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of March 5, 1916.

THESIS

STRAIN CORRELATION TEST

OF

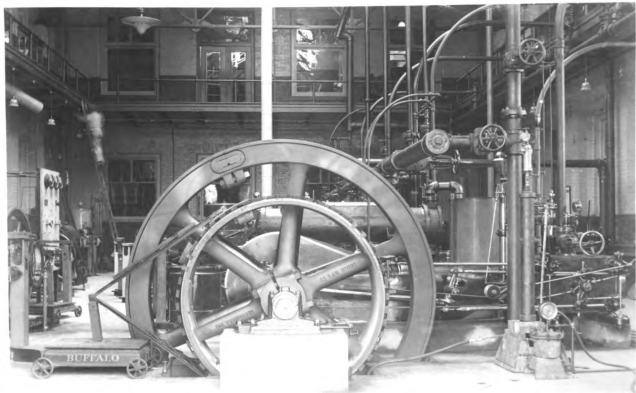
CORRELATED DESIGN ON DIFFERENT SIZES

G. P. Conway

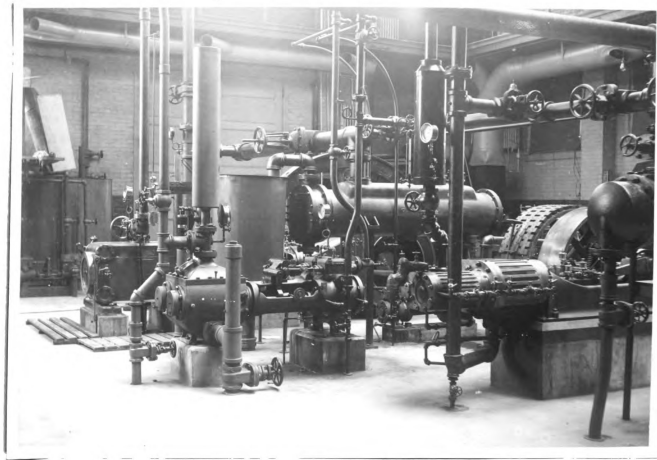
J. A. Holden

MEXICAN AGRICULTURAL COLLEGE

1911.



View of Valve Gear Side of
18" x 30" Corlies Engine used in Thesis.
H.A.C. Engineering Laboratory.



View of Condenser and
Circulating Pump used in Thesis,
M.A.C. Engineering Laboratory.

THESIS
STEAM CONSUMPTION TEST
OF
CORLISS ENGINE ON DEPENDENT STEMS.

Object: An investigation of the steam consumption from no load to full load on 60, 80 and 120 R.P.M. with other conditions as nearly constant as possible.

Apparatus: The test was run in the E.A.C. Laboratory on a Horlberg Corliss Engine manufactured by the Horlberg Construction Co. of Milwaukee, Wis. It is of the long range, cut-off, type, which varies from 0 to .9 of stroke. The valves are operated by a combination of three eccentrics and a double wrist plate with adjustable valve links. Vacuum dash pots are used to close steam valves after cut off. The governor has a safety device attached which advances the cam, thus preventing the steam valves from opening in case the governor belt should break.

Engine Dimensions:

Diameter of Cylinder.....	12 inches
" " Piston Rod.....	2 5/8 "
" " Fly Wheel.....	16 feet
" " Crank "	6 "

Length of Stroke.....50 inches
 " " Connecting Rod.....75 "
 Cylinder Displacement H.E.....1.00 cu.ft.
 " " G.E.....1.800 "
 Clearance Volume H.E.....13.9
 " " G.E.....11.185
 Length of Brake Arm.....5 ft. 3 3/4 ins.
 Weight " " 34 lbs.

Engine Constants:

I.H.P. Constant H.E..... .0000074
 I.H.P. " G.E..... .0000483
 B.H.P. " 001000

The steam is piped 400 ft. from the College Power Plant to a header in the Laboratory Shop, which each engine is provided with a feeder. The piping is so arranged that a unit may exhaust into a condenser, heating system or the atmosphere.

A Throttling Calorimeter was used to determine the quality of the steam as it entered the engine.

A Surface Condenser, manufactured by C.K. Wheeler of Philadelphia, Pa., was used in connection with a wet air pump which was driven by a direct acting steam pump 6" x 7" x 6". It is of the double flow type, having 201 - 5/8" O.D. brass tubes, 7 ft. long, 173 in lower set and 128 in upper set.

The condenser is guaranteed to condense 7000 lbs. of steam per hour under a vacuum of 56 inches of mercury and with cooling water at 70° F.

The cooling water, which was pumped 600 ft. from the river by a Worthington duplex pump, 16" x 6" x 16", into a connection at the bottom of the condenser, makes a double pass and leaves at the top, by means of a waste pipe, into a tank with a standard orifice. In this way the cooling water is conserved.

Two J.L. Robertson Indicators were used with 50-lb. springs. Corrections are found on Curve Sheets Nos. 6 and 7.

Scales Nos. 1, 5 and 7 were used during test and were found to be correct to within .001 lb.

Five Thermometers Nos. 14, 21, 22 and 23 and a Dairy were used and calibrated. Corrections are shown on Curves Nos. 8, 9, 10, 11 and 12 respectively.

Gauges Nos. 20 and 14, for steam and exhaust pressures were used during test and calibrated. Corrections are found on Curves Nos. 13 and 14.

An apparatus, consisting of a separating calorimeter, a condenser and a receiver, was connected to the exhaust line, about 10 ft. from the engine, for the purpose of determining the percentage of moisture in exhaust steam. A cooled pipe, having a connection on one end to

the calorimeter and to a receiver on the other, was inclosed in a 6" pipe about 4 ft. long with a cap on either end. Cold water was passed through the condenser, and the steam which passed through the coiled tube, due to an increase of vacuum in receiver by a water sucker over that of exhaust main, was condensed and run into the receiver. The moisture in the steam was separated in the calorimeter. The calorimeter and the receiver were drained at intervals.

Operation: The engine was run condensing on the three speeds, 60, 80 and 100 R.P.M. with five different loads on each speed. The different speeds were obtained by changing the governor pulley.

An allowance of from 15 to 25 minutes was made on every load to maintain proper running conditions. Then readings of; Time, Brake Load, R.P.M., Steam and Vacuum Gauges, Temperatures in Calorimeter, Exhaust Pipe, Condensed Steam, Inlet and Outlet Water, Weight of Condensed Steam and Head on Orifice were taken every ten minutes for an hour. Then the conditions for the next load were maintained for fifteen minutes and the same operations repeated until the lightest load was reached.

The same method was pursued on all the speeds and the actual running logs for each are found in Tables I, II and III.

Discussion: In all the Curve Sheets it will be noticed that the curves for 60 R.P.M. are not reliable, owing to the fact that the governor "hunted" considerably and it was difficult to secure good results.

The engine was tried out on 30 R.P.M. but the dash pots would not operate very well so we did not run a test on this speed.

The percentage of moisture in exhaust steam was obtained by dividing the weight of water in the calorimeter by the total weight of water in the calorimeter and in the receiver. A percentage of 3% to 5% was obtained, but on looking up further on Testing for Moisture in Exhaust Steam, we found that a separating calorimeter will not separate more than about 70% of the moisture in exhaust steam. The results, therefore, not being reliable, we did not enter them into our computations.

The average readings of the hourly test were used in the calculations.

An attempt was made to find the H.E.P. by the ordinate methods. Those above the atmospheric line were referred to the steam correction curves, and those below to the vacuum correction curves of springs. The difference, however, between this and the planimeter method was so slight that it was not worth while to go through such an elaborate process.

Conclusions: We find by increasing speed, with other conditions as nearly constant as possible, that;

1. A greater B.H.P. can be obtained from the same total steam consumption. Curve Sheet No. 1.

2. The economical point of any steam consumption per B.H.P. i.e. and I.H.P. h.p. is lowered and advanced. Curve Sheet No. 2.

3. The mechanical efficiency is increased and the highest point advanced. Curve Sheets Nos. 3 and 4.

4. The thermal efficiency is increased and the highest point advanced. Curve Sheet No. 5.

Explanatory:

Table No. I is working log of G. B.H.P.

" " II " " " " " 80 "

" " III " " " " 120 "

" IV is a summary of the corrected averages of all of the tests.

" V is a tabulation of the calculations.

Curves:

No. 1. Total dry steam per hr. - B.H.P.

2. " " " " B.H.P. i.e. B.H.P.

3. " " " " I.H.P. " I.H.P.

4. Mechanical efficiency in % - I.H.P.

5. " " " " % - B.H.P.

6. Thermal " " " % - I.H.P.

No.	5.	Thermal efficiency in %	B.H.P.	
	6.	G.E. spring connection.		
	7.	H.E.	"	"
	8.	Thermometer No.	1'	"
	9.	"	"	21
	10.	"	"	22
	11.	"	"	23
	12.	"	"	(Dry)
	13.	Pressure gauge		"
	14.	Manometer	"	"

Notations used in calculations.

I.H.P. - Indicated Horse Power.

B.H.P. - Brake " "

G.E. - Gear End.

H.E. - Head End.

R.P.M. - Revolutions per Minute.

R - Revolutions per Minute.

W - Weight of Seale Ball.

" - " " Piston Area.

η_i - Indicated Efficiency.

η_t - Thermal " "

x - Pressure of Steam in %.

Δ - Total heat in the steam at

absolute calculating pressure.

T_1 - Temperature of the steam at
absolute calorimeter pressure.
 T_2 - Temperature of superheated steam in
calorimeter.
 q - Heat of liquid at absolute boiler
pressure.
 q_1 - Heat of liquid at initial steam
pressure.
 q_2 - Heat of liquid at exhaust pressure.
 r - " " " vaporization at absolute
boiler pressure.
 r_1 - Heat of vaporization at initial
steam pressure.
 W_1 - Lbs. of dry steam per B.H.P. hr.
 W_2 - Weight of cu.ft. of water at outlet
temperature.
 C - Coefficient of discharge of orifice.
 a - Area of orifice in sq.ft.
 h - 32.16 ft.
 h - Head on center of orifice in feet.

Computation of Test No. 1 - 60 R.P.M.

I. Indicated Horse Power.

$$\begin{aligned}
 \text{I.H.P. Heat } T.H. &= H.T. \text{ Constant} \times R.P.M. \times H \\
 &= .0025074 \times 27.65 \times 52.5 \\
 &= 11.8
 \end{aligned}$$

$$\begin{aligned}
 \text{I.H.P. Crank Pin} &= \text{D.R. Constant} \times \text{H.P.} \times \pi \times H \\
 &= .0000223 \times 44.1 \times 52.5 \\
 &= 47.1
 \end{aligned}$$

$$\begin{aligned}
 \text{Total I.H.P.} &= 40.2 + 47.1 \\
 &= 87.3
 \end{aligned}$$

II. Engine Horse Power.

$$\begin{aligned}
 \text{E.H.P.} &= \text{D.R. Constant} \times (P - w) \\
 &\quad \times H \\
 &= .001008 \times (1500 - 14) \\
 &\quad \times 52.5 \\
 &= 76.8
 \end{aligned}$$

III. Mechanical Efficiency.

$$\begin{aligned}
 \eta_m &= \frac{\text{E.H.P.}}{\text{I.H.P.}} \\
 &= \frac{76.8}{87.3} \\
 &= .877 \\
 &= 87.7\%
 \end{aligned}$$

IV. Quality of Steam.

$$\begin{aligned}
 x &= \frac{h + .43 (T_2 - T_1) - q}{T} \\
 &= \frac{1150.5 + .43 (212.67 - 212.3) - 716.5}{872.6} \\
 &= .9917 \\
 &= 99.17\%
 \end{aligned}$$

V. Total Dry Steam in lbs.

$$\begin{aligned}
 &= 8070 \times .9917 \\
 &= 8007.6
 \end{aligned}$$

VI. Lbs. Dry Steam per I.H.P. hr.

$$= \frac{3767.6}{167.8}$$

$$= 22.4$$

VII. Lbs. Dry Steam per S.H.P. hr.

$$= \frac{3767.6}{77.2}$$

$$= 48.7$$

VIII. Thermal Efficiency.

$$E_t = \frac{33,456}{H_1(P_1 + p_1 - p_2)}$$

$$= \frac{33,456}{37.7(1180 - 160)}$$

$$= \frac{33,456}{36,720}$$

$$= .91 = 91\%$$

XI. Lbs. of Cooling Water per Syst.

$$Q = c a (2ch)^{\frac{1}{4}} \times W_c$$

$$= .62 \times \frac{7.962}{144} (2 \times 22.16 \times 1.0)^{\frac{1}{4}} \times 68.23$$

$$= 73.25$$

TABLE No. IV

Test No	Length of Test	
1	1 hour	5
2	"	5
3	"	6
4	"	6
5	"	6
1	1-hour	8
2	"	8
3	"	8
4	"	8
5	"	8
6	50-min.	9
1	1-hour	11
2	"	11
3	"	11
4	"	11
5	"	11

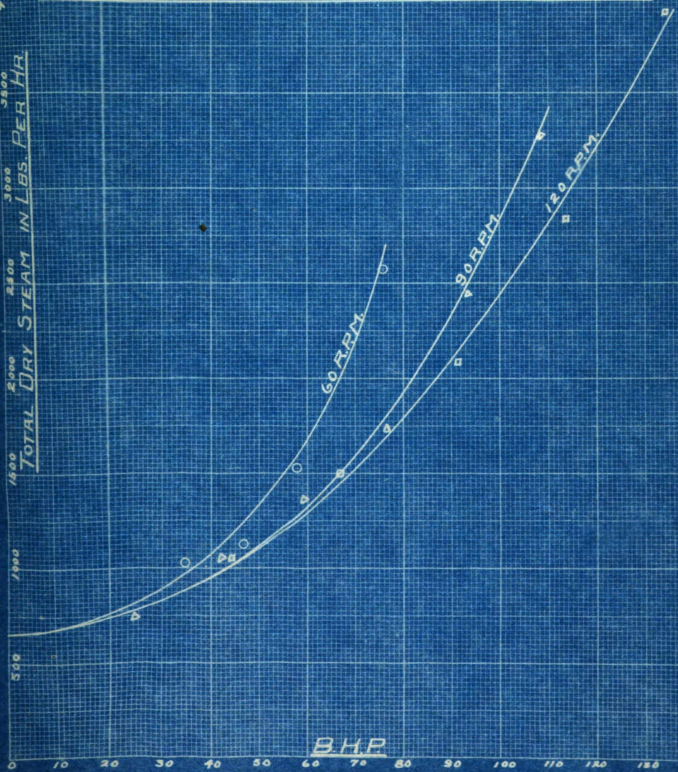
TABLE No.

Test No.	Length of Test	
1	1-hr.	
2	"	
3	"	
4	"	
5	"	
1	1-hr.	
2	"	
3	"	
4	"	
5	"	
6	"	
1	1-hr.	
2	"	
3	"	
4	"	
5	"	

1

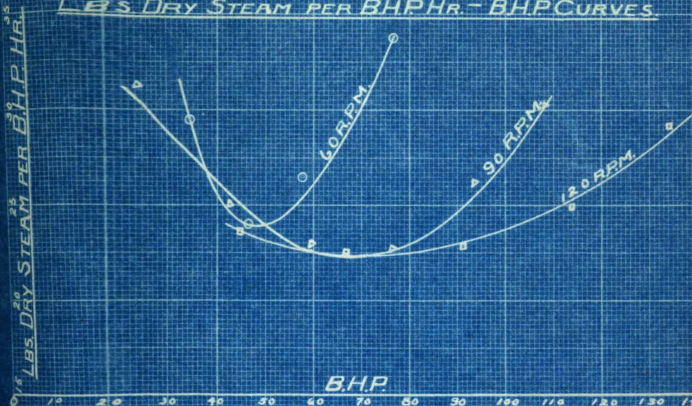
TOTAL DRY STEAM IN LBS. PER HR. - BHP CURVES.

TOTAL DRY STEAM IN LBS. PER HR.

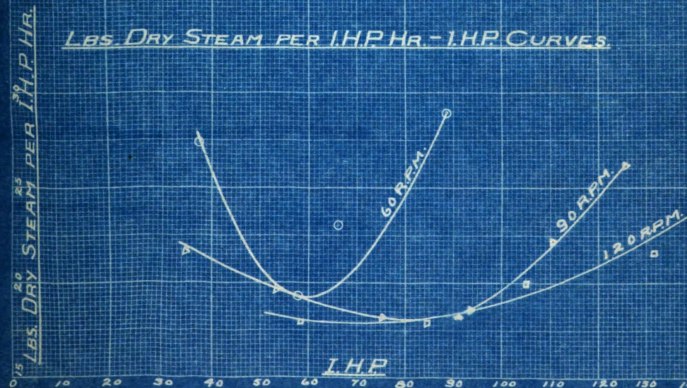


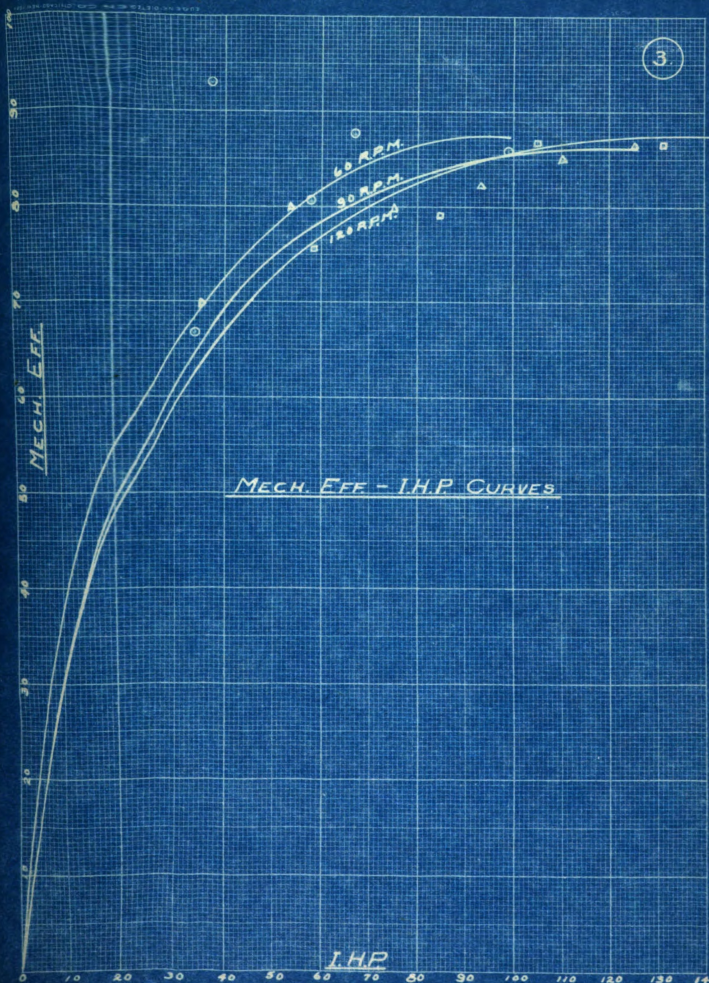
BHP

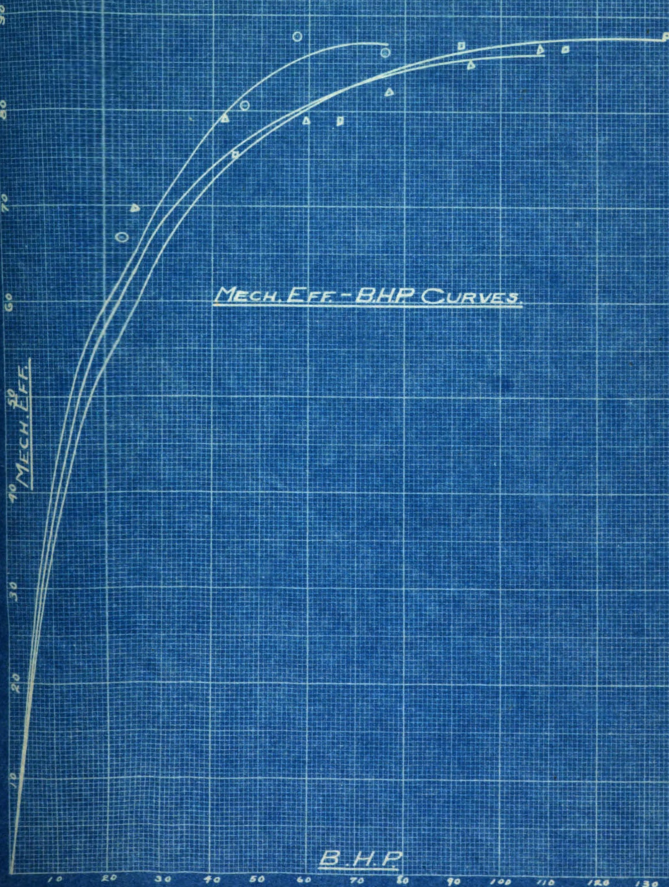
LB'S DRY STEAM PER BHP.HR. - BHP CURVES.



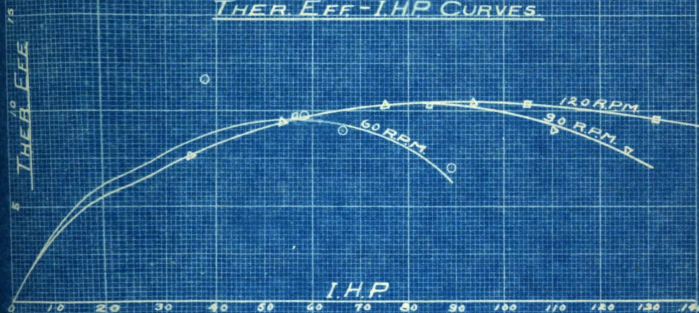
LB'S DRY STEAM PER IHP.HR. - IHP CURVES.



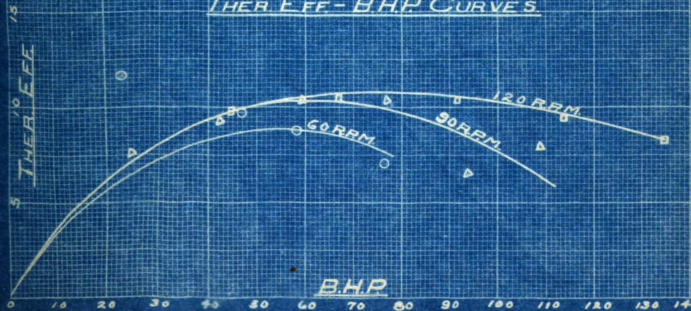




THER. EFF. - I.H.P. CURVES



THER. EFF. - B.H.P. CURVES



A P P E N D I X

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Bibliography: The engine on which this study was to investigate the steam consumption on a direct system is the following bibliography of testing notes was used:

1. Colburn's "Steam & Gas Plant Engineering", Chap. IX, pages 557 to 566. Thermal and Mechanical efficiencies of oil engines in a steam engine.

2. Trans. A.S.M.E. Nov. 1908, Vol. 30. "Report of Committee on Standardization of Steam Engine Tests". Steam Consumption per H.P. hr. and the efficiency of the steam.

3. A.S.M.E. Engineering Laboratory Notes by Prof. J.A. Holson, page 27 a, "Journal Test of Various Engines". Steam Consumption per H.P. hr. Pages 40 a - 40 b, "Test on Surface Condensers". Operation and Functions of a Condenser.

4. Thurston's "Elements of Steam Engines". Part II, Chap. VI, Page 525 - "Steam Engine Tests".

5. Carpenter's "Experimental Engineering". Chap. XVIII, page 511 - "Methods of Testing Steam Engines".

TABLE No. I.

Feeding	No.	Time	
1	12:10	130	
2	12:20	"	
3	12:30	"	
4	12:40	"	
5	12:50	"	
6	1:00	"	
7	1:10	"	
1	1:40	100	
2	1:50	"	
3	2:00	"	
4	2:10	"	
5	2:20	"	
6	2:30	"	
7	2:40	"	
1	3:00	80	
2	3:10	"	
3	3:20	"	
4	3:30	"	
5	3:40	"	
6	3:50	"	
7	4:00	"	
1	2:10	60	
2	2:20	"	
3	2:30	"	
4	2:50	"	
5	3:00	"	
6	3:10	"	
7	3:20	"	
8	3:30	"	
1	3:50	40	
2	4:00	"	
3	4:10	"	
4	4:20	"	
5	4:30	"	
6	4:40	"	
7	4:50	"	

TABLE No. II

Reading No.	Time	Barometer
1	10:00	130
2	10:10	"
3	10:20	"
4	10:30	"
5	10:40	"
6	10:50	"
7	11:00	"
1	11:30	110
2	11:40	"
3	11:50	"
4	12:00	"
5	12:10	"
6	12:20	"
7	12:30	"
1	12:45	90
2	12:55	"
3	1:05	"
4	1:15	"
5	1:25	"
6	1:35	"
7	1:45	"
1	2:00	70
2	2:10	"
3	2:20	"
4	2:30	"
5	2:40	"
6	2:50	"
7	3:00	"
1	3:15	50
2	3:25	"
3	3:35	"
4	3:45	"
5	3:55	"
6	4:05	"
7	4:15	"
1	4:30	30
2	4:40	"
3	4:50	"
4	5:00	"
5	5:10	"
6	5:20	"
7	Last Test only	"

TABLE No. III

Reading No.	Time
1	9:15
2	9:25
3	9:35
4	9:45
5	9:55
6	10:05
7	10:15
1	10:25
2	10:35
3	10:45
4	10:55
5	11:05
6	11:15
7	11:25
1	11:45
2	11:55
3	12:05
4	12:15
5	12:25
6	12:35
7	12:45
1	1:00
2	1:10
3	1:20
4	1:30
5	1:40
6	1:50
7	2:00
1	2:15
2	2:25
3	2:35
4	2:45
5	2:55
6	3:05
7	3:15

+2

+1

0

-1

-2

+3

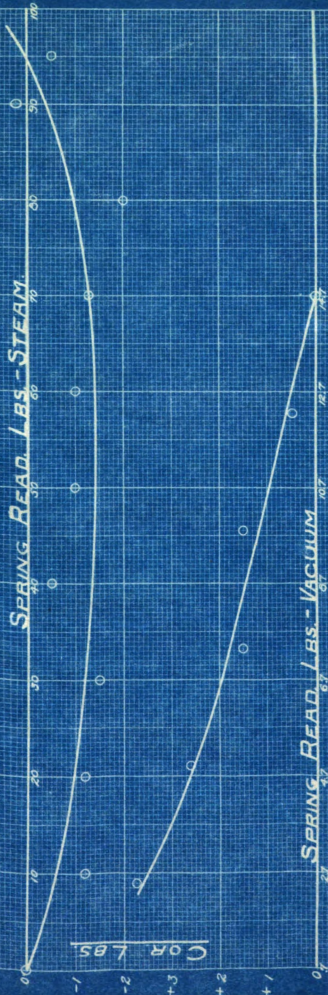
+2

+1

0

COR. LBS.

SPRING READ. LBS. - STEAM.



SPRING READ. LBS. - VACUUM

CORRECTION CURVE - C.F. SPRING.

6

+2

+1

0

-1

-2

+2

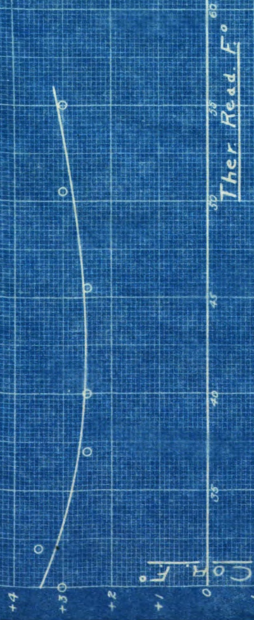
+1

0

COR. LBS.

SPRING READ. LBS. - STEAM.SPRING READ. LBS. - VACUUM.CORRECTION CURVE - H.E. SPRING.

7

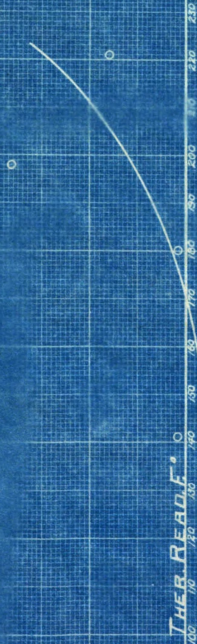


CORRECTION CURVE Ther. No. 14

+3
+2
+1
0
-1

Cor. F.°

Ther. Read. F.°



CORRECTION CURVE Ther. No. 21

COA. F.

TEMP. READ. F.

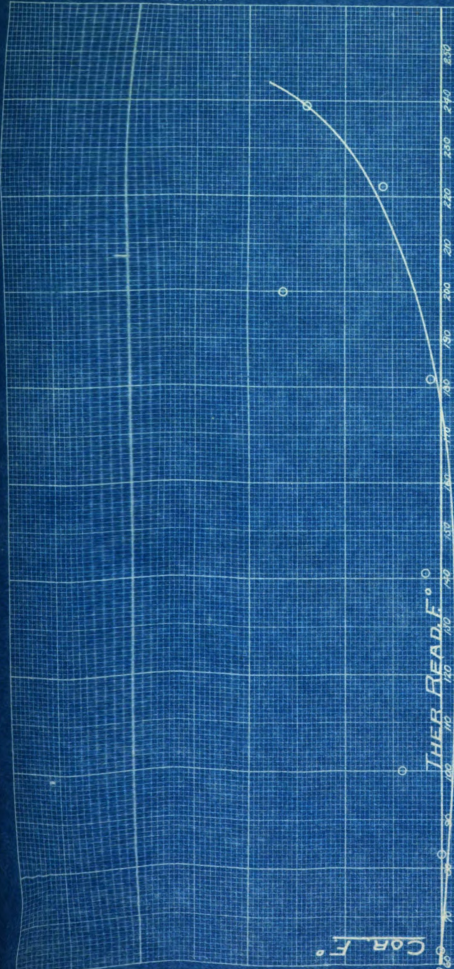
CORRECTION CURVE - THER. NO. 22

+2

+1

0

-1



Cor.
F.
0
1
2

Ther. Read. F.

CORRECTION CURVE THERM No. 53

11

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THEB. READ. F°

COR. F°

CORRECTION CURVE THEB. DAIRY

14

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220

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-4

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-9

-10

-11

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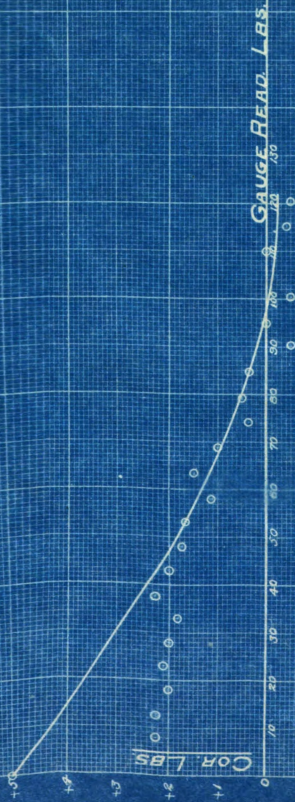
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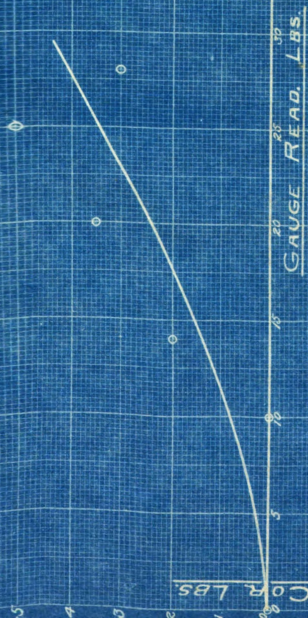
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