant tension and speed.

The speed can be approximated by means of an electric tachometer which is connected to the electric dynamometer. The brake band lining is then oiled, and a fine stream of water is played into the pulleys. The beam balance is brought to rest at the pointer and the load on the Sprague dynamometer balanced.

When results have become constant, the light on the dials is switched on, and an exposure of one twenty-fifth of a second

is made. The exposure is of long enough duration to give full detail to the film, yet short enough to show no motion of the dial pointers. At the end of five minutes, another exposure is made. By subtracting the initial dial reading from the final, the difference in revolutions of the two pulleys is found. By means of the stop-watch and the serial number, the time, load, tension and speed can be determined. The following data is observed while making the run:

1. Number of run.
2. Approximate speed.
3. Sprague dynamometer load.
4. Prony brake load.
5. Total tension.

When the negatives have been developed, the dial readings are observed, and the following data calculated:

6. Difference in total number of revolutions.
7. Revolutions per minute.

8. Length of run.

9. Slip.

10. Per cent of slip.

11. Input horse-power.

12. Output horse-power.

13. Loss in horse-power.

14. Per cent of loss.

15. Per cent efficiency.

Number 6. is found by subtracting the final reading from the initial readings of both the driving and the driven pulleys. Subtracting the total number of revolutions of the driven pulley from that of the driving, gives the difference in the total number of revolutions.

7. By dividing the total number of revolutions of either of the pulleys by the length of the run in minutes, gives the revolutions per minute.

8. The length of run is read directly from the negatives of the initial and final exposures.

9. By subtracting the number of revolutions

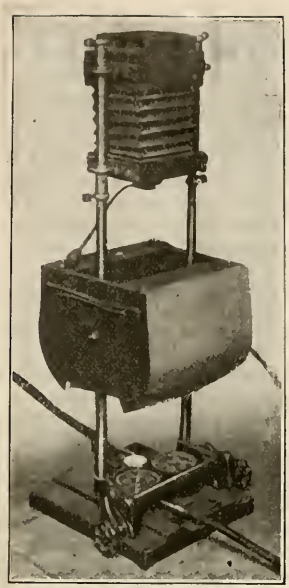


FIG. 6. SPEED-REGISTERING MECHANISM

of the driving pulley from that of the driven, the slip in revolutions can be found.

10. Dividing the slip by the total number of revolutions of the driving pulley, gives the slip in per cent when multiplied by one hundred.

11. The input horse-power was calculated by means of the formula

$$H.P. = \frac{T\ R}{4000}$$

where T = indicated load on the Sprague beam.

R = R.P.M. as indicated on the film.

12. The output horse-power was calculated by means of the same formula, substituting the T and R of the driven pulley.

13. Subtracting 12 from 11 gives the horse-power lost in transmission.

14. Dividing 13 by one hundred gives the loss in per cent.

15. Subtracting 14 from one hundred gives the efficiency of the belt transmission, in per cent.

The object of the runs was to determine the belt performance under varying conditions of load, tension and speed. It was impossible to obtain runs at variable speeds, so that a belt speed of two thousand feet per minute was maintained throughout the runs.

The first series of runs (1-6) were made with a tension of one hundred fifty eight pounds, total. The load was varied from approximately five and one-half horse-power to ten and one-half horse-power.

The second series of runs was made with a tension of two hundred forty pounds, or sixty pounds tension per inch of width. The load was again varied within the capacity of the machine.

Successive runs were made with tensions of ten, twenty, forty and eighty pounds per inch of width. At these lower tensions, considerable difficulty was experienced, as the belt sagged to such an extent that the carriage of the belt machine ran against a stop, and erroneous

readings of the tension were obtained. In some of the runs, the sag was so great that the tight and slack sides of the belt scraped on one another.

The complete data is shown on the data sheet. The results were drawn up in a series of curves. These curves show the performance of a four inch, three-ply fabric belt.

Runs 1-6 inclusive show the effect of varying the load at a constant tension. The resulting slip is shown. These curves were obtained by plotting the original data.

Curve number 7 was obtained by choosing runs of approximately the same horse-power and plotting the efficiency against the tension.

Curve number 8 was obtained by plotting the same points, showing the slip against the efficiency.

Curve number 9 shows the effect of variable input and efficiency against a constant tension.

Curve number 10 shows the same application as number 9, using a tension of twenty pounds

per inch of width rather than eighty pounds per inch of width.

Curve number 11 shows variable input and efficiency against a tension of ten pounds per inch of width.

Curve number 12 is a combination of curves number 1 to 5 inclusive.

Curve number 13 is the plotting of efficiency against tension, at a constant slip.

Curve number 14 shows the result of varying input and tension at constant slip.

8

CONCLUSIONS.

The results of the tests can be best adjudged by the curves. The effect of belt speed on slip, efficiency and input have not been investigated in this thesis,as the construction of the belt machine required too much time to allow for a full set of runs. The following deductions are therefore based on the performance of the belt at a belt speed of two thousand feet per minute. Further information could have been obtained,had a comparative set of tests been made on various specimens of belts.

Curve number 12 shows the results of runs 1 to 5 inclusive. The curves are fairly consistent. As the input increases,the slip increases almost proportionately. Between a four and a six per cent slip,the transmitted horsepower begins to fall off. At extremely heavy loads,the belt seized on the driven pulley and the driving pulley speeded up greatly. At the low tensions,the runs were not very

accurate,owing to the reasons already assigned.

Curve number 6 illustrates the fact that,as the tension increases,the slip decreases,until at a tension of ninety pounds per inch of width, the slip becomes zero. This applies only to the special conditions under which this belt was run.

Curve number 7 presents a contradiction to natural suppositions. Instead of there being the maximum efficiency at the least slip, the maximum efficiency occurs at a point where the tension shows a value of sixty pounds per inch of width.

Curve number 8 serves to substantiate the results obtained in curve number seven, showing a maximum efficiency at a slip of twenty-eight hundredths of one per cent. Owing to the conditions under which the belt was run,these results were fairly plausible.

Curve number 9 shows a direct proportion between the input and the efficiency. As the input increases,the efficiency increases in

a direct ratio. This curve was obtained at a tension of eighty pounds per inch of width. It gave the most consistent results of any of the tensions.

Curves number ten and eleven tended to become assymptotic at about ninety eight and one-half per cent efficiency. This shows the fact that, although the load be increased, the efficiency remains constant after a load of about five horse-power has been applied.

Curve number thirteen shows the effect of tension on efficiency at a constant slip.

Curve number fourteen shows the effect of tension on the hores-power transmitted at a constant slip. The curve shows that the greater the tension, the more horse-power is transmitted

Runs should be made at constant horse-powers and variable speeds. A great variety of runs can be made by holding ths speed constant and varying the load, the slip and the tension and holding each of these constant and varying the others. Probably the best method of

presenting the complete characteristics of a belt would be by means of a surface.

Comparative tests would,no doubt show vastly different characteristics.

The machine should be changed so that a longer travel of the bed is possible,otherwise it performs very creditably. The carriage can be easily made so that the travel of six inches can be increased to about three feet. This would eliminate the necessity of having to shift the whole machine when the tension is varied.

The belt tested gave good results; in no case was the slippage over one per cent. A leather belt without dressing would no doubt have given a far greater slip than this specimen.

In the greater part,the results of this thesis were satisfactory,and conform to the general expectations in regard to belt performance.

MATERIALS OF BELT CONSTRUCTION.

Belting is manufactured from quite a variety of materials. The belts which have given the longest service are the oak-tanned leather belts.

The best material for these belts is provided from a strip of the hide running along the back of the animal, about eighteen inches in width. The hide then decreases in value to the hide which is cut from the belly of the animal. The best hide is about two-tenths of an inch thick. The siding is thirty five hundredths of an inch thick,but of inferior quality.

After tanning,the belt is cut into the proper widths,bevelled,and cemented into the required lengths. Properly tanned oak leather belting, curried with cod-oil and tallow has given from thirty to fourty years service in some instances. The United States Navy has drawn up specifications relative to belting. These specifications are found in Kent,"Mechanical Engineers' Pocket Book" 1916 pp.1151 .

Canvas is a popular material for belt manufacture. The canvas is used without surfaceing or is coated with a layer of rubber,making the rubber belts. This belt does not give the length of service that a leather belt does,but, economically,owing to the high initial cost of the leather belt,the rubber belt may prove the better.

A number of departures from these types are manufactured,such as wire-woven canvas,composition,etc.. The wire which is woven into the belt tends to increase its life and strength. The specimen used in this test was a composition belt of the self-dressing type. This feature eliminates the use of dressing with the belt.

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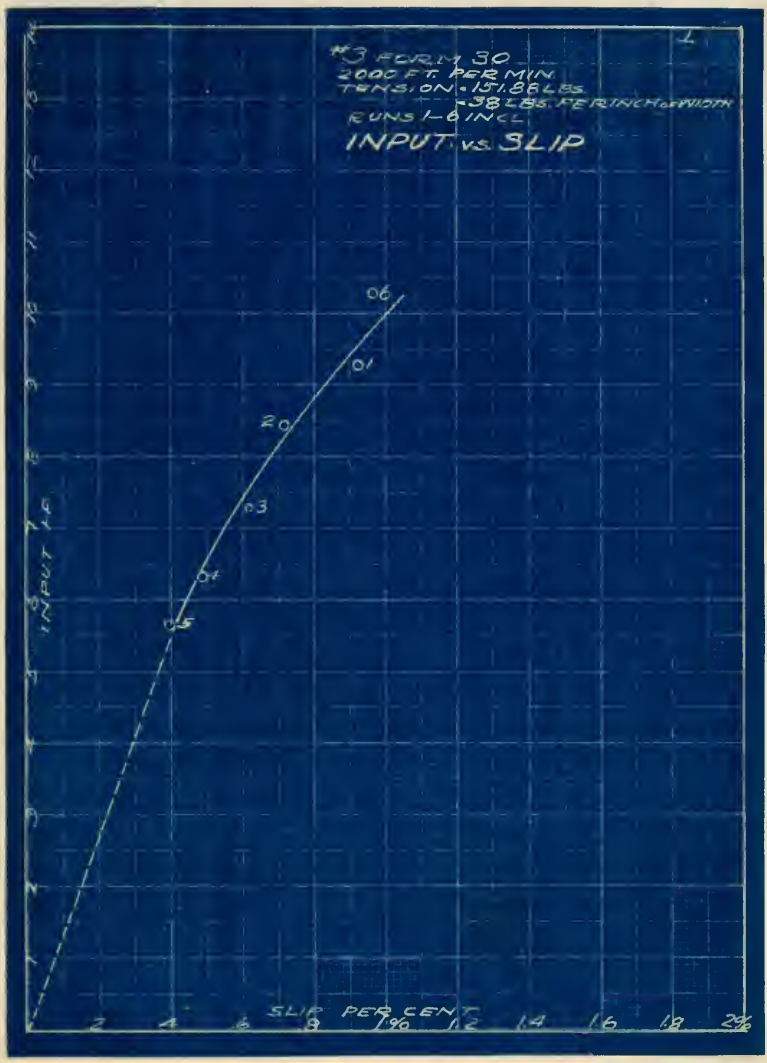
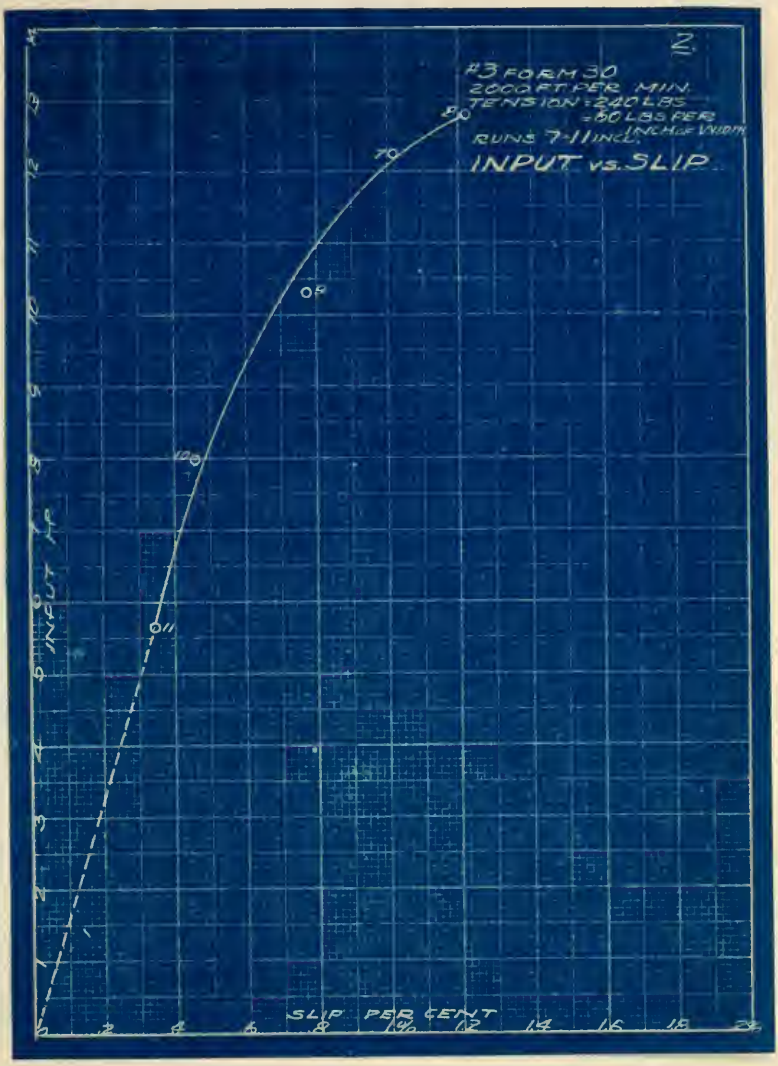
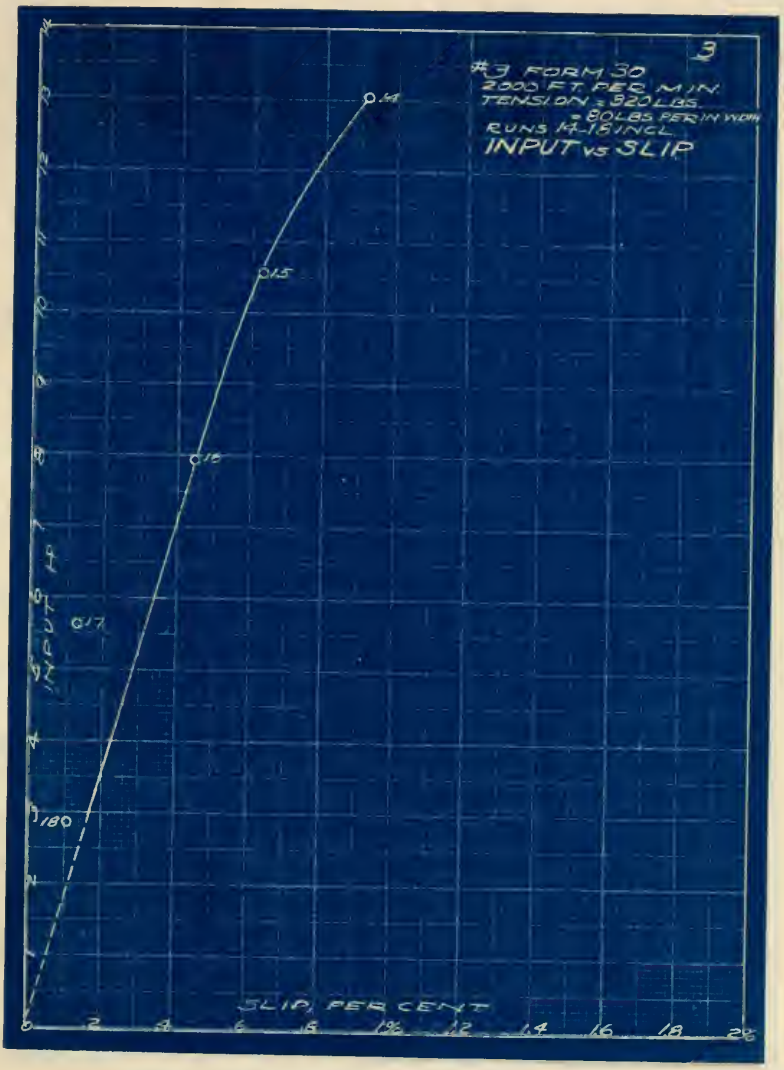
BELT TEST DATA

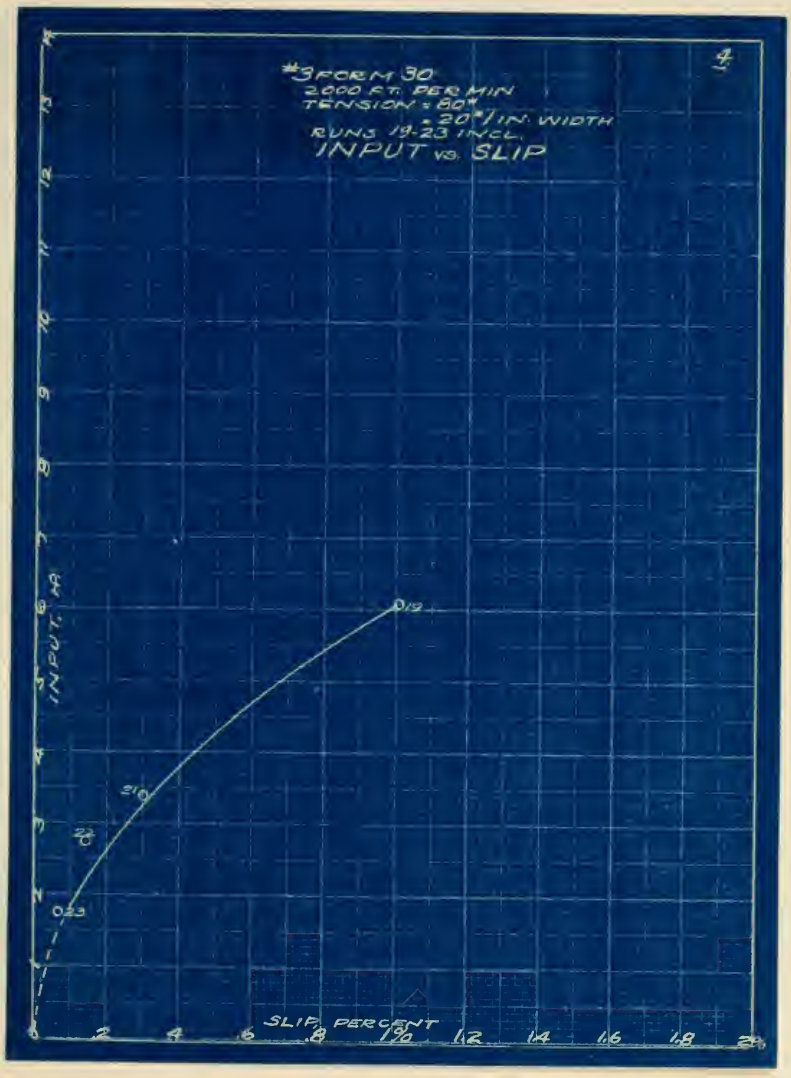
BELT TEST DATA

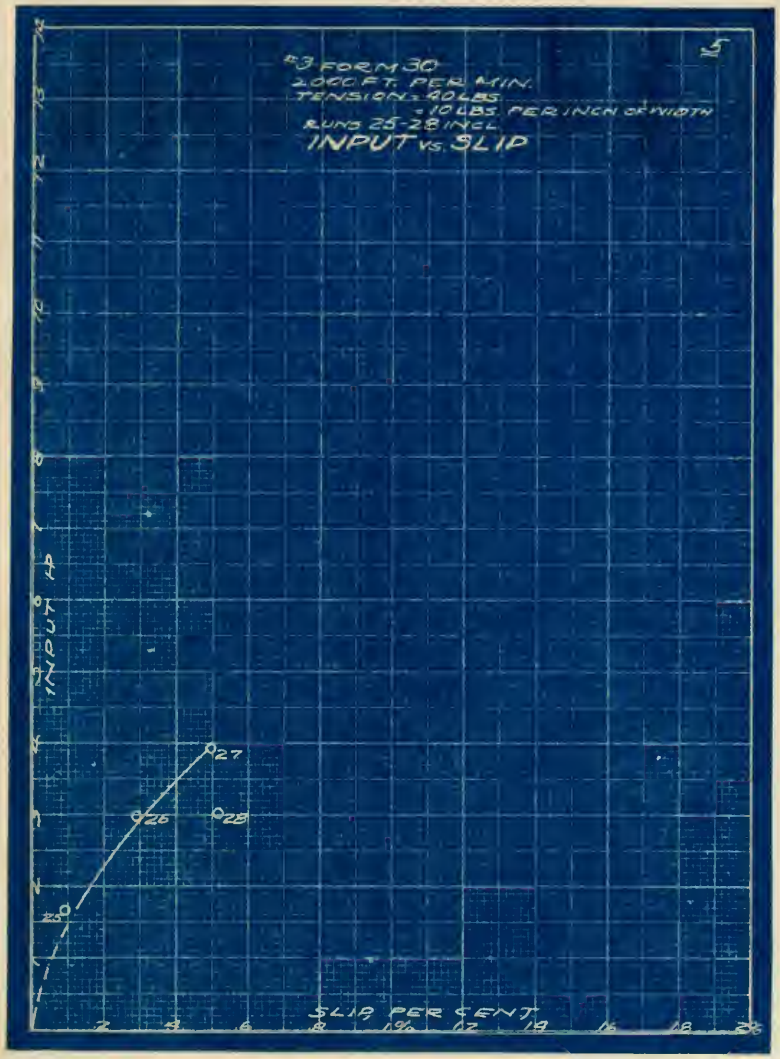
RUN	DRIVER A INITIAL	DRIVER B FINAL	DRIVEN C INITIAL	DRIVEN D FINAL	DIFF. REV. E A-B	DIFF. REV. F C-D	SLIP REV G E-F	SLIP % H G/E×100	LOAD J SPRGE	LOAD K PRONY	TENSION L TOTAL	R.P.M. M DRIVING	R.P.M. N DRIVEN	HP O DRIVING	HP P DRIVEN	LOST HP R O-P	% LOSS S R/O×100	EFFCY. T 100-S
1.	00284.0	08617	83919.4	85482.6	1577.7	1563.2	14.5	0.920	118.00	118+	151.88"	315.50	312.60	9.30	9.30	0	0	100.
2.	05207.0	06804.4	89852.7	91438.8	1597.4	1586.1	11.3	0.708	105.50	105.5+	"	319.48	317.22	8.425	8.45	0.025	0	100.
3.	07809.9	09379.0	92437.9	94097.3	1569.1	1559.4	9.7	0.620	93.75	93.30	"	313.82	311.88	7.35	7.26	0.090	1.225	98.775
4.	10354.0	11919.6	94966.7	96528.4	1565.6	1558.7	6.9	0.441	81.25	80.00	"	313.12	311.74	6.35	6.235	0.115	1.810	98.190
5.	13495.2	15195.0	98194.7	99887.7	1699.8	1693.0	6.8	0.400	69.00	66.70	"	339.96	338.60	5.86	5.65	0.210	3.580	96.420
6.	23590.4	25128.3	08074.6	09686.6	1647.9	1632.0	15.9	0.965	125.50	126.5+	"	329.58	326.40	10.31	10.31	0	0	100.
7.	31403.6	31045.0	15841.0	17430.0	1614.4	1597.6	16.8	1.040	157.00	157.00+	240	322.88	319.52	12.25	12.75	0	0	100.
8.	34020.7	35585.8	18403.8	19950.0	1565.1	1546.2	18.9	1.210	164.00	173.00	"	313.02	309.24	12.81	13.36	0	0	100.
9.	77759.1	79305.8	71643.0	73183.8	1550.7	1540.8	9.9	0.637	133.00	133.00	"	310.14	308.16	10.30	10.22	0.080	0.777	99.223
10	80553.5	81819.0	74925.0	75604.8	1265.5	1259.8	5.7	0.450	101.00	100.00	"	316.36	314.95	8.00	7.87	0.130	1.625	98.375
11.	85456.8	87139.3	79302.0	81087.7	1682.5	1676.7	5.8	0.344	67.25	66.67	"	336.5	335.30	5.65	5.59	0.060	1.06	98.940
12.																		
13.																		
14.	651989.8	653573.0	46068.7	47638.4	1584.2	1569.7	14.5	0.915	165.00	166.60	320	316.84	313.94	13.08	13.06	0.02	0.153	99.846
15.	55600.0	57164.7	49551.0	51106.0	1564.7	1555.0	9.7	0.620	135.00	133.33	"	312.94	311.00	10.55	10.37	0.18	1.706	98.294
16.	57164.7	61889.0	51106.0	55809.6	4724.3	4703.6	20.7	0.438	101.50	100.00	"	314.95	313.87	7.99	7.58	0.31	3.882	96.118
17.	68270.4	70242.2	62172.8	64142.2	1971.8	1969.4	2.4	0.123	69.00	66.66	"	328.63	328.23	5.67	5.48	0.19	3.650	96.350
18.	70649.8	71964.2	64550.0	65963.0	1314.4	1313.0	1.4	0.106	35.00	33.33	"	328.60	328.25	2.878	2.738	0.14	5.000	95.000
19.	98025.0	99622.0	91835.2	93415.2	1697.0	1680.0	17	1.005	75.50	75.33	80	319.40	316.00	6.030	5.95	0.08	1.333	98.67
20.	99622.0	701214.0	93415.2	95992.0	1592.0	1577.8	16.2	1.015			"							
21.	706042.3	07602.3	997964	701351.8	1560.0	1555.4	4.6	0.295	47.25	46.52	"	312.00	311.08	3.64	3.62	0.07	1.900	98.1
22.	08882.9	10490.5	703628.6	704223.8	1607.6	1605.2	2.4	0.140	34.50	33.33	"	321.52	321.04	2.77	2.67	0.10	3.610	96.39
23.	11823.8	13481.3	05565.6	07221.8	1657.5	1656.2	1.3	0.0786	21.50	20.00	"	331.50	331.24	1.78	1.652	0.128	7.200	92.8
24.																		
25	20093.7	21715.3	13830.7	15450.7	1621.6	1620.0	1.6	0.0987	21.25	20.00	40	324.32	324.00	1.672	1.62	0.052	3.110	96.89
26.	23023.9	24662.8	16756.8	18390.8	1638.9	1634.0	4.9	0.299	35.00	33.33	"	327.78	326.80	2.863	2.721	0.142	4.960	95.04
27.	27153.7	28763.3	20871.7	22473.3	1609.6	1601.6	8.0	0.498	47.50	46.60	"	321.92	320.32	3.82	3.74	0.08	2.092	97.908
28.	36182.1	37841.7	29609.5	31260.7	1659.6	1651.2	8.4	0.5165	37.25	36.60	"	321.92	320.32	3.00	2.93	0.07	2.330	97.670

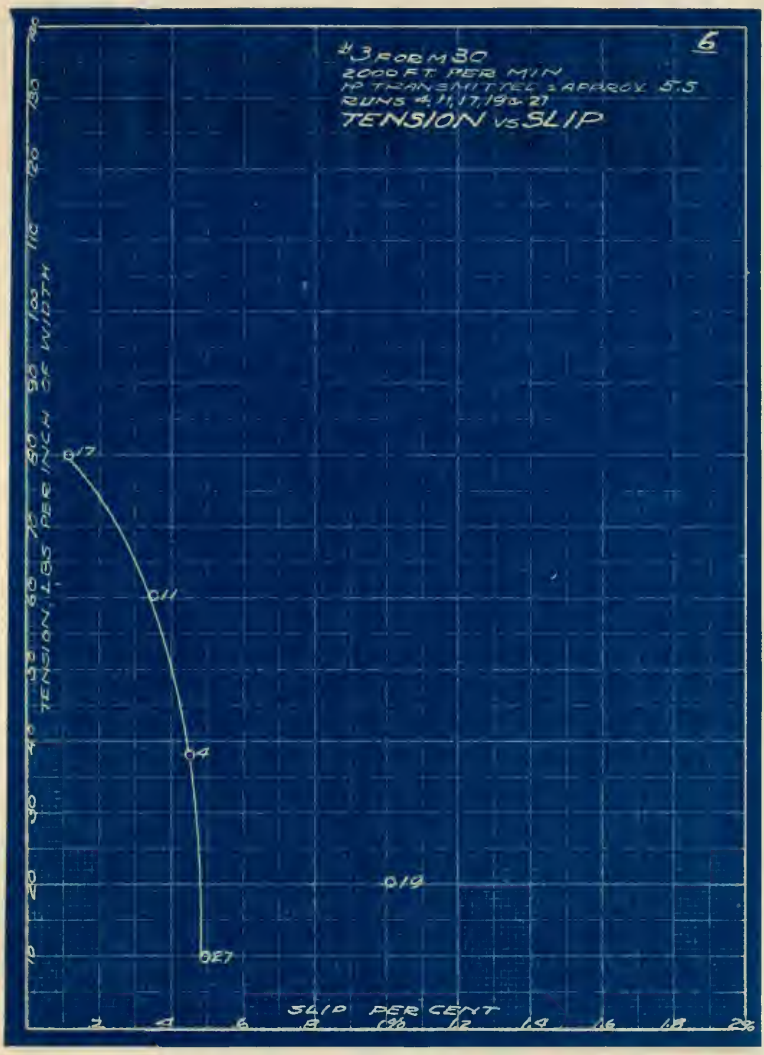

#3 FORM 30
2000 FT. PER MIN.
TENSION - 151.86 LBS
- 38 LBS. PER INCH of WIDTH
RUNS 1-6 INCL
INPUT vs. SLIP
06
01
20
03
04
05
INPUT HP
SLIP PER CENT
2
4
6
8
1%
12
14
16
18
2%

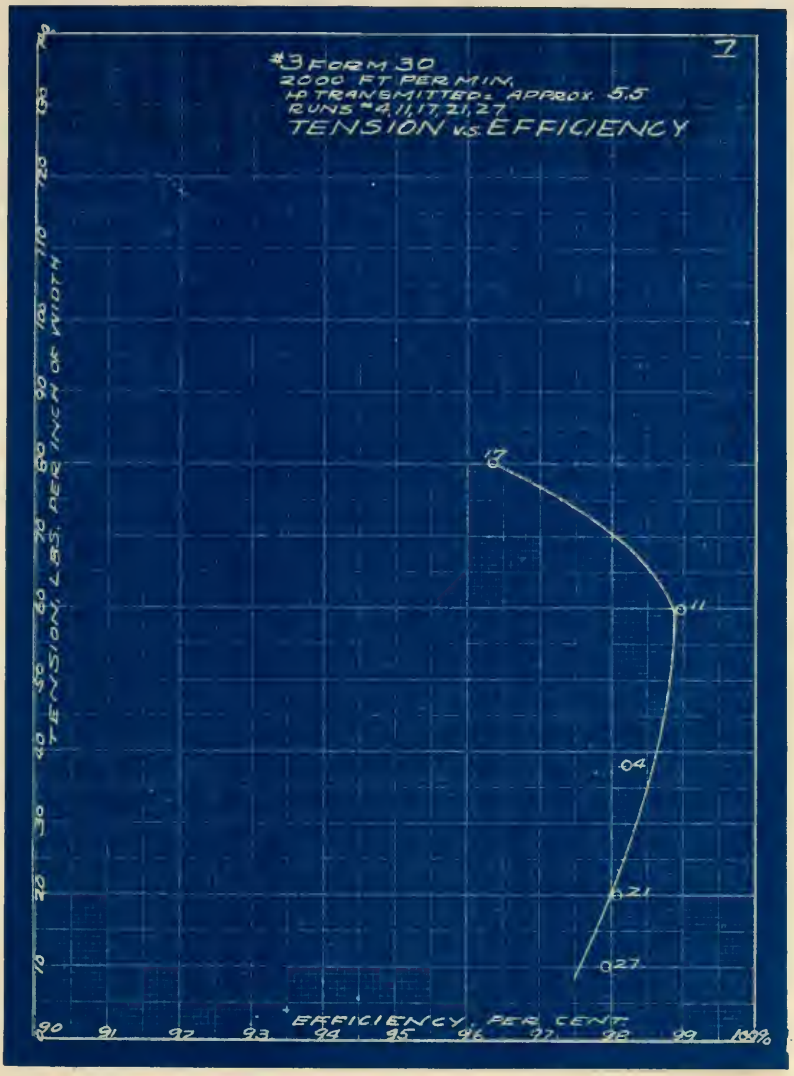

2.
#3 FORM 30
2000 FT PER MIN.
TENSION: 240 LBS
= 80 LBS PER INCH OF WIDTH
RUNS 7-11 INCL.
INPUT vs. SLIP.
80
70
OR
100
011
INPUT HP
SLIP PER CENT
0
2
4
6
8
10
12
14
16
18
20

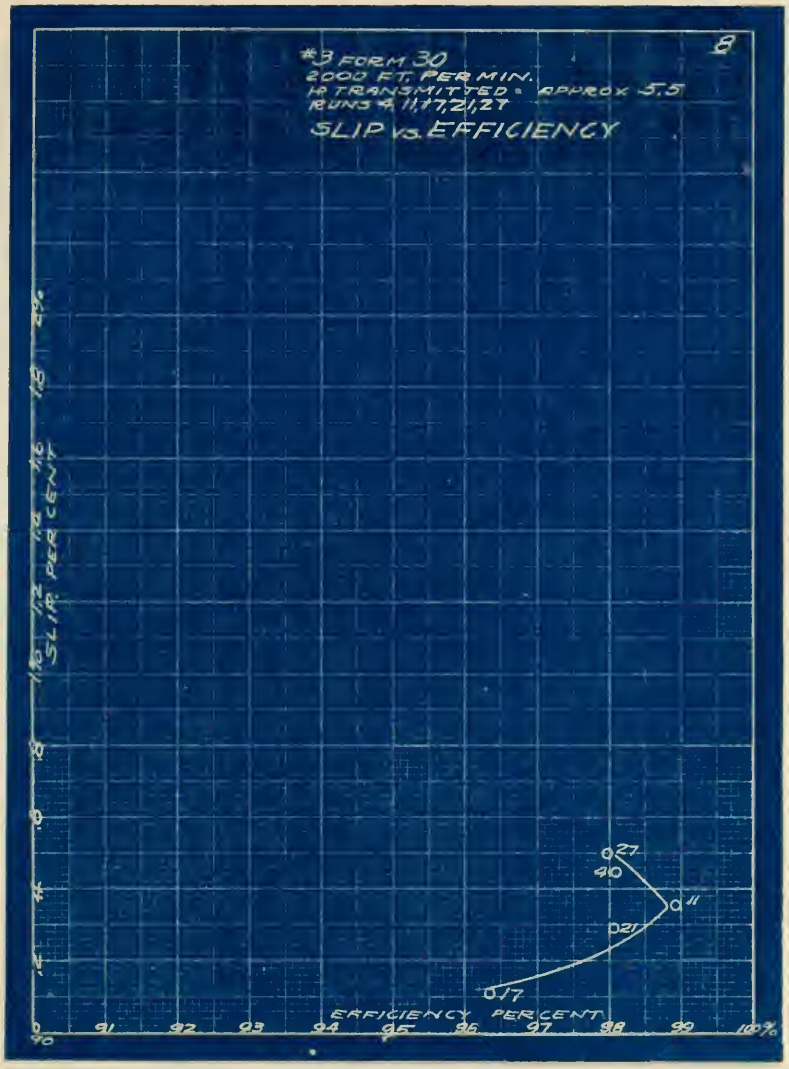

3
#3 FORM 30
2000 FT. PER MIN.
TENSION = 320 LBS.
= 80 LBS PER IN WDTH
RUNS 14-15 INCL.
INPUT vs SLIP
0.14
0.15
0.16
0.17
0.180
INPUT
SLIP, PER CENT
0
2
4
6
8
10
12
14
16
18
20

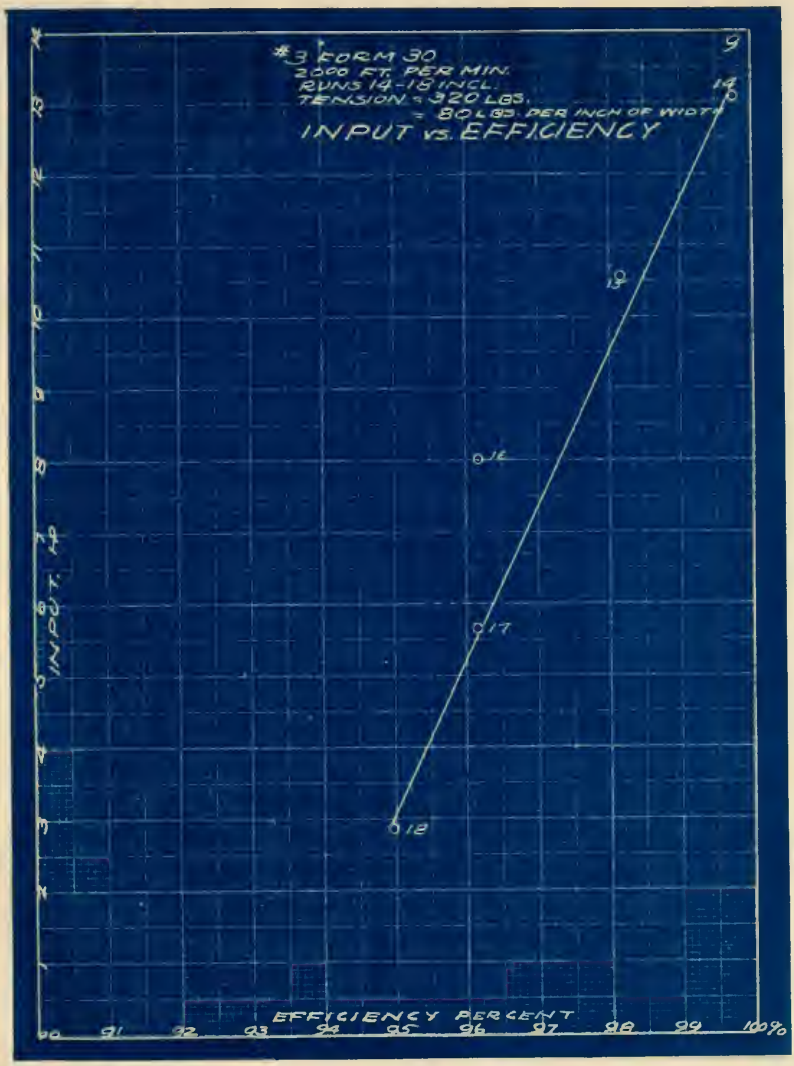

#3 FORM 30
2000 FT. PER MIN
TENSION = 80#
20#/IN. WIDTH
RUNS 19-23 INCL.
INPUT VS. SLIP
4
INPUT, KW
SLIP PERCENT
0
2
4
6
8
1.0
1.2
1.4
1.6
1.8
2.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0.19
2.10
2.30
0.23

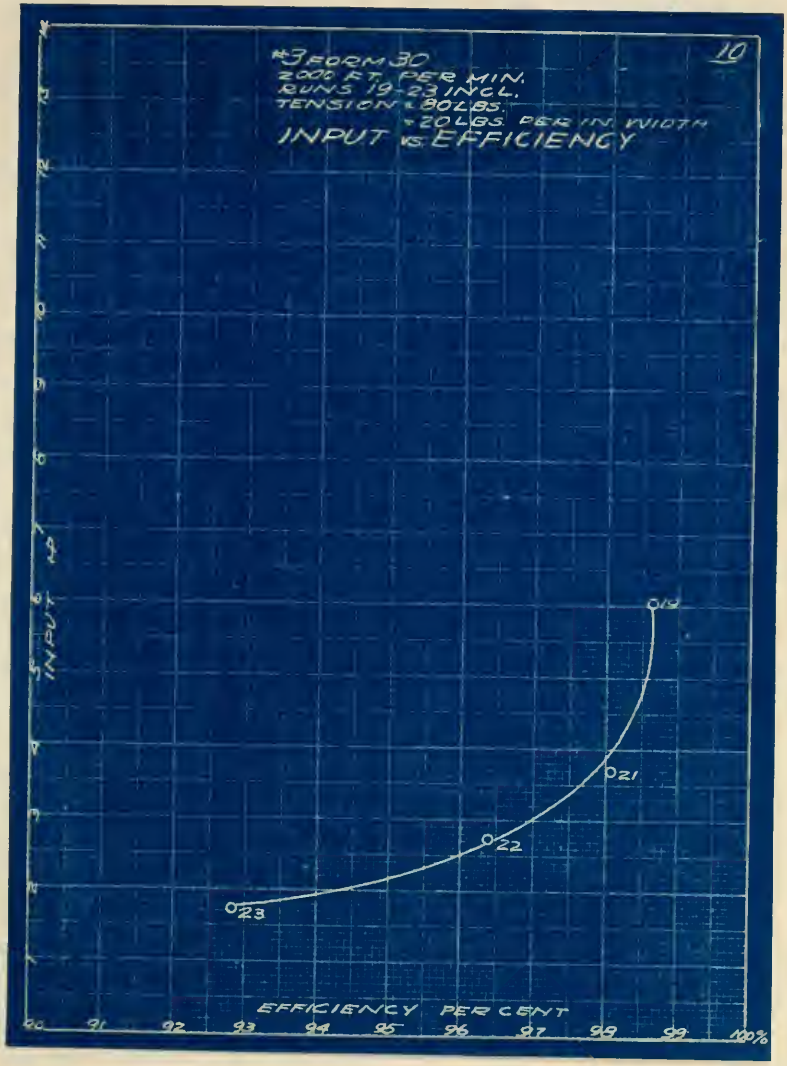

#3 FORM 30
2000 FT. PER MIN.
TENSION = 40 LBS.
= 10 LBS. PER INCH OF WIDTH
RUNS 25-28 INCL.
INPUT vs. SLIP
27
26
28
25
SLIP PER CENT
2
4
6
8
10
12
14
16
18
20

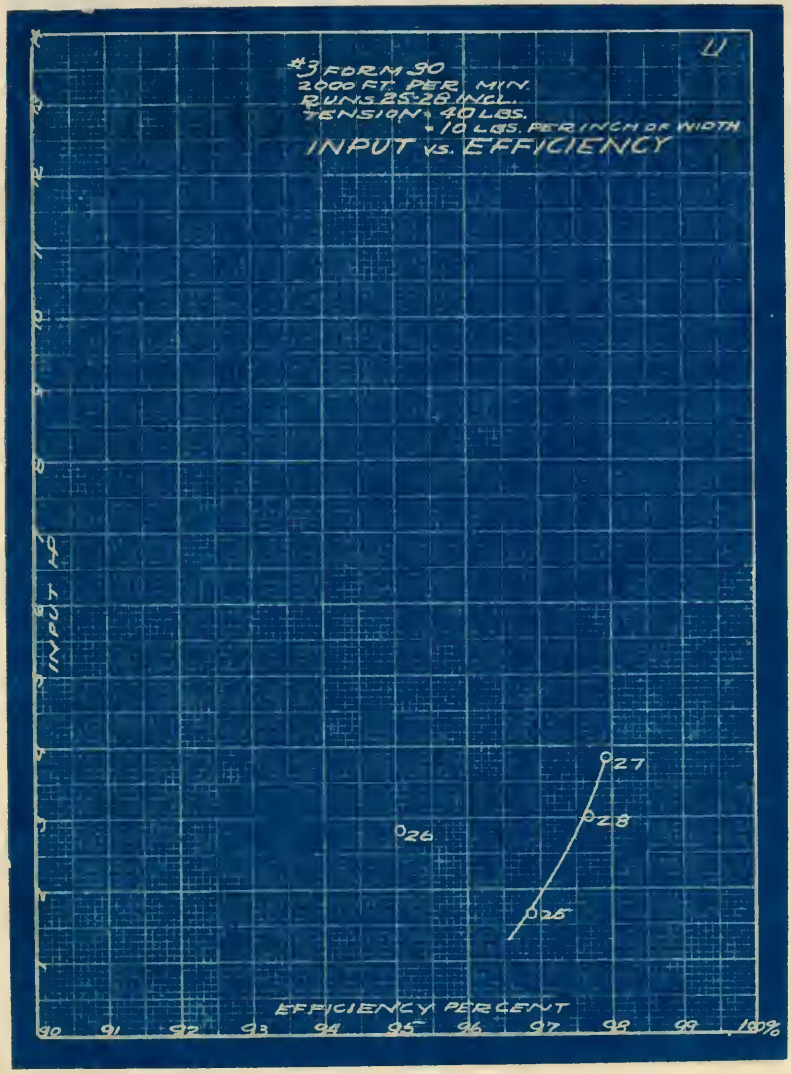

6
#3 FOR M30
2000 FT. PER MIN
HP TRANSMITTED = APPROX. 5.5
RUNS #11, 17, 19 & 21
TENSION vs SLIP
TENSION, LBS PER INCH OF WIDTH
SLIP PER CENT
0.17
0.11
0.4
0.19
0.27

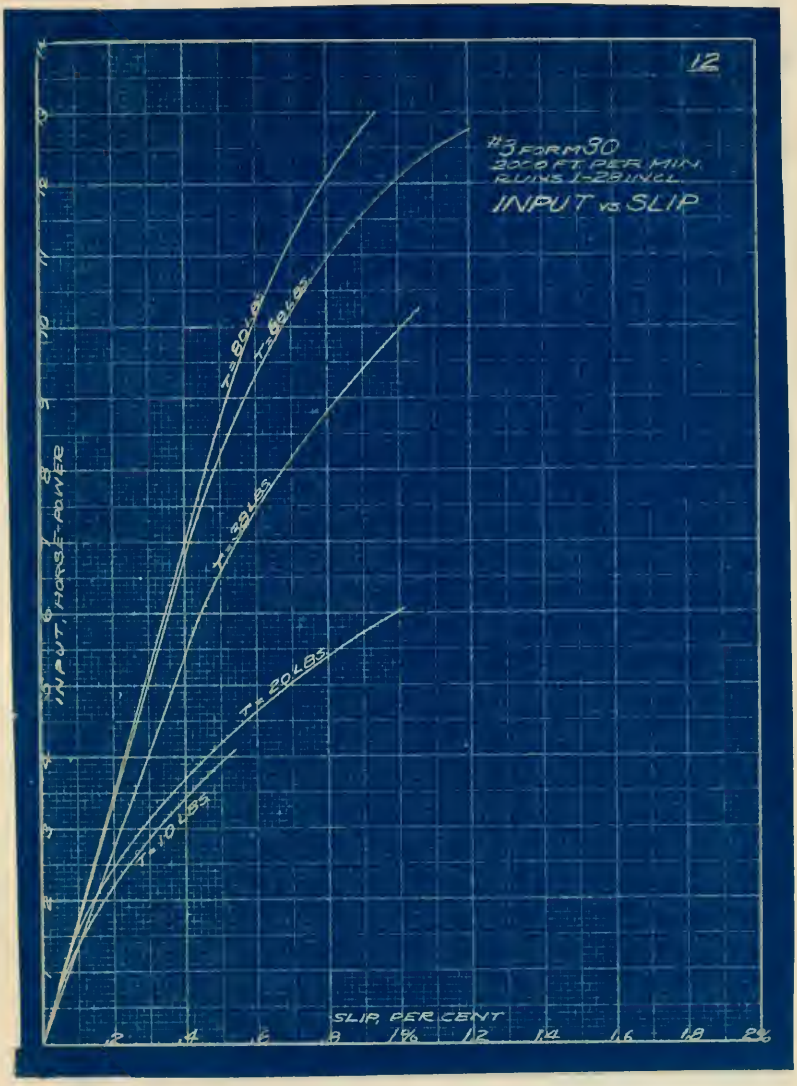

#3 FORM 30
2000 FT PER MIN.
HP TRANSMITTED = APPROX. 5.5
RUNS #4, 11, 17, 21, 27
TENSION vs. EFFICIENCY
7
TENSION, LBS. PER INCH OF WIDTH
10
20
30
40
50
60
70
80
90
100
110
120
130
140
EFFICIENCY, PER CENT
90
91
92
93
94
95
96
97
98
99
100%
17
11
04
21
27

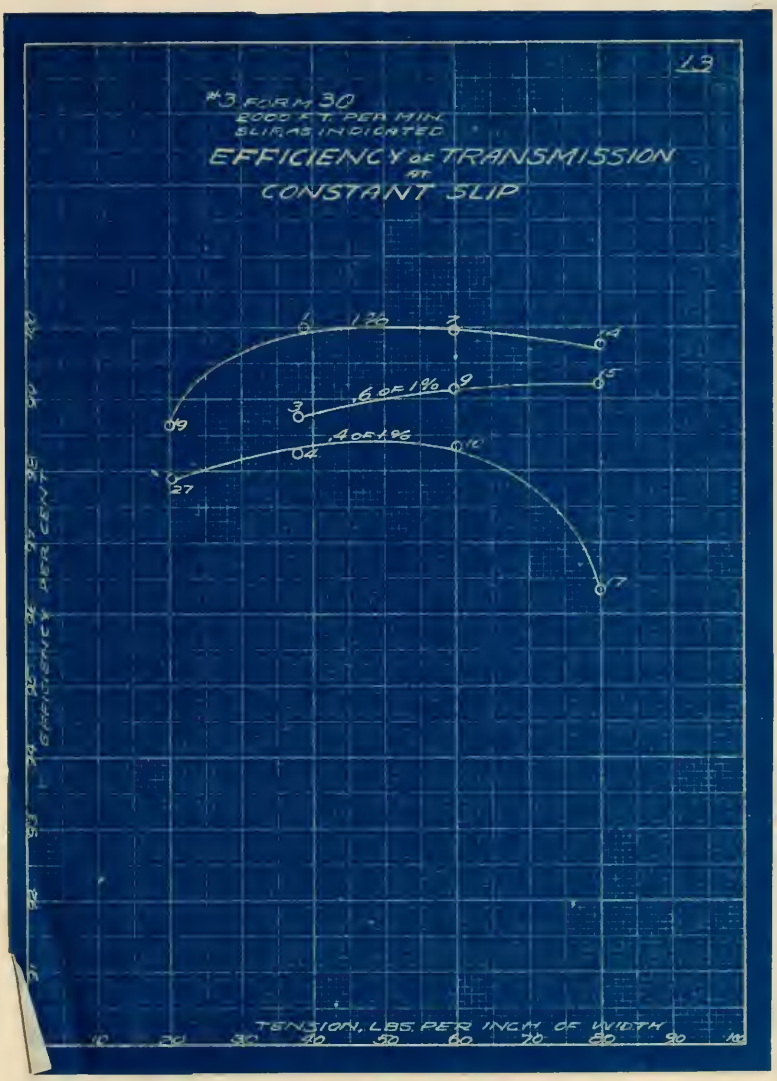

8
#3 FORM 30
2000 FT. PER MIN.
H.P. TRANSMITTED = APPROX 5.5
RUNS 9, 11, 17, 21, 27
SLIP vs. EFFICIENCY
SLIP PERCENT
EFFICIENCY PERCENT
27
9.0
11
21
17
90
91
92
93
94
95
96
97
98
99
100%

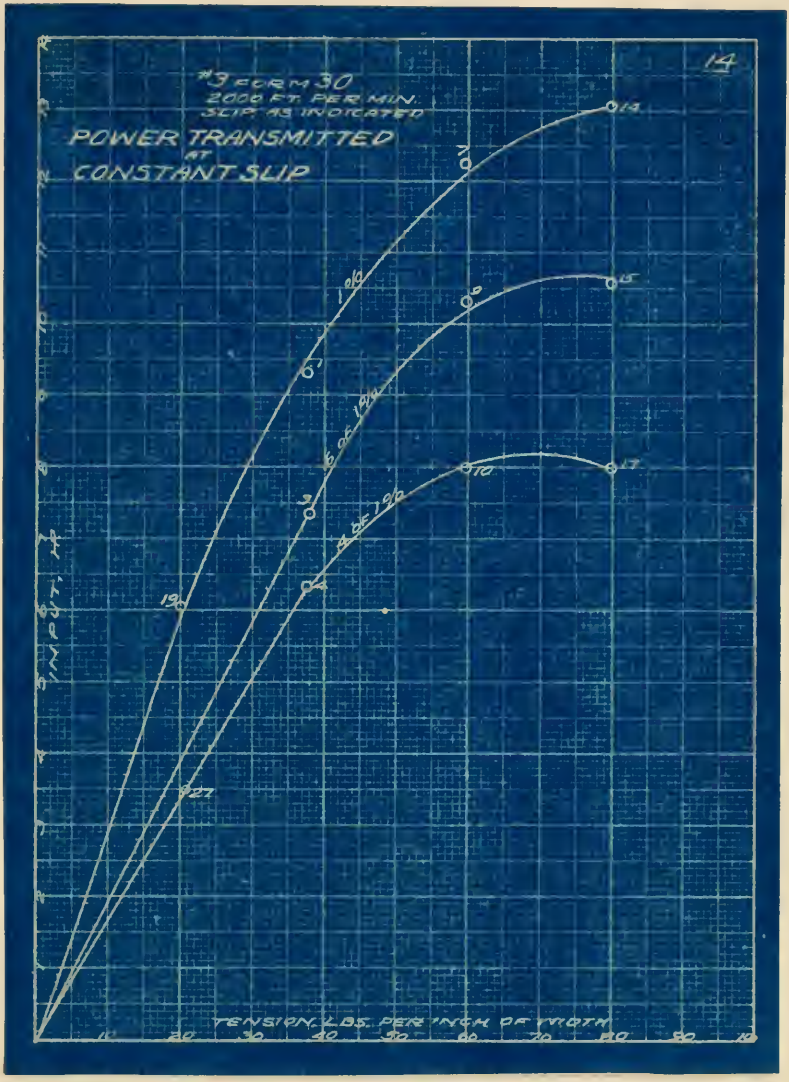

#3 FORM 30
2000 FT. PER MIN.
RUNS 14-18 INCL.
TENSION = 320 LBS.
= 80 LBS. PER INCH OF WIDTH
INPUT vs. EFFICIENCY
INPUT, HP
EFFICIENCY PERCENT
90
91
92
93
94
95
96
97
98
99
100%
9
14
13
16
17
12


#3 FORM 30
2000 FT. PER MIN.
RUNS 19-23 INCL.
TENSION = 80 LBS.
= 20 LBS. PER IN. WIDTH
INPUT VS. EFFICIENCY
10
INPUT
EFFICIENCY PER CENT
90
91
92
93
94
95
96
97
98
99
100%
19
21
22
23


#3 FORM-90
2000 FT. PER MIN.
RUNS 25-28 INCL.
TENSION = 40 LBS.
+10 LBS. PER INCH OF WIDTH
INPUT vs. EFFICIENCY
INPUT
EFFICIENCY PERCENT
90
91
92
93
94
95
96
97
98
99
100%
25
26
27
28


12
#3 FORM 30
3000 FT. PER MIN.
RUNS 1-28 INCL.
INPUT vs SLIP
T=80 LBS.
T=68 LBS.
T=38 LBS.
T=20 LBS.
T=10 LBS.
INPUT, HORSE-POWER
SLIP, PER CENT
.2
.4
.6
.8
1%
1.2
1.4
1.6
1.8
2%


13
#3 FORM 30
8000 FT. PER MIN.
SLIP AS INDICATED
EFFICIENCY OF TRANSMISSION
AT
CONSTANT SLIP
1.2%
.6 OF 1%
.4 OF 1%
EFFICIENCY PER CENT
TENSION, LBS. PER INCH OF WIDTH
10
20
30
40
50
60
70
80
90
100


14
#3 FORM 30
2000 FT. PER MIN.
SLIP AS INDICATED
POWER TRANSMITTED
AT
CONSTANT SLIP
INPUT H.P.
TENSION LBS. PER INCH OF WIDTH
20
30
40
50
60
70
80
90
100
1 1/2
6 OF 1 1/2
4 OF 1 1/2
19
27
14
7
15
9
17
10
3
4