THESIS

TEST OF STEAM TURBINES AT THE SOUTHERN RAILWAY POWER HOUSE.

For the Degree of

BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

by

Bruce L. Thomas,

Under

Prof. J. A. Switzer.

1909

1909

The plant of the Southern Railway Shop, at Knoxville, Tennessee, was tested on March 31st and April 1st, 1909, by J. C.Mayes, B.L.Thomas and Bruce Helm, with the aid of the senior and junior engineers.

The boiler and furnace test was in charge of J.C.Mayes, the air compressor test in charge of Bruce Helm and the test of the turbines was in charge of B.L.Thomas.

The plant consists of a boiler house and a power house. The boiler house is equipped with a battery of four 300 H.P. Stirling boilers fed by Roney stokers, run by an 8 H.P. Edison engine, a Cochrane open feed-water heater, a duplex steam pump manufactured by the Laidlow, Dunn, Gordon Co.; an auxiliary simple steam pump and a coal and ash conveyor made by the Link-Belt Co. The power house is equipped with an Ingersoll-Rand air compressor driven by twin steam engines, a 150 H.P. synchronous motor driving a 100 K.W. direct current generator, one 500 K.W. and one 300 K.W. Westinghouse Parsons steam turbine, with Westinghouse standard engines directly connected to 25 K.W. and 17½ K.W. exciters, and a Wheeler condenser.

Preparation for the Test of the Turbines.

Generators. The usual load on the turbines is of a very fluctuating nature so that a reliable test could not be made with the turbines carrying this load. The turbine under test was therefore disconnected from the bus-bars and its output was absorbed by means of water rheostats while the other machine was run non-condensing to carry the usual load. After testing one turbine the con-

nections were changed and the other turbine was tested.

The water rheostats used were three in number. They consisted of wooden tanks 5' x 8' x 6' which were made in the wood shop of the Southern Railway Shops. In these tanks were placed three plates of sheet iron 4' x 5' x $\frac{1}{8}$" which served as electrodes. The two outside plates were so arranged that they could be moved side-wise while the middle plate of each rheostat was mounted on a block and tackle so that it could be raised or lowered. The tanks were filled with water to which was added some salt. The current density was then regulated by controlling the specific gravity of the brine in the tanks and adjusting the electrodes to the proper immersion.

The plates on the rheostats were first arranged in the delta connection, but it was found to be exceedingly difficult to obtain the load required with this connection, so the Y connection was substituted and it was found to be comparatively easy to obtain any desired load. The connections of the rheostats and instruments for obtaining the power delivered are shown diagrammatically on the accompanying blue print of generator connections. The power generated was obtained by two integrating watt meters, the percent correction for each being shown on the accompanying correction sheets for the watt meters, which were connected as shown in the diagram after being carefully calibrated. The total power generated was found by taking the sum of the power indicated by each meter. The electrical portion of these tests was under the supervision of Mr. N. L. Alison and Mr. T. Hopkins.

Turbines. The pipe which ordinarily returns the condensation from the condenser to the boiler was disconnected and the condensation was conveyed into four weighing tanks outside of the power house, from which the water after being weighed was discharged into the sewer. The steam from the condenser pump was conveyed to a condensing coil outside of the power house where it was condensed and discharged into a tank which in turn discharged into a weighing tank, from which after being weighed was discharged into the sewer. The steam pressure was taken from a gauge placed in the main steam line in the basement of the power house. The quality of the steam was taken by means of a Carpenter calorimeter placed in the steam line near the throttle valve of the 300 K.W. turbine. The vacuum on the condenser pump was measured by means of a manometer which was attached to a pipe connected to the pump on the condenser.

Test. There were six runs made on each turbine with the following loads: the friction load, one quarter, one half, three quarters, full and 25 percent over load. The observations were taken at intervals of five minutes with the exception of the 25% over load on the 500 K.W. turbine for which the observations were taken at intervals of two and one half minutes.

The steam from the condenser pump was not condensed during the test of the 300 K.W. turbine on account of the condensing coil being used to condense the steam from the exciter engine. The amount of steam used by the pump, however, was estimated to be on an average of 1260 pounds per hour by comparing the vacuum on the pump during the test with that during the test on the 500 K.W. tur-

bine, when the condensation was weighed, and obtaining the corresponding amount of steam as shown by the curves on plate I.

During each run the following observations were taken: (1) The number of revolutions of the disks on the watt meters were counted from which the number of kilowatts generated were calculated by multiplying the number of revolutions by 100, by the constant for the meters, which was 18, by the time in seconds, by the ratio of transformation of the transformer, and dividing this result by 1000. (2) The condensation from the turbines and the condenser pump was weighed. (3) The steam pressure, temperature and back pressure of the calorimeter were taken from which the quality of the steam was calculated by means of the formula $x = \frac{y_1 + 0.48(t_s - t_1) - q}{r}$, (4) The condenser vacuum was taken and (5) the number of strokes made by the oil pump per minute, on the turbines from which the number of revolutions per minute of the turbines were calculated by multiplying the number of strokes by a constant which was 42. This constant was obtained by dividing the rated number of revolutions per minute of the turbine, 3600, by 85.7 which is the number of strokes that the pump was designed to make for 3600 revolutions of the turbine.

The results of the test on the 500 K.W. turbine are shown numerically on the result sheet, page 6, and are also shown graphically on plates I and II. The results of the test on the 300 K.W. turbine are shown numerically on the result sheet, page 7, and graphically on plates III and IV.

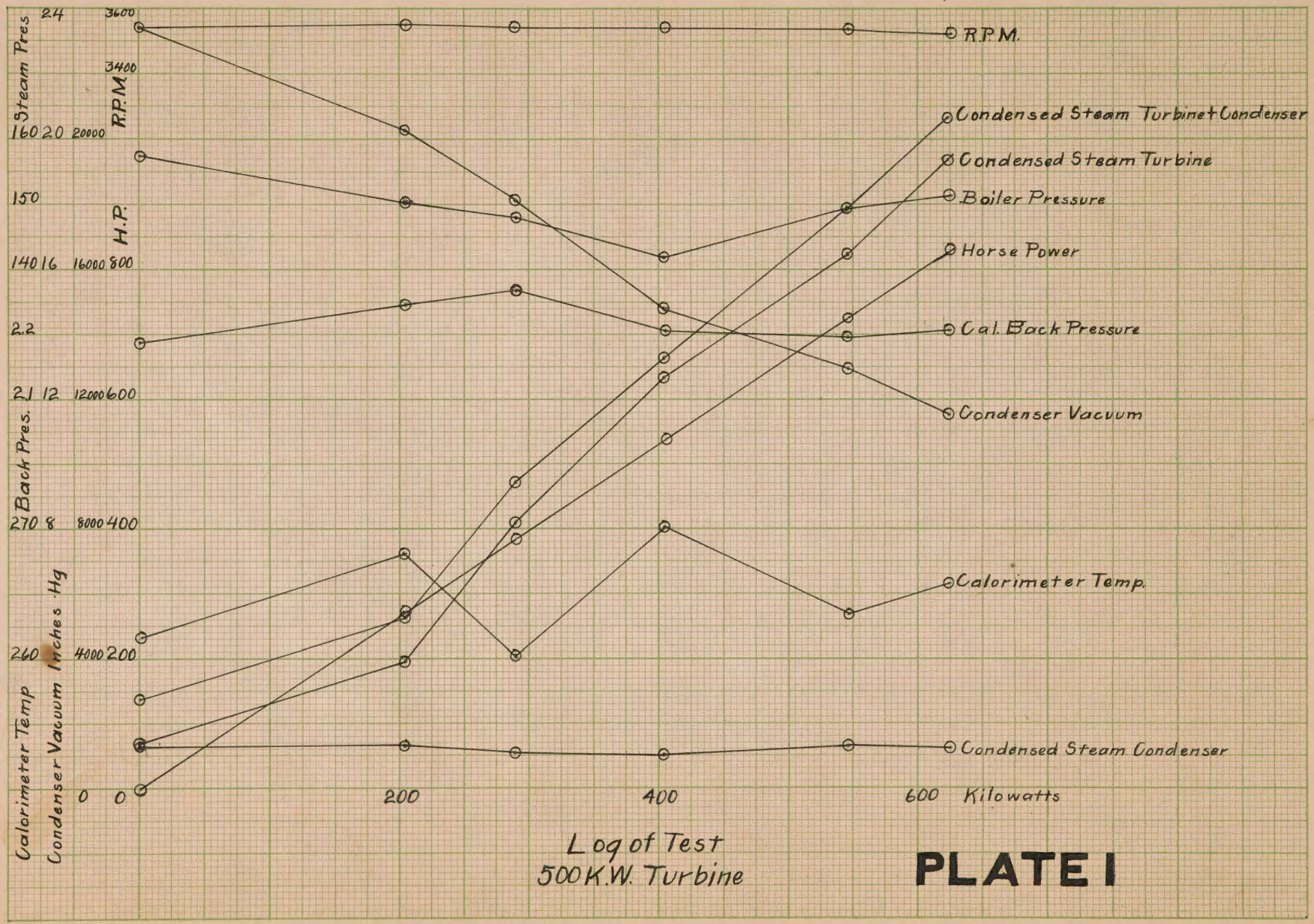
RESULTS OF THE TEST ON 500 K.W. WESTING-HOUSE PARSONS TURBINE.

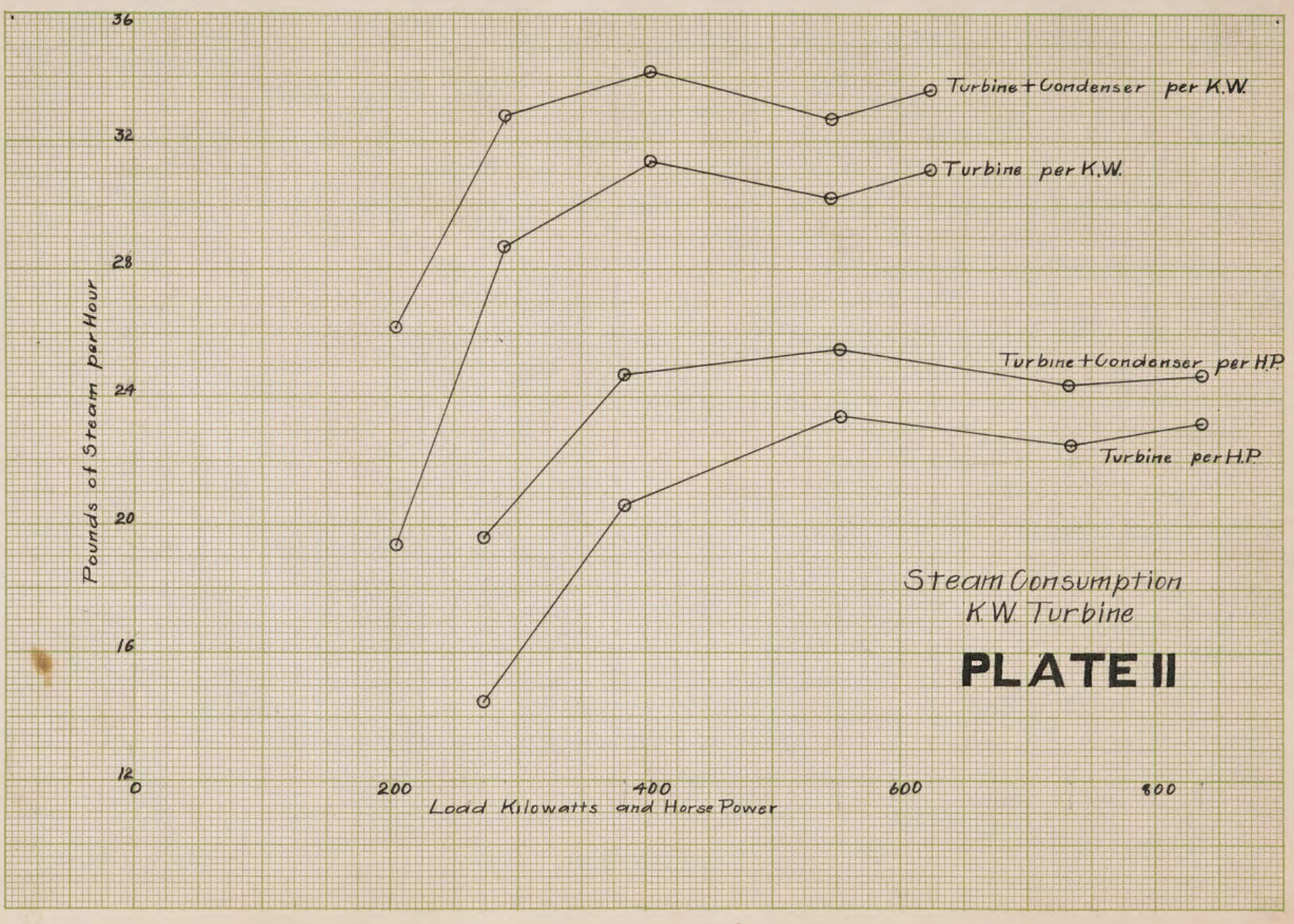
Kind of turbine	Westinghouse Parsons Turbine.					
Duration of run minutes	45	45	50	30	20	7
Load	0	¼	½	¾	1	1¼
Revolutions per minute	3571	3571	3516	3470	3419	3319
Boiler pressure	1578	150·5	148.4	142.0	150.0	150.0
Barometer pressure inches	28.95	28.97	28.95	28.95	28.98	28.96
Condenser pressure inches	23.5	20.4	18.2	14.9	13.0	11.6
Calorimeter temperature	261.8	268.2	260.4	270.1	263.6	266
Calorimeter back pressure	2.19	2.25	2.27	2.21	2.20	2.21
Quality of steam	0.965	0.969	0.965	0.964	0.967	0.967
Total weight steam per hr.turbine act.	1512	4093	8626	13258	17088	20073
Total weight steam per hr.turbine cor.	1459	3966	8324	12781	16524	19411
Total weight steam per hr.condenser act.	1410	1432	1224	1082	1404	1340
Total weight steam per hr.condenser cor.	1361	1388	1182	1043	1358	1296
Total weight steam per hr.tur.& con.cor.	2820	5354	9506	13824	17882	20701
Total delivered kilo-watts	0	204	290	404	547	624
Total delivered horse power	0	273	384	541	733	836
Lbs.steam per K.W.per hr.turbine act.	0	20.1	29.7	32.8	31.2	32.2
Lbs.steam per K.W.per hr.turbine cor.	0	19.4	28.7	31.4	30.2	31.1
Lbs.steam per K.W.turbine & condenser.	0	26.2	32.8	34.2	32.7	33.6
Lbs.steam per H.P.per hr.turbine act.	0	15.0	22.4	24.5	23.3	24.0
Lbs.steam per H.P.per hr.turbine cor.	0	14.5	21.6	23.4	22.5	23.2
Lbs.steam per H.P.turbine & condenser	0	19.6	24.7	25.5	24.4	24.7
Thermodynamic efficiency	26.2	24.7	23.6	21.8	21.6	21.1
Heat supplied per hour B.T.U.	1663260	4575764	9647516	14659807	19010124	22342061
Heat discharged & radiated per hr.B.T.U.	"	3878779	8771236	13282962	17122639	20214441
Heat utilized per hr. B.T.U.	0	696985	976280	1376845	1887485	2127620
B.T.U. per delivered H.P. per minute	0	278	419	451	432	425

Conclusion. These tests show that the turbines are not very efficient in steam consumption. A test given in Steam power Plant Engineering by Gebhart shows that a 400 K.W. Westinghouse Parsons turbine at full load consumed .14 pounds of steam per horse power per hour with a back pressure of 1.6 pounds absolute, while the test on the 500 K.W. turbine used 22.6 pounds with a back pressure of 7.8 pounds absolute. Now the thermodynamic efficiency of the 400 K.W. turbine is 30.1 percent while that of the 500 K.W. turbine is only 21.6, hence it is plainly seen that much of the heat of the steam is lost by the very low vacuum maintained. The condenser was working under very adverse circumstances since only a few days before the test the fan which ordinarily operated in conjunction with the cooling tower had suffered an accident and it was therefore not possible to use this means of cooling the condensing water. But, before the tests of the heavier loads on the large turbine were begun, the condensing water was renewed from the city mains, thus insuring cold condensing water, yet the condenser was unable to maintain an economical vacuum. I would therefore, say that the poor efficiency of the turbines is traceable to the lack of condenser capacity.

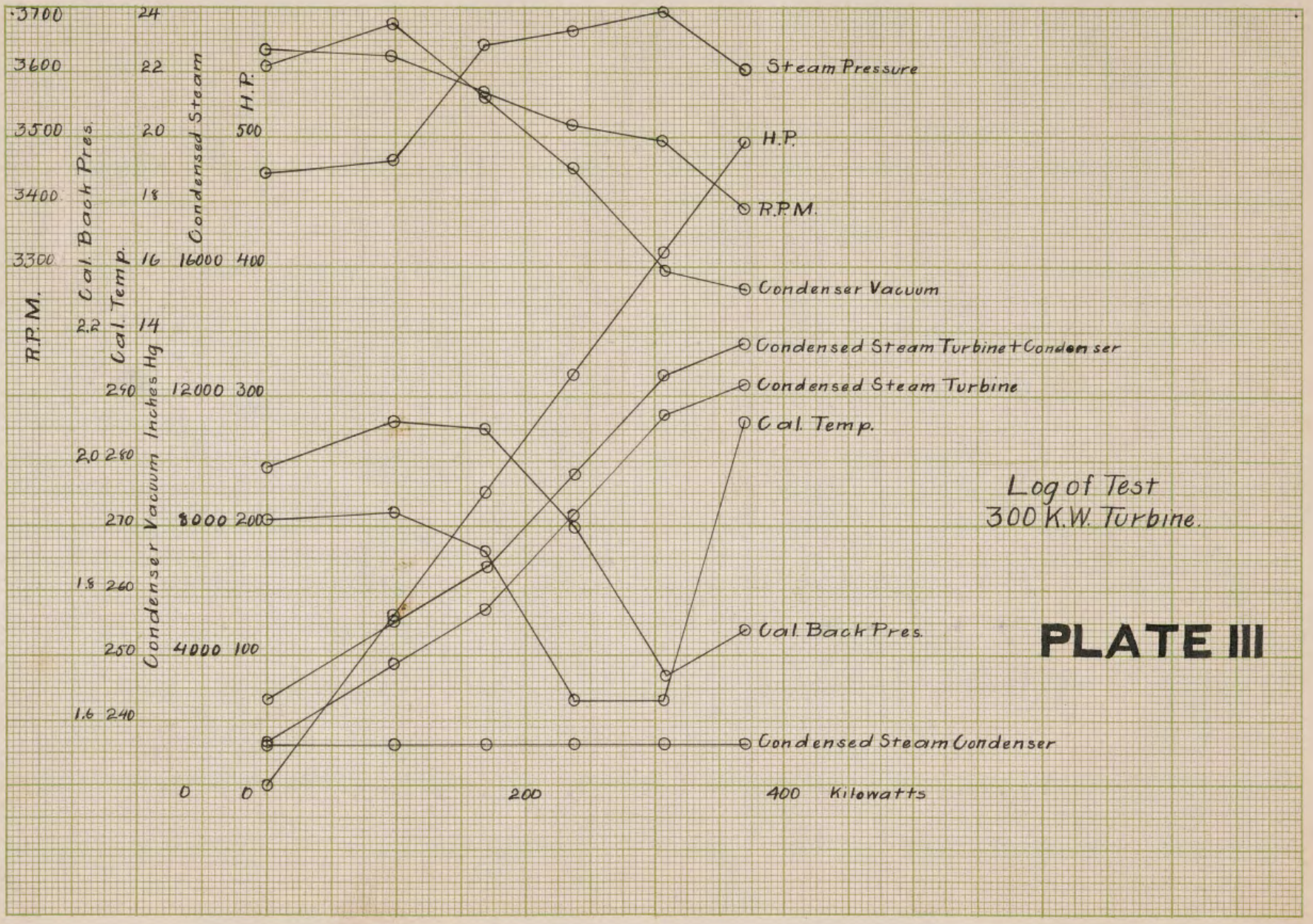
RESULTS OF TURBINE TEST.

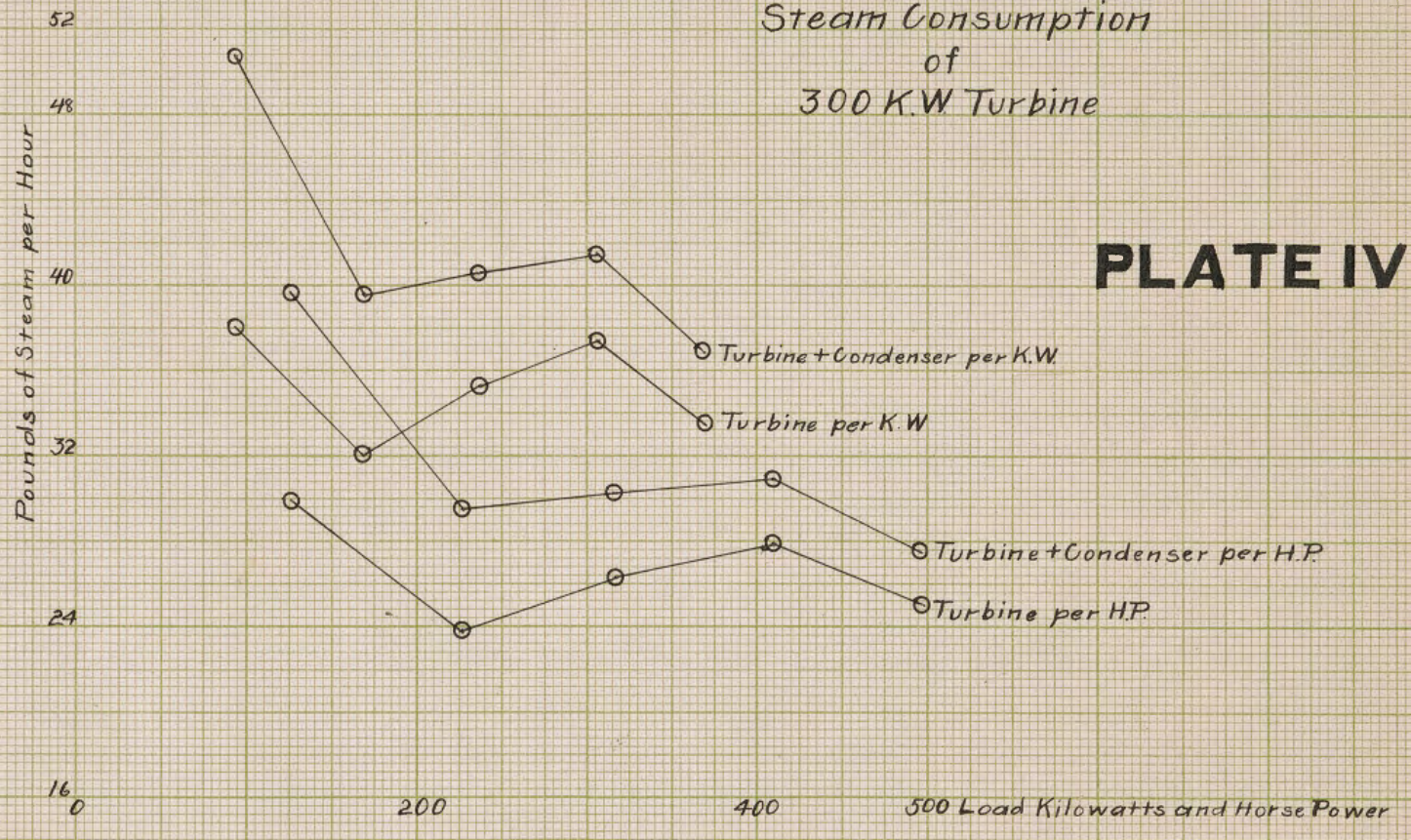
Kind of turbine	300 K.W. Westinghouse Parsons.					
Duration of run minutes	45	45	45	45	45	45
Load	0	¼	½	¾	1	1¼
Revolutions per minute	3638	3625	3571	3520	3495	3390
Boiler pressure pounds	94.7	96.6	124.4	126.7	129.5	120.5
Barometer pressure inches	28.98	28.99	29.00	29.01	29.02	29.00
Condenser pressure inches	22.2	23.5	21.3	19.1	15.9	15.4
Calorimeter temperature	279	286	285	270	248	255
Calorimeter back pressure	1.91	1.92	1.86	1.63	1.63	2.06
Quality of steam	0.988	0.990	0.983	0.974	0.961	0.968
Total weight steam per hr.turbine actual	1382	3825	5501	8469	11876	12777
Total weight steam per hr.turbine correc.	1365	3787	5408	8339	11413	12368
Total weight steam per hr.condenser actual	-	-	-	-	-	-
Total weight steam per hr.condenser correc.	1260	1260	1260	1260	1260	1260
Total weight steam per hr.condenser & turb.	2625	5047	6668	9599	12673	13628
Total delivered kilowatts	0	99.5	169	237	306	370
Total delivered horse power	0	127.0	226.5	318	410	496
Lbs.steam K.Wper hr.turbine actual	0	38.4	32.5	35.7	38.8	34.5
Lbs.steam K.W.per hr.turbine corrected	0	38.1	32.0	35.2	37.3	33.4
Lbs.steam H.P.per hr.turbine actual	0	30.1	24.3	26.6	28.9	25.8
Lbs.steam H.P.per hr.turbine corrected	0	29.8	23.8	26.2	27.8	24.9
Lbs.steam K.W.per hr.turbine & condenser	0	50.7	39.6	40.5	41.4	36.8
Lbs.steam H.P.per hr.turbine & condenser	0	39.6	29.5	30.2	30.9	27.5
Thermodynamic efficiency	22.9	23.9	24.0	23.4	21.4	20.7
Heat supplied per hour B.T.U.	1591590	4392922	6311136	9639884	13033646	14198464
Heat radiated & discharged per hr.B.T.U.	1591590	4069487	5733594	8830574	12000196	12936144
Heat utilized per hour B.T.U.	0	323435	577542	809310	1035450	1262320
B.T.U. per D.H.P. per minute	0	575	464	505	530	477


Steam Pres.
Back Pres.
Calorimeter Temp
Condenser Vacuum Inches Hg
R.P.M.
H.P.
24
160 20 20000
150
140 16 16000 800
2.2
21 12 12000 600
270 8 8000 400
260 4000 200
0 0
3600
3400
200
400
600 Kilowatts
R.P.M.
Condensed Steam Turbine-Condenser
Condensed Steam Turbine
Boiler Pressure
Horse Power
Cal. Back Pressure
Condenser Vacuum
Calorimeter Temp.
Condensed Steam Condenser
Log of Test
500 K.W. Turbine
PLATE I



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EUGENE DIETZGEN CO. CHICAGO-NEW YORK

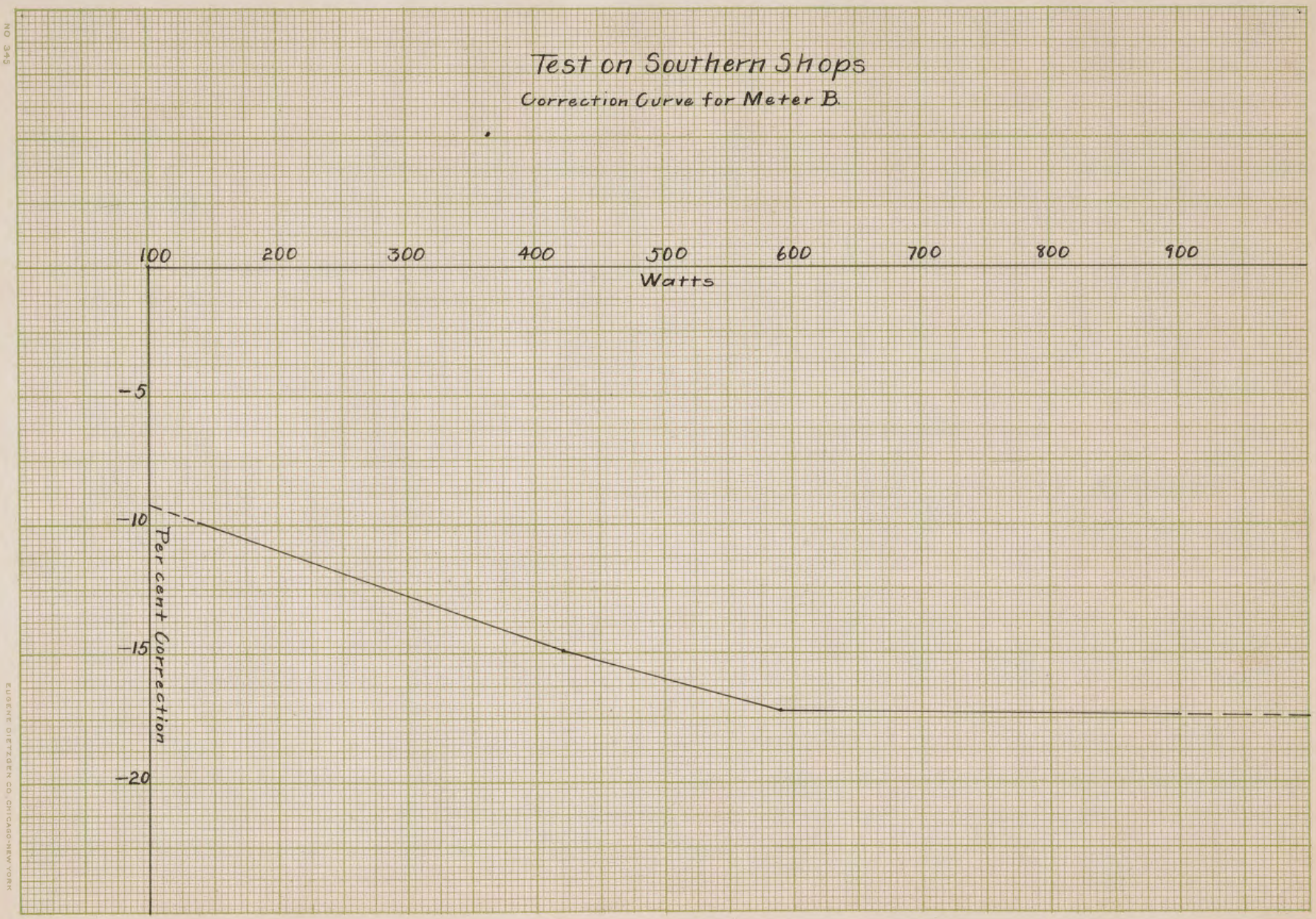

R.P.M.
Cal. Back Pres.
Cal. Temp.
Condenser Vacuum Inches Hg
Condensed Steam
H.P.
3700
3600
3500
3400
3300
2.2
2.0
1.8
1.6
250
240
16000
12000
8000
4000
0
400
300
200
100
0
200
400 Kilowatts
Steam Pressure
H.P.
R.P.M.
Condenser Vacuum
Condensed Steam Turbine + Condenser
Condensed Steam Turbine
Cal. Temp.
Cal. Back Pres.
Condensed Steam Condenser
Log of Test
300 K.W. Turbine.
PLATE III



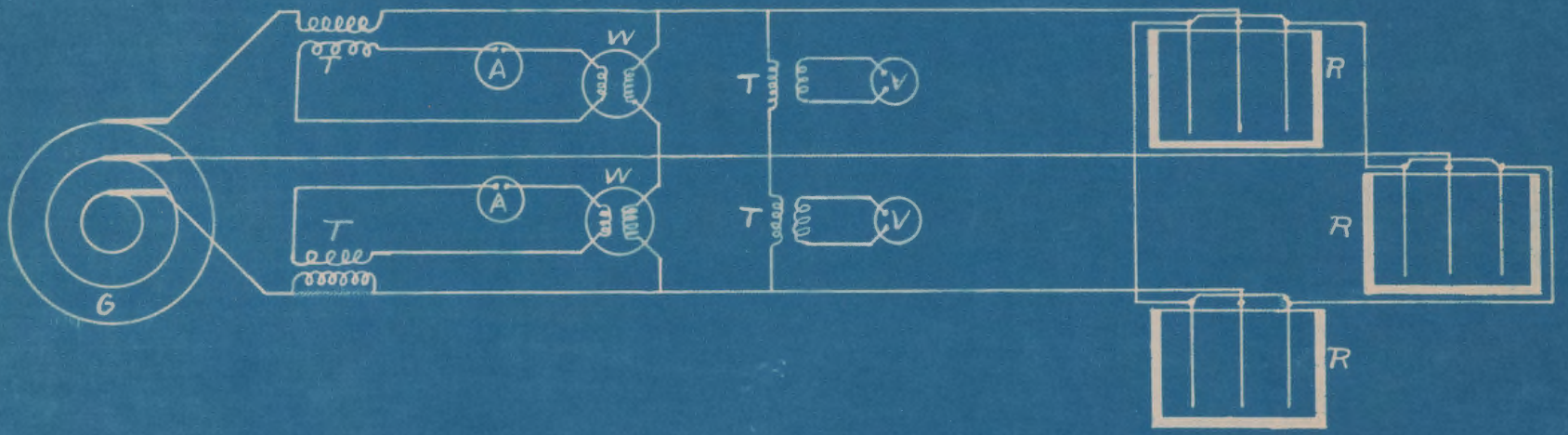
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Generator Connections

Southern Shops Test.

B.L.T

EXCITER ENGINE TEST.

A test was made on the 17.5 K.W. Westinghouse standard Exciter engine. It is a 6 x 7, two cylinder, single acting engine with an inch and three quarters offset and the cranks and eccentric being enclosed in a cast iron case.

The horse power delivered by the exciter was found by means of an ammeter and voltmeter placed in the circuit leading to the switchboard. The horse power delivered to the engine was found by means of indicator cards.

Since all the reciprocating parts were enclosed in the crank case a special reducing motion for the indicator had to be made. This reducing motion was designed and made in the University machine shop. It consisted of a plate, which was bolted on the end of the projecting shaft with three set screws, in which a three quarter wrist pin was placed so as to give a throw of 2 5/16 inches, a connecting rod 6 5/32 inches between centers, a cross head on which was a connecting rod pin and a small rod with a hook at the top for attaching the indicator string, and a slide in which the cross-head was made to travel. This slide block was placed on a suitable support placed so as to give $\frac{5}{8}$ inches offset. Thus the cross-head made an exact reproduction of the piston on one third scale. The water relief valves at the top of the cylinders were removed and were replaced by pipes leading to a three way cock to which the indicators were attached.

The exhaust pipe from the engine was disconnected near the engine and was piped to a condensing coil just outside of the power

house where the steam used by the engine was condensed and weighed.

The Test. The test was of two hours duration, observations being taken at intervals of five minutes each. The test consisted in taking indicator cards, the number of revolutions per minute, taken by a speed indicator, the current and voltage and weighing the condensed steam, the steam pressure and the quality of the steam being taken in the test of the 300 K.W. turbine.

From the indicator cards and the speed, the indicated horse power was calculated and the delivered horse power and kilowatts were calculated from the electrical readings. The ratio of the delivered horse power to the indicated horse power gives the efficiency of the engine and exciter combined.

The log of the test is shown on page 10 and the numerical results are shown on the result sheet page 11 . A graphical log is also seen on plate V.

Conclusions. Some undiscovered error occurred in the course of the test, in consequence of which the efficiency of the engine and exciter is excessively high. The steam consumption is also high as compared with the amount given in the Westinghouse catalog for this size engine.

Engine built by Westinghouse Co. Kind of Engine Westinghouse Standard
Clearance Right Cylinder percent 12.8 Length of Stroke 7 ins. Date April 1 1909.
" Left " " " 12.8 Diam of Cylinder 6 "
Scale of Spring 60+5 cor Area " " Sq.ins. 28.27

Number	Time	R.P.M	Pressure Steam.	Barom. inches Hg	Calorimeter Back pres inches Hg	Temp.	Quality	Weight of Condst Steam	M.E.P. Right Cylinder	M.E.P. Left Cylinder	I.H.P. Right Cylinder	I.H.P. Left Cylinder	I.H.P. Total	Amperes Meter Reading	Amperes Correction	Amperes Corrected Reading	Volts Meter Reading	Volts Correction	Volts Corrected Reading	K'lowatts	Delivered H.P.	Pounds Steam per IHP per Hr.
1	6:25	384	92.0	28.99	1.80	282			36.6	39.0	7.39	7.49	14.88	96.5	+3.5	100.0	104.0	+2.30	106.3	10.63	14.24	
2	6:30	384	132.0		2.00	282			37.4	37.9	7.18	7.28	14.46	"	"	100.0	"	"	106.3	10.63	14.24	
3	6:35	391	130.5		1.90	284			37.4	36.8	7.33	7.21	14.54	"	"	100.0	"	"	106.3	10.63	14.24	
4	6:40	375	126.0		1.85	286			38.5	36.8	7.24	6.86	14.10	96.0	+3.4	99.4	103.0	+2.31	105.3	10.48	14.03	
5	6:45	380	130.5		1.85	283			37.9	37.9	7.20	7.20	14.40	"	"	99.4	"	"	105.3	10.48	14.03	
6	6:50	376	125.0		1.70	286			40.1	39.5	7.54	7.43	14.97	"	"	99.4	"	"	105.3	10.48	14.03	
7	6:55	385	134.0		1.90	284			37.9	36.3	7.31	7.01	14.32	"	"	99.4	"	"	105.3	10.48	14.03	
8	7:00	390	136.5	29.00	1.90	285			36.8	36.7	7.18	6.96	14.14	"	"	99.4	"	"	105.3	10.48	14.03	
9	7:05	383	132.5		1.85	284			36.8	36.8	7.07	7.07	14.14	"	"	99.4	102.0	+2.32	104.3	10.37	13.89	
10	7:10	370	132.0		1.86	271			31.4	31.1	5.81	5.75	11.56	80.0	+1.0	81.0	103.0	+2.31	105.3	8.53	11.43	
11	7:15	373	128.0		1.75	275		451	30.9	30.8	5.78	5.67	11.45	"	"	81.0	"	"	105.3	8.53	11.43	
12	7:20	372	129.0		1.65	272			31.4	32.5	5.84	6.05	11.89	"	"	81.0	"	"	105.3	8.53	11.43	
13	7:25	373	129.6		1.70	270			30.9	30.3	5.78	5.67	11.446	"	"	81.0	"	"	105.3	8.53	11.43	
14	7:30	375	126.5		1.65	269			30.9	30.9	5.81	5.81	11.62	"	"	81.0	"	"	105.3	8.53	11.43	
15	7:35	380	124.0		1.60	284			30.9	31.4	5.84	5.94	11.78	"	"	81.0	"	"	105.3	8.53	11.43	
16	7:40	380	118.0		1.55	266			31.4	32.0	5.97	6.08	12.05	"	"	81.0	"	"	105.3	8.53	11.43	
17	7:45	382	120.5		1.60	274			29.8	29.8	5.66	5.66	11.32	79.5	+0.8	80.3	102.5	"	104.8	8.42	11.28	
18	7:50	383	126.0		1.65	272			29.3	30.3	5.70	5.79	11.49	79.0	+0.6	79.6	101.5	+2.33	103.8	8.27	11.08	
19	7:55	378	133.5		1.60	276			29.8	29.8	5.72	5.72	11.42	"	"	79.6	"	"	103.8	8.27	11.08	
20	8:00	378	131.5	29.01	1.50	266			28.7	30.0	5.42	5.67	11.09	"	"	79.6	"	"	103.8	8.27	11.08	
21	8:05	383	130.0		1.45	248		499	28.2	30.3	5.41	5.82	11.23	"	"	79.6	"	"	103.8	8.27	11.08	
22	8:10	380	128.5		1.40	245			29.1	29.8	5.53	5.66	11.19	80.0	+1.0	81.0	"	"	103.8	8.27	11.08	
23	8:15	376	133.0		1.60	256			34.7	34.2	6.52	6.43	12.95	"	"	81.0	116.0	+2.46	118.5	9.73	12.89	
24	8:20	368	130.5		1.60	248			46.6	46.5	8.58	8.37	16.95	101.0	+3.4	104.4	118.0	+2.45	120.5	12.65	16.86	
25	8:25	384	132.5		1.65	250		263	45.6	42.1	8.74	8.08	16.82	100.0	+2.9	102.9	118.5	+2.45	121.0	12.56	16.68	
Averages		378	127.7	29.10	1.70	272	0.976	Total 1213			6.22	6.83	13.05							9.56	12.81	45.67

45.67 lbs

RESULTS OF TEST.

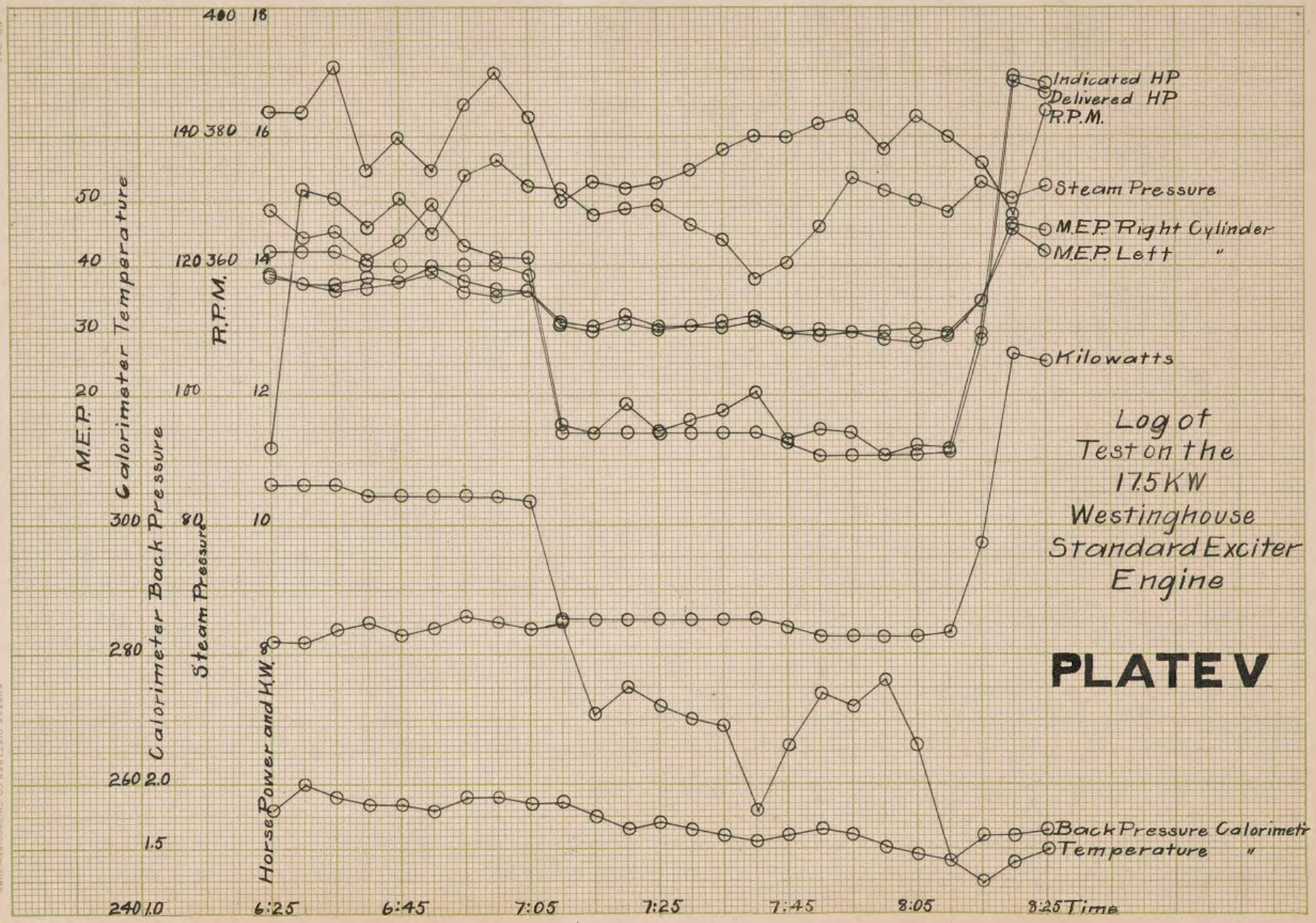
Kind of Engine	Westinghouse Standard Exciter Engine	17.5K.W.
Duration of run	hours	2
Revolutions per minute		378
Dimensions.		
Diameter of cylinder	inches	6
Length of stroke	"	7
Volume of clearance right cylinder	percent	12.8
Volume of clearance left cylinder	"	12.8
Make of indicator	Thompson	
Spring	Lbs.per sq.in.	60+5 cor.
Temperature.		
Calorimeter		272
Pressure		
Steam pressure gauge	Lbs.	127.7
Barometer	Inches	29.00
Calorimeter, back pressure	"	1.70
Weights.		
Total steam per hour actual	Lbs.	606.5
Total steam per hour corrected Cal.	"	596.0
Work.		
I.H.P. right cylinder		6.22
I.H.P. left cylinder		6.83
Total I.H.P.		13.05
D.H.P.		12.81
Water Consumption		
Moisture in steam	Percent	2.4

Water Consumption, Con,

Per I.H.P. per hour actual	46.47
Per I.H.P. per hour corrected cal.	45.67

Efficiency.

Mechanical Engine and Exciter combined percent	98.16
Thermodynamic	14.79



Log of Test on the 17.5 KW Westinghouse Standard Exciter Engine

PLATE V

NO 345
EUGENE DIETZGEN CO. CHICAGO-NEW YORK