



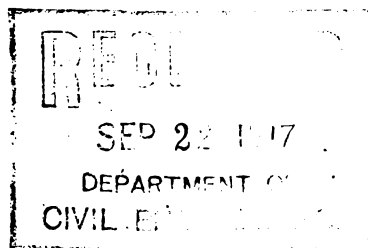
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T H E S I S

/ AN INVESTIGATION OF

STEAM ENGINE

PERFORMANCE.

under

VARIABLE LOAD /

MICHIGAN AGRICULTURAL COLLEGE

1909.

By F. C. Taylor and F. E. Wood.

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THE STEAM ENGINE UNDER VARIABLE LOAD.

Object: To determine, experimentally, the relation between variable loads and constant load as to their effect upon steam consumption in steam power installation.

Method: The steam consumption per indicated horsepower per hour for the engine on which the tests were made was carefully determined for a series of constant loads and its characteristic curve plotted as shown. We then selected what seemed to be characteristic load curves of two large power stations, one a lighting plant and one an electric railway power station. (See Plate I). It was not thought feasible to run a full twenty-four hour test for each of these curves but as our determinations were designed to be only relative the scale of time was reduced so that the test could be made in something more than three hours. That is, the twenty-four hour period was reduced to one hundred and ninety-two minutes. The scale of power output was reduced so as to come within the limit of the engine used. With these reduced scales the tests were made as described in detail later. The average value of indicated horsepower and of steam consumption per indicated horsepower hour were plotted upon the sheet containing the characteristic curve for the engine. The difference between the steam consumption ordinate for this horsepower and the ordinate for constant load at the same horsepower should show the effect which was to be determined.

Apparatus: The engine used in these tests is a new Corliss of the Nordberg type built by the Nordberg Construction Company of Milwaukee which was installed in the engine laboratory of this college during the fall of 1908.

Diameter of cylinder	12	inches	
Stroke	30	"	
Diameter of piston rod	2 5/16	"	
Connecting rod	6 ft. 3	"	$R/L = 1/5$
Fly wheel diameter	10	"	
Brake wheel	6	"	
Main bearing	5 3/4 in. x 9 in.		

Cylinder displacements:

Head end	3393 cu. in. = 1.96 cu. ft.
Crank end	3267 " " = 1.839 " "

Clearance volumes:

Head end	67.83 cu. in. = 2%
Crank end	63.63 " " = 1.94%

Indicated horsepower constants:

Head end	0.0085674
Crank end	0.0082493

Brake horsepower constant	0.001098
Rated revolutions per minute	90.

Indicators: Two indicators were used one for each end. Both, however, were run from the same Crosby reducing motion by attaching a double pulley which carried the cords running around the drums in place of that regularly supplied with the reducing gear. The springs were calibrated (See Table VII) and the proper correction applied to the mean effective pressure.

Calorimeter: A standard make of the Carpenter Throttling Calorimeter was used. The sample steam was taken out of the steam pipe just above the throttle valve.

Thermometer: The thermometer used was compared with a standard instrument and found to be correct in the limits of accuracy within which it could be read.

Scales: All scales used were calibrated and their calibration curves, if any error was noted, are shown herewith. (See Plate III.)

Formulas:

$$\text{I.H.P.} = \text{PKN}$$

$$\text{B.H.P.} = \text{WKN}$$

Where P = mean effective pressure

K = horsepower constant

N = revolutions per minute

W = brake weights.

$$\text{Quality of steam} = \frac{H + .48 (t'' - t') - h}{L}$$

Nomenclature is that used in Peabody's steam tables.

Pounds of dry steam per horsepower hour

$$\frac{Q \times W \times 60}{H.P. \times T}$$

where

Q = quality of steam

W = weight of condensed steam

H.P.=horsepower

T = time in minutes.

The first work was done on Tuesday, March 30th, 1909. We spent the day in getting the engine into shape and rigging up the indicators.

The next day, Wednesday, we found that the cutoff on the crank end was considerably greater than that on the head end and so proceeded to reset the valves to correct this. Wednesday afternoon we were running the engine when the main bearing got hot enough so that the babbitt metal filled the oil grooves in the quarter boxes and cap. We took these parts out, renewed the oil grooves and scraped the bearing to a fit. We experienced no more difficulty from this cause throughout the tests.

Thursday morning was spent in final adjustments of the indicator rig. Thursday afternoon a preliminary run was made for the purpose of testing our apparatus, the engine and auxiliaries and to familiarize ourselves with the method and requirements.

On Friday, April 2nd, our test No. 1 was run.

TEST NO. 1. Made April 2, 1909.

In this test, which was run for seven and a half hours, we used eight loads. The first six were kept constant for fifty minutes each, allowing ten minutes for the brake to take up each new load, and for the air pump etc. to be brought under the new conditions. The seventh load was only applied for ten minutes and was found to be too small for the overload we wished. This was then increased until the cards showed cutoff at about 80% of the stroke. This gave as high an overload as the scale would stand and it was kept constant for fifty minutes.

Cards were taken from each end every ten minutes, and the M. E. P. and I. H. P. were figured in the usual way.

The vacuum was kept constant at 20" as nearly as was possible varying but slightly either way.

The I. H. P. and B. H. P. and quality of steam were figured by means of the formulae given above.

Average values of I. H. P., B. H. P. and pounds of dry steam per horse-power-hour were computed and plotted, as before mentioned, on Plate II. Any point on these curves giving the average steam consumption of the engine if run at that corresponding load.

Characteristic indicator cards were selected from each load and tracings were made of them. Blue prints will be found of these cards under Fig's. 1 and 2. Fig's. 1a -

1h being cards from the head end of the cylinder, and Fig's 2a-2h, being cards from the crank end.

A copy of the running log, or the observed data will be found in Table I, computed data will be found in Table II.

TEST NO. II. Made May 13, 1909.

In this test we followed out the variable load of a Street Railway Power plant, as given by the ampere chart for a day, and which is shown in full line in Plate I. We assumed the peak load of 1,120~~f~~ on the brake and reduced the ampere scale to correspond to this. Loads were changed every minute of the test and cards and readings were taken every four minutes. Our computations were based on these readings. The condensed steam from the condenser would lag behind a few minutes and when the steam consumption per horse-power-hour was figured from these readings, taken at the same times, we obtained such absurd results as 130 pounds of dry steam per I. H. P. H. So to correct this error we took the average horse power and average steam consumption for the whole test and plotted these on Plate II giving as the average steam consumption for this class of load.

This test was also run with a vacuum of about 20 inches. The air pump stopped at the peak load for about a minute but the vacuum only changed to seventeen inches.

At time there appears to be a discrepancy between the I. H. P. and B. H. P. sometimes the I. H. P. being less than the B. H. P. This is probably due to the fact that the load was decreasing and the brake had not been entirely adjusted to the new load. While running at the minimum load the cylinder

did not take steam at every revolution, this gave a negative horsepower at times, cards taken at this time are shown in Fig's. 3b and 4b. Cards for maximum load are shown at 3a and 4a, and cards taken at the minimum load when the cylinder was taking steam are shown in Fig's. 3c and 4c. Fig's. 3a-3c being head end cards and 4a-4c being crank end cards.

A copy of the running log or observed data will be found in Table III, computed data in Table IV.

TEST NO III.

Made May 18, 1909.

In general this test was run and worked up as No. II had been. The load used however, was that of an Electric Lighting plant. Plotted as shown in broken line of Plate I.

Both the peak and minimum loads of this test were higher than those of No. II. The average load being at the most efficient load as shown by the steam consumption curves of test No. I.

The average H. P. and steam consumption are shown on Plate II.

Fig's 5a and 5b are cards from the head end taken at maximum and minimum loads respectively. Fig's. 6a and 6b are cards from the crank end taken simultaneously with 5a and 5b.

A copy of the running log or the observed data will be found in Table V; the computed data in Table VI.

(Fig's. 7 and 8 are cards taken just as we were starting this test, before the steam was entirely turned on. These show the action of this type of Corliss valve. It allows the cylinder to receive steam its full stroke when starting.)

Conclusion: The tests show conclusively that the effect of considerable variation in loads during the day is to increase the steam consumption largely. Although the method of applying the results of our test might be questioned by some as being inaccurate yet we are very sure that any inaccuracies due to this cause would show only a possible varia-

tion in the amount of the increase as shown by our Plate II and would not affect our conclusion. An interesting point for further investigation would be the economic limit to which the increase in the number of power units employed might be carried in reducing the unit steam consumption.

TABLE I.

Number	Time	Trake Weights	Calorimeter Temperature	Steam Pressure	Vacuum	Weight of Condensed Steam	Revolution Counter.	Load Number
0	1	2	3	4	5	6	7	Load.
1	9:32	135	222	95	20		10270	I
2	:42	"	223	96	"			
3	:52	"	224.3	93	"	250		
4	10:02	"	224.2	91.3	10			
5	:12	"	224.3	95	20			
6	:22	"	223.0	94	"	312	10943	II
7	:32	340	226.0	93.0	"		21044	
8	:42	"	226.2	95	"			
9	:52	"	226	94.5	"	313.25		
10	11:02	"	223	94.4	"			
11	:12	"	226	90	"			III
12	:22	"	"	90	"	312.25	20110	
13	:32	490	226	"	"		27007	
14	:42	"	"	95.2	21			
15	:52	"	227.6	"	20	326.5		
16	12:02	"	227	92	"	122.4		IV
17	:12	"	224.0	93.4	"	105.25		
18	:22	"	227	92.3	"	201.25		
19	:34	640	224.0	96.4	"		20423	
20	:44	"	223.0	93	"	212		
21	:54	"	223	90	"	245		
22	1:04	"	222	"	"	253		
23	:14	"	"	95	"	244		
24	:24	"	223	96	"	252	36930	

0	1	2	3	4	5	6	7	Load
25	1:34	705	212	98	20		37350)	V
26	:44	"	221	"	"	385		
27	:54	"	222	"	"	395		
28	2:04	"	"	"	"	397		
29	:14	"	"	"	"	397		
30	:24	"	220	"	"	"	40104)	VI
31	:34	925	"	"	"		40553)	
32	:44	"	221	"	"	335		
33	:54	"	220	"	"	338		
34	3:04	"	219	"	"	373		
35	:14	"	220	"	"	330		VII
36	:24	"	221	"	"	325	40500)	
37	3:52	2100	"	04	10		40430)	
38	4:02	"	220	03	18	571	50647)	
39	:03	1565	222	00	"		51143)	
40	:13	"	220	03	"	011		VIII
41	:23	"	221	00	"	010		
42	:33	"	220	00	"	007		
43	:43	"	219	01	"	010		
44	:53	"	"	"	"	015	50850)	

TABLE II.

0	R.P.M.	M.E.P.		I.H.P.		I.C.P. Total.
		H.E.P.	C.E.	H.E.	C.E.	
1	89.5	18.3	16.3	9.3	10.47	31.77
2	89	32.2	26.9	16.92	10.73	50.65
3	88	33.3	39.56	25.56	22.7	54.23
4	89	44.06	50.23	33.30	30.33	70.47
5	88	53.5	52.4	41.33	33.02	73.35
6	87	63.4	66.3	50.93	47.5	93.43
7	85	80.4	74.4	53.0	52.15	110.75
8	84	91.4	80.2	65.63	59.72	125.40

TABLE II (Continued.)

0	Corr. Scale Tts.	F.H.P.	Quality of Steam.	# of Dry Steam	
				Per I.H.P.H.	Per F.H.P.H.
1	184.53	13.25	96.5	29.9	25.6
2	339.13	33.17	93.3	24.43	27.03
3	433.33	47.25	96.6	20.42	21.52
4	633.03	62.44	96.2	20.22	22.23
5	763.4	73.75	96.4	21.71	23.15
6	923.23	82.2	96.2	22.51	25.13
7	1143.	103.1	96.4	27.71	29.3
8	1262.30	116.4	95.6	23.25	30.45

TABLE III.

Number.	Time.	Press. Totaling.	Calorimeter Temperature.	Steam Pressure.	Vacuum.	Weight of Condensed Steam.	Revolution Indicator.
1	2	3	4	5	6	7	
1	1:01	330	233	32.2	20	---	31037
2	:05	377	231	32.3	"	43.3	32040
3	:10	447	230	32.4	"	34	32404
4	:15	51	234	32	"	19.6	32765
5	:20	72	234	32.5	"	33.5	33131
6	:25	63	240	32.8	"	22	33500
7	:30	32	242.5	30	"	27	33858
8	:35	35	243.5	30.6	"	31.7	34126
9	:40	75	233	32.2	"	21	34536
10	:45	80	244	32.8	"	20.5	34950
11	2:01	173	233	32	"	21	35312
12	:05	377	227	32.4	"	57	35671
13	:10	625	226	32.8	"	37.5	36033
14	:15	720	220	31.7	"	35.5	36390
15	:17	340	221	30	"	113	36741
16	:21	335	220	37.0	19	114	37091
17	:25	327	"	37.3	20	143.5	37438
18	:29	320	"	31.5	"	137.5	37730
19	:33	750	220.5	35.5	19	123	38135
20	:37	650	222	"	20	159.7	38433
21	:41	635	224	32	"	96.8	38742
22	:45	630	223	31.5	"	32.5	39001

TABLE III. (Continued)

0	1	2	3	4	5	6	7
23	2:49	634	223	86.3	20	83.5	99350
24	:53	652	222	87.2	"	84.2	99904
25	:57	675	221	86	"	89	99955
26	3:01	637	222	85	"	103.6	99607
27	:05	635	221	84.3	"	103.5	99939
28	:08	"	"	86.6	19	103.1	91310
29	:14	710	220	85	20	103	91750
30	:17	693	"	83.5	"	84.2	92016
31	:21	700	220.2	82.6	"	83.5	92365
32	:25	703	220	83.2	"	106	92714
33	:29	650	221	82	"	112	93000
34	:33	700	222	82.5	"	101.2	93413
35	:37	910	220	82.2	"	109	93763
36	:41	1000	219.5	80.4	19	125.2	94119
37	:45	933	213	82.6	17	176.5	94402
38	:49	727	222	81.5	19	149.5	94302
39	:53	620	223	82.5	21	113.5	95143
40	:57	630	224	89.	20	83.5	95501
41	4:01	657	"	91.5	"	35	95957
42	:05	572	224.2	92	16	92	96210
43	:09	485	223.5	92.8	20	82.5	96566
44	:13.5	430	220	93.6	"	74.1	96904
45	:17	"	223	94	22	53.5	97273
46	:21	450	"	94.4	21	63.2	97634
47	:25	425	220.3	"	"	66	97991
48	:32	343	232	94	"	101	98017

TABLE IV.

O	R.P.M.	M.E.F.		I.H.F.		I.H.F. Total.
		H.E.	T.E.	H.E.	T.E.	
1	-----	50.9	19.4	---	---	-----
2	88	10.4	15.4	12.37	11.6	23.97
3	91	6.4	8.4	5.12	7.04	12.16
4	90	5.4	11.4	4.55	8.43	12.98
5	92	-3.0	-3.0	-0.86	-1.59	-----
6	"	"	"	-0.36	"	-----
7	90	1.4	2.4	1.21	1.77	2.98
8	92	3.4	5.4	2.33	4.01	7.01
9	"	1.4	3.4	1.55	2.56	3.91
10	99	"	3.9	1.13	2.34	3.97
11	90	-3.	-3.	-2.3	-2.23	-----
12	"	6.9	9.9	5.45	7.33	12.78
13	"	23.4	23.4	12.17	17.25	29.52
14	99	40.4	39.9	30.34	29.37	60.21
15	83	51.4	46.9	39.77	33.99	73.76
16	83	61.9	53.4	46.66	42.35	89.02
17	87	62.4	56.4	46.46	40.47	86.93
18	"	-----	-----	-----	-----	-----
19	"	60.4	56.4	44.96	40.47	85.40
20	89	54.4	50.4	41.34	38.46	80.00
21	83	43.4	45.4	36.59	32.91	69.5
22	90	44.4	40.9	34.40	31.34	66.24
23	87	43.4	40.9	32.36	29.33	61.69
24	83	41.4	33.9	31.21	23.19	59.40
25	"	43.5	40.4	32.71	29.29	62.00
26	"	44.9	41.4	33.37	30.01	63.38
27	"	43.4	"	33.71	30.01	63.72
28	"	46.9	43.4	35.39	31.47	66.36

10.7	10.4	10.3	10.2	10.1	10.0
17.7	17.6	17.5	17.4	17.3	17.2
24.7	24.6	24.5	24.4	24.3	24.2
---	---	---	---	---	---
31.7	31.6	31.5	31.4	31.3	31.2
38.7	38.6	38.5	38.4	38.3	38.2
45.7	45.6	45.5	45.4	45.3	45.2
52.7	52.6	52.5	52.4	52.3	52.2
59.7	59.6	59.5	59.4	59.3	59.2
66.7	66.6	66.5	66.4	66.3	66.2
73.7	73.6	73.5	73.4	73.3	73.2
80.7	80.6	80.5	80.4	80.3	80.2
87.7	87.6	87.5	87.4	87.3	87.2
94.7	94.6	94.5	94.4	94.3	94.2
---	---	---	---	---	---
101.7	101.6	101.5	101.4	101.3	101.2
108.7	108.6	108.5	108.4	108.3	108.2
115.7	115.6	115.5	115.4	115.3	115.2
122.7	122.6	122.5	122.4	122.3	122.2
129.7	129.6	129.5	129.4	129.3	129.2
136.7	136.6	136.5	136.4	136.3	136.2
143.7	143.6	143.5	143.4	143.3	143.2
150.7	150.6	150.5	150.4	150.3	150.2
157.7	157.6	157.5	157.4	157.3	157.2
164.7	164.6	164.5	164.4	164.3	164.2
171.7	171.6	171.5	171.4	171.3	171.2
178.7	178.6	178.5	178.4	178.3	178.2
185.7	185.6	185.5	185.4	185.3	185.2
192.7	192.6	192.5	192.4	192.3	192.2
199.7	199.6	199.5	199.4	199.3	199.2
206.7	206.6	206.5	206.4	206.3	206.2
213.7	213.6	213.5	213.4	213.3	213.2
220.7	220.6	220.5	220.4	220.3	220.2
227.7	227.6	227.5	227.4	227.3	227.2
234.7	234.6	234.5	234.4	234.3	234.2
241.7	241.6	241.5	241.4	241.3	241.2
248.7	248.6	248.5	248.4	248.3	248.2
255.7	255.6	255.5	255.4	255.3	255.2
262.7	262.6	262.5	262.4	262.3	262.2
269.7	269.6	269.5	269.4	269.3	269.2
276.7	276.6	276.5	276.4	276.3	276.2
283.7	283.6	283.5	283.4	283.3	283.2
290.7	290.6	290.5	290.4	290.3	290.2
297.7	297.6	297.5	297.4	297.3	297.2
304.7	304.6	304.5	304.4	304.3	304.2
311.7	311.6	311.5	311.4	311.3	311.2
318.7	318.6	318.5	318.4	318.3	318.2
325.7	325.6	325.5	325.4	325.3	325.2
332.7	332.6	332.5	332.4	332.3	332.2
339.7	339.6	339.5	339.4	339.3	339.2
346.7	346.6	346.5	346.4	346.3	346.2
353.7	353.6	353.5	353.4	353.3	353.2
360.7	360.6	360.5	360.4	360.3	360.2
367.7	367.6	367.5	367.4	367.3	367.2
374.7	374.6	374.5	374.4	374.3	374.2
381.7	381.6	381.5	381.4	381.3	381.2
388.7	388.6	388.5	388.4	388.3	388.2
395.7	395.6	395.5	395.4	395.3	395.2
402.7	402.6	402.5	402.4	402.3	402.2
409.7	409.6	409.5	409.4	409.3	409.2
416.7	416.6	416.5	416.4	416.3	416.2
423.7	423.6	423.5	423.4	423.3	423.2
430.7	430.6	430.5	430.4	430.3	430.2
437.7	437.6	437.5	437.4	437.3	437.2
444.7	444.6	444.5	444.4	444.3	444.2
451.7	451.6	451.5	451.4	451.3	451.2
458.7	458.6	458.5	458.4	458.3	458.2
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472.7	472.6	472.5	472.4	472.3	472.2
479.7	479.6	479.5	479.4	479.3	479.2
486.7	486.6	486.5	486.4	486.3	486.2
493.7	493.6	493.5	493.4	493.3	493.2
500.7	500.6	500.5	500.4	500.3	500.2
507.7	507.6	507.5	507.4	507.3	507.2
514.7	514.6	514.5	514.4	514.3	514.2
521.7	521.6	521.5	521.4	521.3	521.2
528.7	528.6	528.5	528.4	528.3	528.2
535.7	535.6	535.5	535.4	535.3	535.2
542.7	542.6	542.5	542.4	542.3	542.2
549.7	549.6	549.5	549.4	549.3	549.2
556.7	556.6	556.5	556.4	556.3	556.2
563.7	563.6	563.5	563.4	563.3	563.2
570.7	570.6	570.5	570.4	570.3	570.2
577.7	577.6	577.5	577.4	577.3	577.2
584.7	584.6	584.5	584.4	584.3	584.2
591.7	591.6	591.5	591.4	591.3	591.2
598.7	598.6	598.5	598.4	598.3	598.2
605.7	605.6	605.5	605.4	605.3	605.2
612.7	612.6	612.5	612.4	612.3	612.2
619.7	619.6	619.5	619.4	619.3	619.2
626.7	626.6	626.5	626.4	626.3	626.2
633.7	633.6	633.5	633.4	633.3	633.2
640.7	640.6	640.5	640.4	640.3	640.2
647.7	647.6	647.5	647.4	647.3	647.2
654.7	654.6	654.5	654.4	654.3	654.2
661.7	661.6	661.5	661.4	661.3	661.2
668.7	668.6	668.5	668.4	668.3	668.2
675.7	675.6	675.5	675.4	675.3	675.2
682.7	682.6	682.5	682.4	682.3	682.2
689.7	689.6	689.5	689.4	689.3	689.2
696.7	696.6	696.5	696.4	696.3	696.2
703.7	703.6	703.5	703.4	703.3	703.2
710.7	710.6	710.5	710.4	710.3	710.2
717.7	717.6	717.5	717.4	717.3	717.2
724.7	724.6	724.5	724.4	724.3	724.2
731.7	731.6	731.5	731.4	731.3	731.2
738.7	738.6	738.5	738.4	738.3	738.2
745.7	745.6	745.5	745.4	745.3	745.2
752.7	752.6	752.5	752.4	752.3	752.2
759.7	759.6	759.5	759.4	759.3	759.2
766.7	766.6	766.5	766.4	766.3	766.2
773.7	773.6	773.5	773.4	773.3	773.2
780.7	780.6	780.5	780.4	780.3	780.2
787.7	787.6	787.5	787.4	787.3	787.2
794.7	794.6	794.5	794.4	794.3	794.2
801.7	801.6	801.5	801.4	801.3	801.2
808.7	808.6	808.5	808.4	808.3	808.2
815.7	815.6	815.5	815.4	815.3	815.2
822.7	822.6	822.5	822.4	822.3	822.2
829.7	829.6	829.5	829.4	829.3	829.2
836.7	836.6	836.5	836.4	836.3	836.2
843.7	843.6	843.5	843.4	843.3	843.2
850.7	850.6	850.5	850.4	850.3	850.2
857.7	857.6	857.5	857.4	857.3	857.2
864.7	864.6	864.5	864.4	864.3	864.2
871.7	871.6	871.5	871.4	871.3	871.2
878.7	878.6	878.5	878.4	878.3	878.2
885.7	885.6	885.5	885.4	885.3	885.2
892.7	892.6	892.5	892.4	892.3	892.2
899.7	899.6	899.5	899.4	899.3	899.2
906.7	906.6	906.5	906.4	906.3	906.2
913.7	913.6	913.5	913.4	913.3	913.2
920.7	920.6	920.5	920.4	920.3	920.2
927.7	927.6	927.5	927.4	927.3	927.2
934.7	934.6	934.5	934.4	934.3	934.2
941.7	941.6	941.5	941.4	941.3	941.2
948.7	948.6	948.5	948.4	948.3	948.2
955.7	955.6	955.5	955.4	955.3	955.2
962.7	962.6	962.5	962.4	962.3	962.2
969.7	969.6	969.5	969.4	969.3	969.2
976.7	976.6	976.5	976.4	976.3	976.2
983.7	983.6	983.5	983.4	983.3	983.2
990.7	990.6	990.5	990.4	990.3	990.2
997.7	997.6	997.5	997.4	997.3	997.2
1004.7	1004.6	1004.5	1004.4	1004.3	1004.2
1011.7	1011.6	1011.5	1011.4	1011.3	1011.2
1018.7	1018.6	1018.5	1018.4	1018.3	1018.2
1025.7	1025.6	1025.5	1025.4	1025.3	1025.2
1032.7	1032.6	1032.5	1032.4	1032.3	1032.2
1039.7	1039.6	1039.5	1039.4	1039.3	1039.2
1046.7	1046.6	1046.5	1046.4	1046.3	1046.2
1053.7	1053.6	1053.5	1053.4	1053.3	1053.2
1060.7	1060.6	1060.5	1060.4	1060.3	1060.2
1067.7	1067.6	1067.5	1067.4	1067.3	1067.2
1074.7	1074.6	1074.5	1074.4	1074.3	1074.2
1081.7	1081.6	1081.5	1081.4	1081.3	1081.2
1088.7	1088.6	1088.5	1088.4	1088.3	1088.2
1095.7	1095.6	1095.5	1095.4	1095.3	1095.2
1102.7	1102.6	1102.5	1102.4	1102.3	1102.2
1109.7	1109.6	1109.5	1109.4	1109.3	1109.2
1116.7	1116.6	1116.5	1116.4	1116.3	1116.2
1123.7	1123.6	1123.5	1123.4	1123.3	1123.2
1130.7	1130.6	1130.5	1130.4	1130.3	1130.2
1137.7	1137.6	1137.5	1137.4	1137.3	1137.2
1144.7	1144.6	1144.5	1144.4	1144.3	1144.2
1151.7	1151.6	1151.5	1151.4	1151.3	1151.2
1158.7	1158.6	1158.5	1158.4	1158.3	1158.2
1165.7	1165.6	1165.5	1165.4	1165.3	1165.2
1172.7	1172.6	1172.5	1172.4	1172.3	1172.2
1179.7	1179.6	1179.5	1179.4	1179.3	1179.2
1186.7	1186.6	1186.5	1186.4	1186.3	1186.2
1193.7	1193.6	1193.5	1193.4	1193.3	1193.2
1200.7	1200.6	1200.5	1200.4	1200.3	1200.2
1207.7	1207.6	1207.5	1207.4	1207.3	1207.2
1214.7	1214.6	1214.5	1214.4	1214.3	1214.2
1221.7	1221.6	1221.5	1221.4	1221.3	1221.2
1228.7	1228.6	1228.5	1228.4	1228.3	1228.2
1235.7	1235.6	1235.5	1235.4	1235.3	1235.2
1242.7	1242.6	1242.5	1242.4	1242.3	1242.2
1249.7	1249.6	1249.5	1249.4	1249.3	1249.2
1256.7	1256.6	1256.5	1256.4	1256.3	1256.2
1263.7	1263.6	1263.5	1263.4	1263.3	1263.2
1270.7	1270.6	1270.5	1270.4	1270.3	1270.2
1277.7	1277.6	1277.5	1277.4	1277.3	1277.2
1284.7	1284.6	1284.5	1284.4	1284.3	1284.2
1291.7	1291.6	1291.5	1291.4	1291.3	1291.2
1298.7	1298.6	1298.5	1298.4	1298.3	1298.2
1305.7	1305.6	1305.5	1305.4	1305.3	1305.2
1312					

TABLE IV. (Continued.)

O	P.P.M.	F.E.P.		I.K.P.		I.H.P. Total.
		H.E.	C.E.	H.E.	C.E.	
29	88	47.42	43.4	35.74	31.47	67.21
30	89	46.82	"	35.76	31.85	67.61
31	87	43.42	45.4	36.11	32.57	68.67
32	"	45.4	41.4	33.93	29.70	63.63
33	82	43.4	40.4	32.71	29.23	61.94
34	"	47.9	43.4	36.11	31.37	67.48
35	"	46.4	44.4	34.99	30.19	65.18
36	"	51.9	49.9	39.14	35.43	74.57
37	86	61.4	49.9	45.26	35.43	80.69
38	85	74.4	72.9	54.13	51.99	106.12
39	87	63.4	61.4	47.27	44.06	91.33
40	83	43.4	47.4	36.49	34.33	70.82
41	"	39.4	39.4	29.69	29.04	58.73
42	89	41.4	40.4	31.56	29.66	61.22
43	"	43.4	41.4	33.06	30.37	63.43
44	83	34.4	34.4	25.84	24.94	50.78
45	90	33.4	32.4	25.73	24.04	49.77
46	89	30.4	32.4	23.19	23.77	46.96
47	"	31.4	31.4	23.96	23.03	46.99
48	"	26.4	23.4	20.15	19.34	39.49
49	"	21.4	24.4	16.32	16.22	32.54

TABLE IV. (Continued.)

0	Corr. Scale Wts.	B.H.P.	Quality of Steam.	# of Dry Steam Per I.H.P.H.	# of Dry Steam Per B.H.P.H.
1	294.2	----	96.8	-----	-----
2	241.3	23.3	97.	30.24	30.6
3	117.4	11.4	97.25	40.51	43.47
4	56.00	5.5	97.6	22.59	52.2
5	37.0	3.7	97.85	-----	113.0
6	30.0	3.0	98.0	-----	107.8
7	45.0	4.5	97.9	-----	88.15
8	54.0	5.5	"	45.5	57.95
9	50.0	5.0	97.25	78.2	61.2
10	40.0	3.9	97.65	75.6	77.1
11	45.0	4.5	97.3	-----	68.19
12	137.6	13.6	96.75	64.9	60.8
13	341.1	33.7	96.7	35.7	37.65
14	588.6	57.5	96.4	23.2	24.0
15	689.5	66.6	96.5	22.0	24.33
16	803.3	77.6	"	17.55	21.37
17	868.3	83.0	"	22.4	23.46
18	850.3	81.3	96.4	-----	24.48
19	783.4	74.8	96.3	21.7	24.7
20	783.5	70.0	96.4	28.85	24.7
21	613.6	59.2	96.6	20.4	24.
22	598.6	"	"	19.55	21.9
23	593.6	56.7	96.7	20.8	22.64
24	597.8	57.7	96.6	20.0	23.65
25	615.6	59.4	"	23.1	24.13
26	638.6	61.7	"	23.55	24.32

TABLE IV (Continued.)

0	Corr. Scale Fts.	P.H.P.	Quality of Steam	# of Dry Steam Per I.H.P.H.	# of Dry Steam Per P.H.P.H.
27	650.6	62.8	96.6	24.5	23.29
28	649.6	"	96.55	24.5	23.79
29	649.6	"	"	22.05	23.62
30	673.5	65.3	"	24.95	24.71
31	657.6	62.8	96.65	20.75	22.33
32	663.6	63.4	"	24.15	24.23
33	666.6	64.4	96.5	26.15	25.13
34	653.6	63.2	"	21.95	23.32
35	725.4	70.1	96.45	23.9	22.51
36	673.2	64.4	"	26.21	23.17
37	1043.1	93.5	96.5	31.65	29.3
38	901.2	84.1	96.7	21.6	42.28
39	690.5	66.	96.75	16.81	16.06
40	593.6	56.43	96.7	13.1	22.72
41	593.6	57.4	96.6	20.93	21.45
42	620.6	60.7	"	21.77	21.96
43	535.3	52.4	96.8	20.25	24.52
44	459.9	54.4	96.85	17.25	24.23
45	443.9	43.9	96.75	19.47	19.35
46	"	43.4	96.7	27.06	22.79
47	413.9	40.4	96.3	10.4	24.51
48	439.1	47.3	96.9	22.24	20.06
49	312.2	30.5	"	-----	43.15

TABLE V.

Number.	Time.	Prake Weights.	Calorimeter Temperature	Steam Pressure.	Vacuum.	Weight of Condensed Steam.	Revolution Counter.	Barometer Reading.
0	1	2	3	4	5	6	7	
1	1:15	390	231	90	20		2710	29.46
2	1:19	345	"	"	"	55.0	3064	
3	1:23	320	"	90.5	"	49.5	3424	
4	1:27	295	230	"	"	"	3785	
5	1:31	"	228	91	"	53.5	4139	
6	1:35	"	"	"	"	"	4492	
7	1:39	"	229	90.5	"	51.5	4854	
8	1:43	"	"	"	"	52.5	5213	
9	1:47	"	228	90	21	53	5580	
10	1:51	"	230	"	"	49.5	5940	
11	1:55	335	227	"	"	59.5	6292	
12	1:59	370	228	"	20	62.5	6658	
13	2:03	425	226	"	"	63.5	7020	
14	2:07	615	224	"	"	91	7372	
15	2:11	650	223	89	"	100.	7730	
16	2:15	660	222	"	"	95	8081	
17	2:19	"	223	"	"	91.5	8432	
18	2:23	650	224	"	"	92.5	8775	
19	2:27	660	222	90	"	96	9130	
20	2:31	"	"	91	"	97.5	9484	
21	2:35	"	223	"	"	96.5	9823	
22	2:39	665	222	90	"	100.5	10186	
23	2:43	660	223	"	"	103.	10541	

TABLE V. (Continued.)

0	1	2	3	4	5	6	7
24	2:47	650	223	90	20	98	10896
25	2:51	480	225	"	"	84.5	11246
26	2:55	650	224	"	"	37.5	11604
27	2:59	720	"	"	"	102.5	11960
28	3:03	750	223	"	"	110.5	12313
29	3:07	800	222	82	"	114.5	12653
30	3:11	825	220	"	"	124.	11310
31	3:15	860	221	"	"	128.	13323
32	3:19	920	"	22.5	"	155.	13704
33	3:23	1025	219	83	13	152.	14056
34	3:27	1100	218	37.5	17	197.5	14398
35	3:31	1230	219	85	"	323.5	14730
36	3:35	1130	222	"	13	123.0	14061
37	3:39	1075	"	"	"	214.5	15414
38	3:43	1000	"	26	19	120.5	15759
39	3:47	950	"	33	20	146.5	16104
40	3:51	935	"	39	"	143.5	16456
41	3:55	840	"	90	21	126.5	16799
42	3:59	800	"	"	20	114.5	17161
43	4:03	775	223	"	"	111.5	17509
44	4:07	660	224	"	21	99.5	17302
45	4:11	590	226	"	"	86	18218
46	4:15	570	"	"	"	65	12509
47	4:19	470	228	"	"	75	18225
48	4:23	440	230	"	20	65	19231
49	4:27	390	"	"	"	52	19036

TABLE VI.

O	R.P.M.	M.E.P.		I.H.P.		I.H.P. Total.
		H.E.	C.E.	H.E.	C.E.	
1	-----	24.4	23.9	---	---	-----
2	80.	22.4	21.4	17.06	15.71	32.77
3	90.	20.4	20.4	15.73	15.15	30.88
4	90.	16.4	13.4	12.65	13.00	26.31
5	99..	17.4	"	13.29	13.51	26.80
6	"	"	19.4	"	14.25	27.54
7	90	"	17.9	13.42	13.23	26.71
8	"	"	13.4	14.20	13.06	27.86
9	82	19.4	19.4	15.26	14.62	29.91
10	90	17.9	"	13.90	14.40	28.20
11	83	18.4	20.4	13.27	14.21	28.63
12	82	23.4	22.9	13.45	17.33	35.83
13	91	27.4	24.4	21.36	13.32	32.68
14	83	37.9	36.9	23.59	26.79	55.33
15	90	46.4	42.9	35.79	31.35	67.64
16	83	"	"	34.89	31.15	66.14
17	"	44.4	42.4	33.49	30.72	64.78
18	95	43.4	40.4	31.60	23.32	59.92
19	90	"	41.9	33.12	30.75	63.87
20	"	34.9	42.4	33.50	31.12	64.62
21	85	45.9	41.9	33.41	29.39	62.20
22	91	46.4	42.4	36.15	31.23	67.93
23	89	42.4	43.4	32.33	31.63	63.26
24	"	43.9	43.9	33.50	32.25	65.73
25	83	33.4	37.9	23.25	27.51	50.46
26	90	40.4	40.4	31.15	30.00	61.15
27	99	40.9	40.4	35.30	34.09	69.39

TABLE VI (Continued)

O	R.P.M.	M.E.P.		I.H.P.		I.H.P. Total.
		H.E.	C.E.	H.E.	C.E.	
28	33	49.9	49.4	37.60	38.83	76.43
29	36	53.9	53.4	39.70	37.39	77.09
30	39	55.4	54.4	40.71	40.40	81.11
31	37	56.9	56.4	42.40	40.50	82.90
32	35	60.4	59.4	43.98	41.65	85.64
33	33	64.9	64.9	43.91	47.10	91.01
34	36	70.4	70.4	37.75	54.20	111.95
35	"	85.4	84.4	60.80	52.85	113.65
36	"	85.9	67.4	67.30	47.80	115.10
37	32	84.9	69.4	64.00	45.30	109.30
38	36	71.4	67.4	37.60	47.30	104.90
39	"	67.4	65.4	42.65	44.55	87.20
40	33	66.4	"	50.05	46.00	96.05
41	36	57.9	55.9	42.65	39.65	82.30
42	31	44.9	55.4	35.00	40.10	75.10
43	37	53.4	50.4	32.30	32.30	64.60
44	30	45.4	44.4	34.31	32.21	66.52
45	30	40.4	40.4	30.52	28.63	59.15
46	33	35.9	35.4	27.93	25.70	53.63
47	30	31.9	31.9	24.35	23.32	47.67
48	"	26.4	26.4	22.43	21.59	44.02
49	"	26.4	27.4	20.52	20.12	40.64

TABLE VI. (Continued.)

0	Corr. Scale Wts.	P.H.P.	Quality of Mean.	% of Dry St. For I.L.P.H.	% of Dry Steam For P.H.P.H.
1	-----	-----	97.1	-----	-----
2	309.	30.31	"	24.47	25.63
3	334.22	33.11	96.9	23.30	25.60
4	259.27	25.62	"	27.25	27.22
5	"	25.35	96.8	26.20	26.62
6	"	"	"	23.10	"
7	"	25.62	96.25	23.30	23.20
8	"	"	"	27.40	25.75
9	"	26.31	"	23.74	23.37
10	"	25.62	96.9	25.60	23.03
11	289.19	28.90	96.3	21.50	23.90
12	334.12	33.77	"	35.50	26.39
13	339.02	33.25	96.7	23.22	27.73
14	573.03	55.90	96.6	23.63	27.59
15	613.53	60.60	"	21.42	23.20
16	623.61	60.20	96.55	20.75	23.64
17	"	"	96.6	20.62	22.02
18	613.63	57.20	"	20.32	23.43
19	623.61	60.90	96.55	21.73	22.32
20	"	"	96.5	21.32	23.13
21	"	59.15	"	22.22	24.32
22	623.61	62.79	"	21.40	23.17
23	623.61	60.90	96.55	23.60	24.49
24	613.63	60.16	"	21.61	23.60
25	443.87	42.95	96.7	21.73	23.30
26	613.63	60.60	96.6	20.75	20.91

TABLE VI. (Continued.)

0	Corr. Scale Wts.	R.H.P.	Quality of Steam.	λ of Dry Steam Per I.H.P.H.	λ of Dry Steam Per R.H.P.H.
27	633.50	66.33	96.6	21.60	22.82
28	713.43	62.67	96.55	21.70	22.83
29	793.40	71.10	"	21.40	27.01
30	793.37	77.32	96.45	21.60	27.04
31	823.33	37.60	96.5	22.50	27.53
32	833.25	32.40	"	22.20	27.71
33	803.13	91.50	96.4	21.95	27.51
34	1123.90	106.00	96.3	25.50	26.90
35	1123.13	112.00	96.5	22.20	42.85
36	1093.01	103.20	96.65	23.20	27.62
37	1033.13	100.20	"	23.40	32.00
38	933.15	90.90	96.6	20.65	22.76
39	913.21	96.20	96.55	22.40	22.61
40	893.25	90.90	"	21.60	27.04
41	803.51	71.60	96.5	22.20	27.02
42	763.40	76.20	"	22.02	21.72
43	733.42	70.50	96.55	21.35	22.22
44	623.62	60.20	96.6	21.72	23.95
45	553.72	54.10	96.7	20.61	27.36
46	433.20	43.70	"	22.32	26.40
47	413.94	42.40	96.3	21.22	25.62
48	404.00	39.47	96.9	21.45	25.98
49	354.09	34.60	"	12.60	21.26

TABLE VII.

CALIBRATION OF INDICATOR 3.

Road Fr3.

Pounds Actual Press.	App. Press. from Card. Up.	Press. Down.	Error. Up.	Error. Down.	App. Press. from Card. Up.	Press. Down.	Error. Up.	Error. Down.
10	10.5	9.5	+0.5	-0.5	20	20	0	+2
20	20.	20.	0	0	30	31.5	+1.5	+2.
30	31.5	30.	+1.5	+2.	40	42.	+1.	+2.5
40	42.	42.5	+1.	+0.5	50	53.	+3.	+4.
50	53.	54.	+3.	+4.	60	63.5	+0.5	+5.5
60	63.5	65.	+3.	+5.	70	75.	+5.	+7.
70	75.	77.	+5.	+7.	80	85.	+5.	+3.
80	85.	86.	+5.	+3.	90	95.	+5.	+5.
90	95.	95.5	+5.	+0.5				
				24.	31.	31.	43.	

$$\text{Average} = \frac{(24+31+31+43)}{4} = 3.50\% \text{ error on H.E.}$$

Crank End.								
10	11	12	+1	+2	20.5	11	+0.5	+1
20	21	22.5	+1	+1.5	31.5	22.5	+1.5	+2.5
30	31	33	+1	+2	41.5	33	+1.5	+3.
40	41	43.5	+1	+2.5	51.5	43.5	+0.5	+3.5
50	51	53.5	+1	+2.5	61.5	54.5	+1.5	+4.5
60	61	63	+1	+2	71	65.5	+0.5	+5.5
70	72	74	+2	+2	81.5	75	+3.5	+5
80	82	84	+2	+2	91	87	+2	+7
90	93	97.5	+4.5	+4.5	97	93	+4	+3
				13.	29.	19.	35.	

$$\text{Average} = \frac{(13+29+19+35)}{4} = 2.65\% \text{ error on C.F.}$$

5.30 P.M.

6. 80PMA

5:30 PM
JUL 20

7:00 PM.

7:30 PM.

KEUFFEL & ESSER CO. NEW YORK

6:30 PM SPANISH PROFILE PLATE A. 4-20

Load Factor - 45.5%

Electric Lighting Load Curve
of
Detroit Edison Company

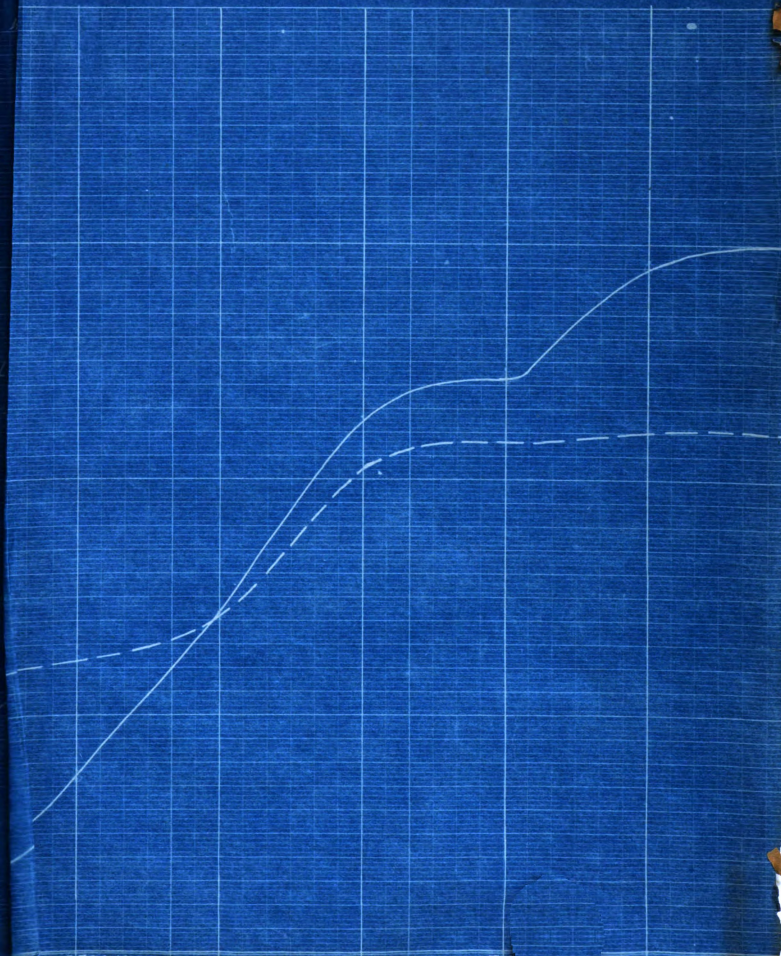
Detroit Edison Company

Plate I

Theirs of

F.E. Wood - F.C. Taylor

60.2 Hz



STANDARD PROFILE P. 1.30 PM

2.00 PM

2.30

18.30 PM

18

0

30

60

90

120

150

180

210

240

270

300

330

360

390

420

450

480

510

540

570

600

630

660

690

720

750

780

810

840

870

900

930

960

990

1020

1050

1080

1110

1140

1170

1200

1230

1260

1290

1320

1350

1380

1410

1440

1470

1500

1530

1560

1590

1620

1650

1680

1710

1740

1770

1800

1830

1860

1890

6.525

5.085

12.000

3.390

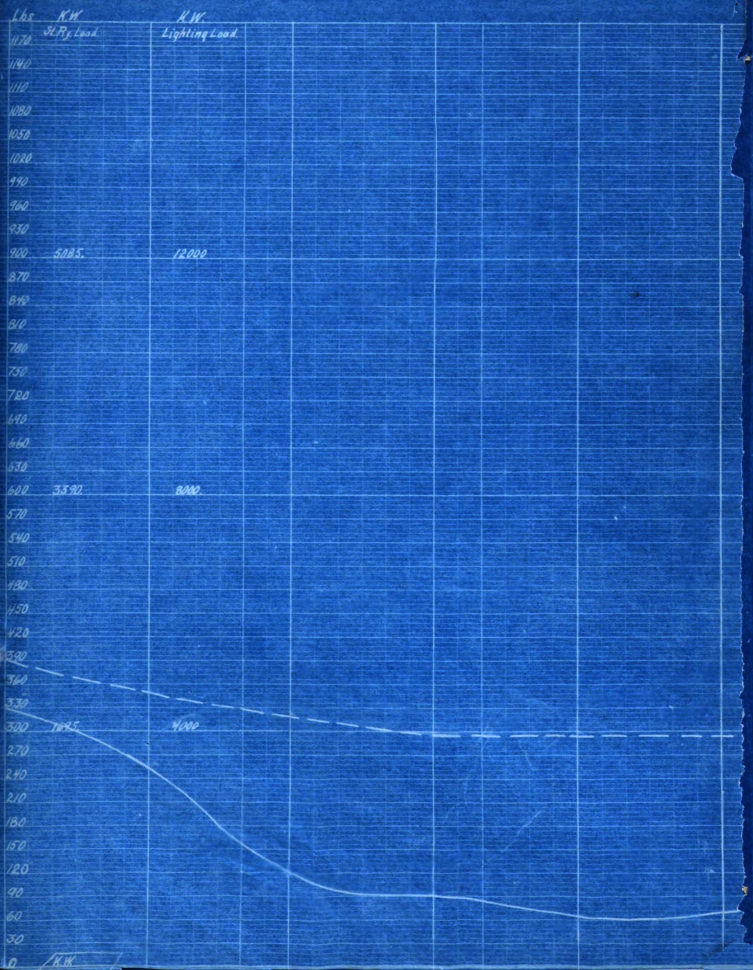
8.000

16.95

42.00

Buffalo

Street

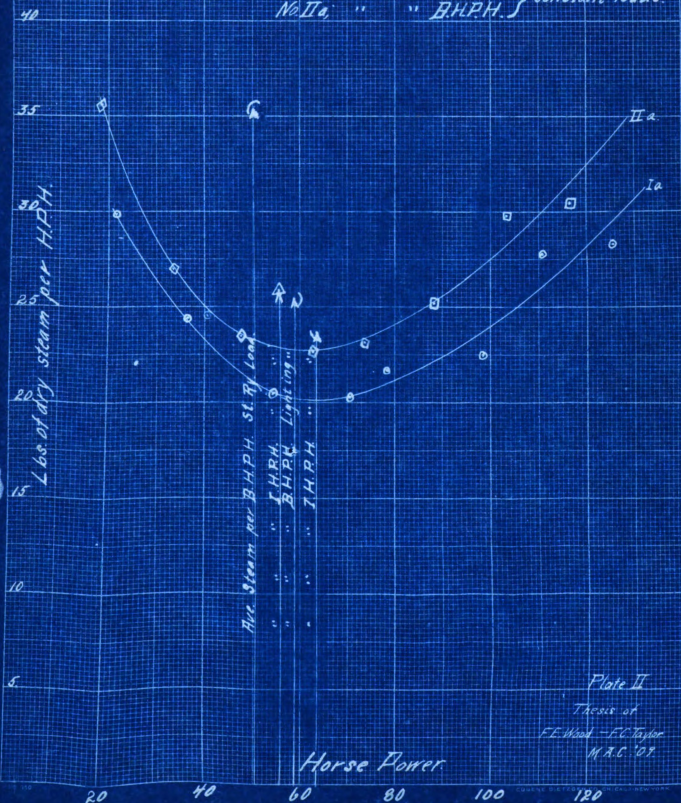




Steam Consumption Curves for

12x30 Simple Nordberg-Corliss Engine

No. Ia; steam per I.H.P.H. } constant loads.
No. IIa; " " B.H.P.H.





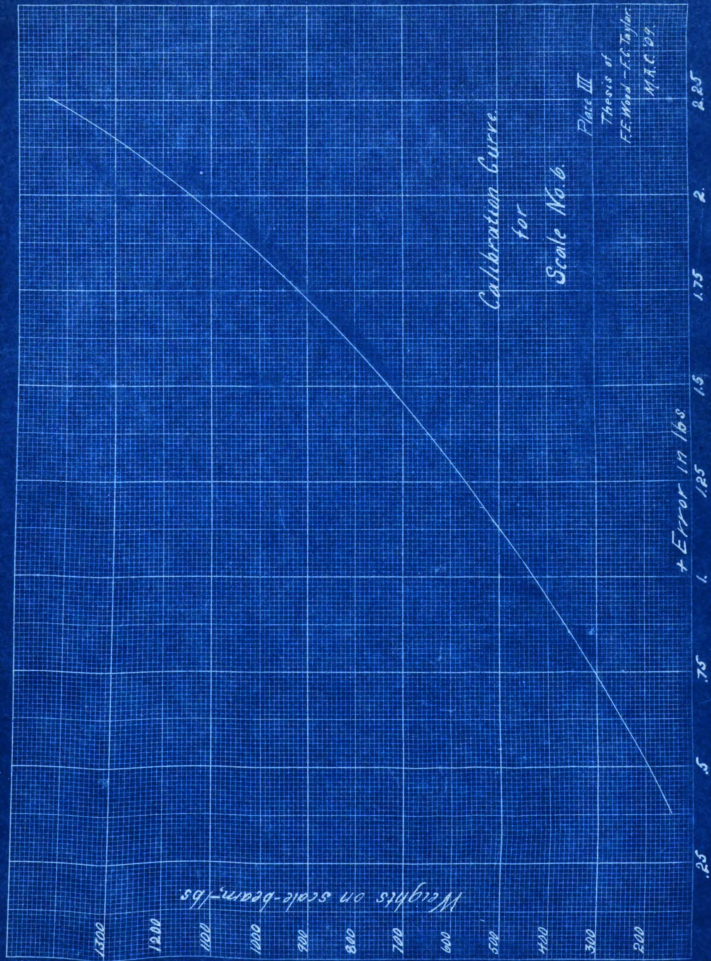




Fig. 1c.



Fig. 1b.



Fig. 2c.



Fig. 2b.



Fig. 2a.



Fig. 1a.



Fig. 11.

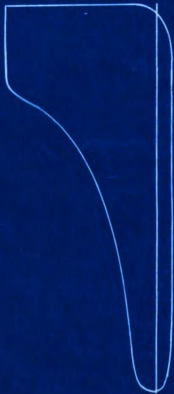


Fig. 12.



Fig. 13.



Fig. 21.



Fig. 22.



Fig. 23.

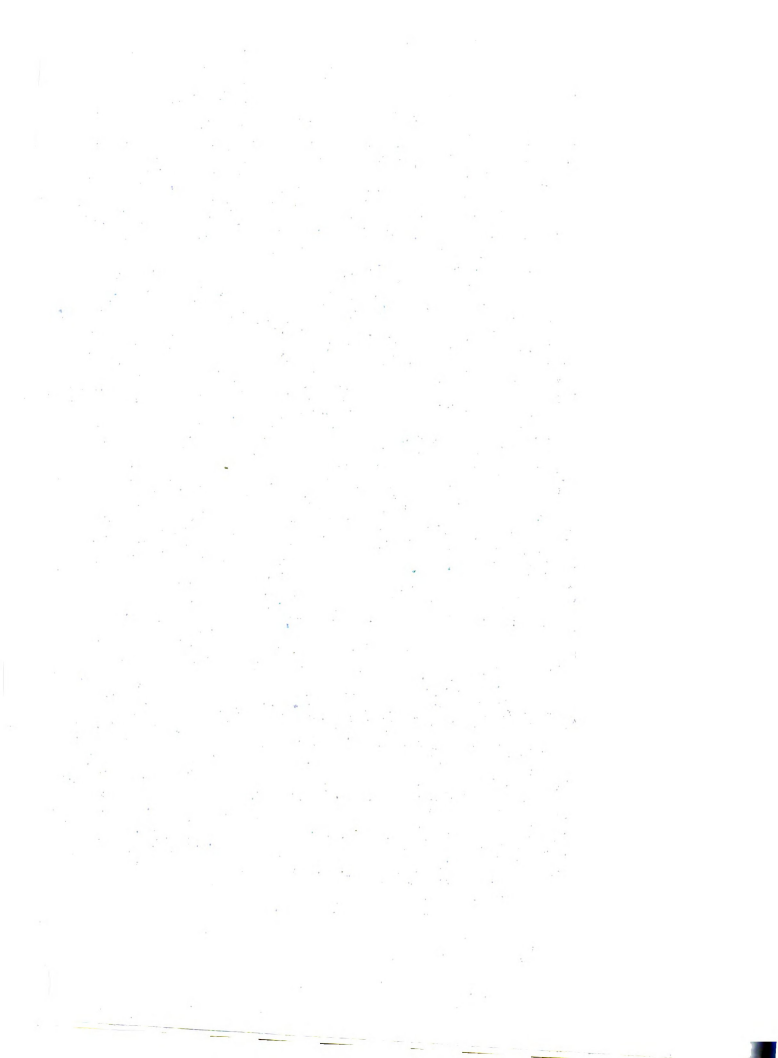




Fig. 3a.



Fig. 4a.



Fig. 3b.



Fig. 4b.



Fig. 3c.



Fig. 4c.



321 1104 14
40516



Fig. 5a



Fig. 6a



Fig. 5b

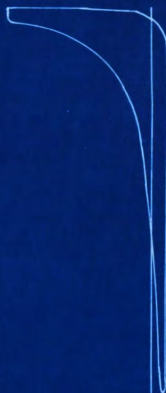


Fig. 6b



Fig. 7



Fig. 8













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