AUTOMOBILE ENGINE ECONOMY

BY

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ARMOUR INSTITUTE OF TECHNOLOGY

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THE REPRESENTATION OF AUTOMOBILE ENGINE ECONOMY PERFORMANCE BY SURFACES

A THESIS

PRESENTED BY

H. G. ANDERSON AND J. A. KEETH

TO THE

PRESIDENT AND FACULTY

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FOR THE DEGREE OF

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IN

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Part I. Object

The object of this thesis is the development of a new method of representing the economy tests of automobile engines. The engine tests were carried out according to the latest method in which load, speed and throttle openings are varied. This gives results which closely simulate operating conditions. Instead of plotting the data in the usual manner with reference to two coordinate axes, this thesis brings out a method of plotting data with reference to three coordinate axes, thus giving a surface which represents all possible operating conditions of the engine. Two surfaces, one giving gasoline per horse power per hour and the other total gasoline, were made for each engine tested so that comparisons of their respective performances could be made readily.

The data for the Ford and Chalmers economy surfaces was obtained from previous tests made by Fritze, King and White in their thesis of 1917 at Armour Institute of Technology.

Part II. Description of Apparatus

Engines

The engine which was tested in this thesis was the twelve cylinder Packard illustrated in figure 1. The twelve cylinders are cast in two blocks of six, arranged in V-type and making an angle of 60 degrees with each other. The cylinders have a 3" bore and a 5" stroke with L-head arrangement of the valves, The cylinders are staggard with the left block 1 1/4" ahead of the right block to permit the connecting rads being placed side by side on the crank pin. By this arrangement separate cams can be used for each valve thus making 24 cams in all. The single Cam shaft is plaeed directly over the crankshaft and is driven by gears. The crankshaft is of the usual six cylinder type supported by three main bearings. Mounted on the end of the crankshaft is a vibration damper. Two centrifugal pumps, one for

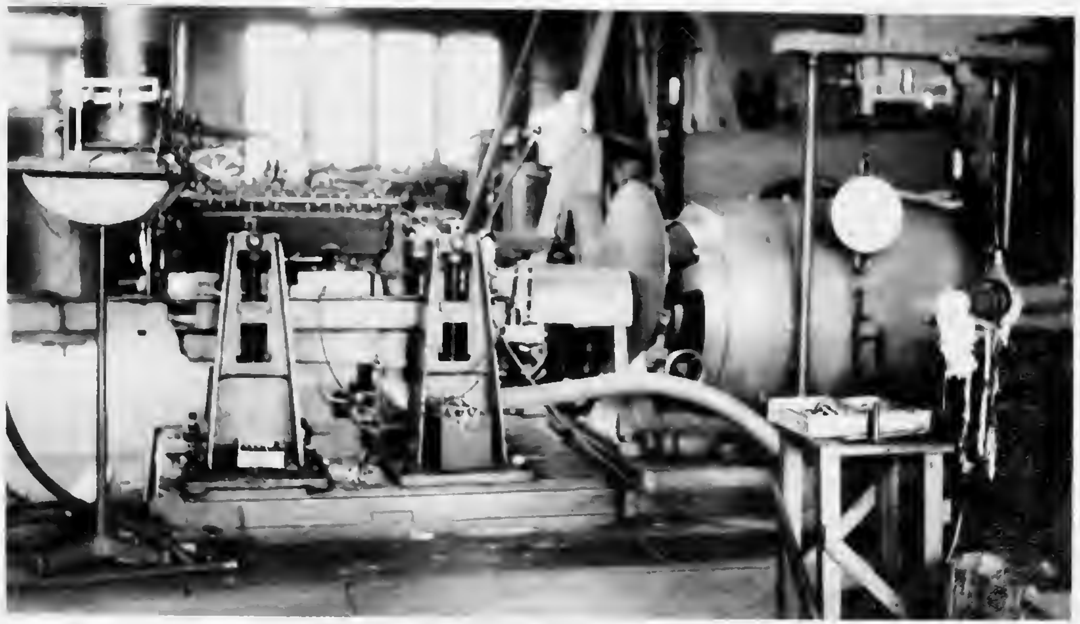


Figure 1.

each block of cylinders, circulate the jacket water. The carburettor is of Packard design and construction and is of the single jet type. It is mounted between the cylinder blocks. A twelve cylinder Delco ignition system is usdd.

The Ford engine from which test data was obtained was a four cylinder 3 3/4" by 4" block motor. It is built in unit with the transmission. The engine has the L-head valve arrangement. The customary three bearing type of crankshaft is used. Cooling is by thermo-syphon and the ignition current is supplied by a low tension magneto built into the fly-wheel. All tests were made with a Kingston carburettor.

The Chalmers engine was of the type 35A and numbered 15039. It was known to the public as the Chalmers 3400 R.P.M. engine. It is a six cylinder four cycle L-head engine

with cylinders 3 1/4" by 4 1/2" cast enbloc. The valves are located on the right hand side and the pushrods are inclosed. Thermo-syphon cooling is employed. The ignition consists of a six volt Remy battery and coil system. Bosch 7/8" plugs were used. Tests were made with both Rayfield and Stromberg Carburettors. The air intake for both carburettors was heated by a stove placed around the exhaust pipe.

Electric Dynamometer

A Sprague 300 H.P. electric dynamometer was used to absorbe and measure the power developed in the Packard test. The dynamometer consisted of a 300 H.P. D.C. interpole generator so mounted on ball bearing trunions that the field is free to rotate about the center line of the armature shaft as an axis. The torque is taken through a link mechanism one end of which is attached to the frame of the

generator and the other end to a spring balance and a set of Buffalo scales. The length of the torque arm is 1.75 feet so that the horsepower is equal to the torque m multiplied by the R.P.M. divided by 3000. The whole apparatus is mounted on a heavy ir iron bed plate provided with tee slots for bolting down engine supports. These supports are adjustable in height so that any engine can be mounted onnthem and connected to the generator by means of a universal coupling. A switchboard is mounted on a stand within easy reach of the scale beam. On this board are the control switches, field reostat, circuit breaker, ammeter and voltmeter and electric tachometer. In addition to this tachometer, a positive revolution counter is attached to the generator shaft. The field of

the generator is separately excited thus assuring a steady field flux with variations in speed. Figures 2 and 3 show the dynamometer and switchboard respectively.

Jacket Water Cooling

Figures 4 and 5 show the methods employed in jacket water cooling. This was found to be the only practical method of maintaining the water temperature at the desired point of about 150 degrees. By proper control of the cold water supply valve, the jacket water temperature could be made anything desired. In some of the tests the fan was disconnected but in general it was used. At speeds under 300 or 400 R.P.M., the centrifugal circulating pumps on the engine were found practically useless so that it became necessary to place an extension on the outlet pipe so as to keep its orifice below the level of the

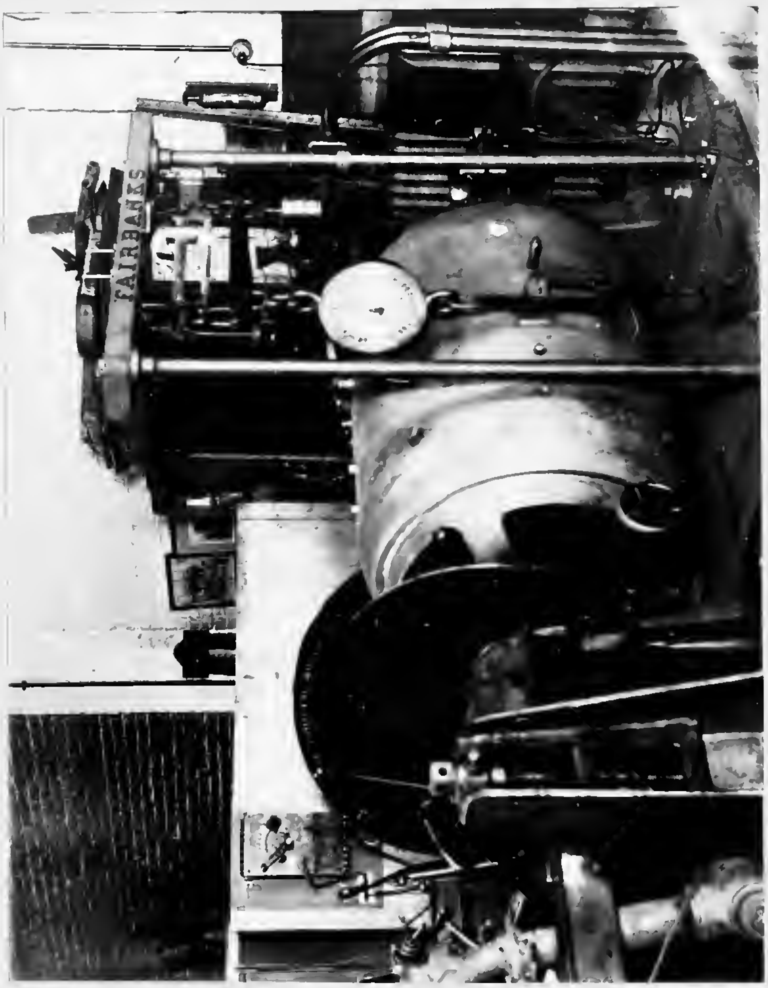


Figure 2.

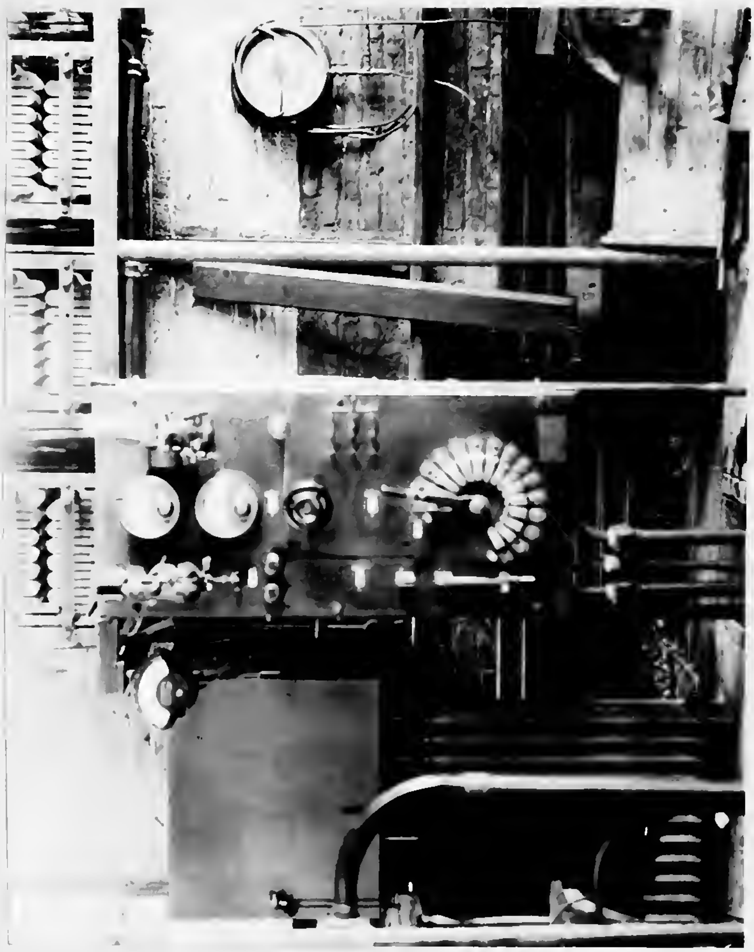


Figure 3.

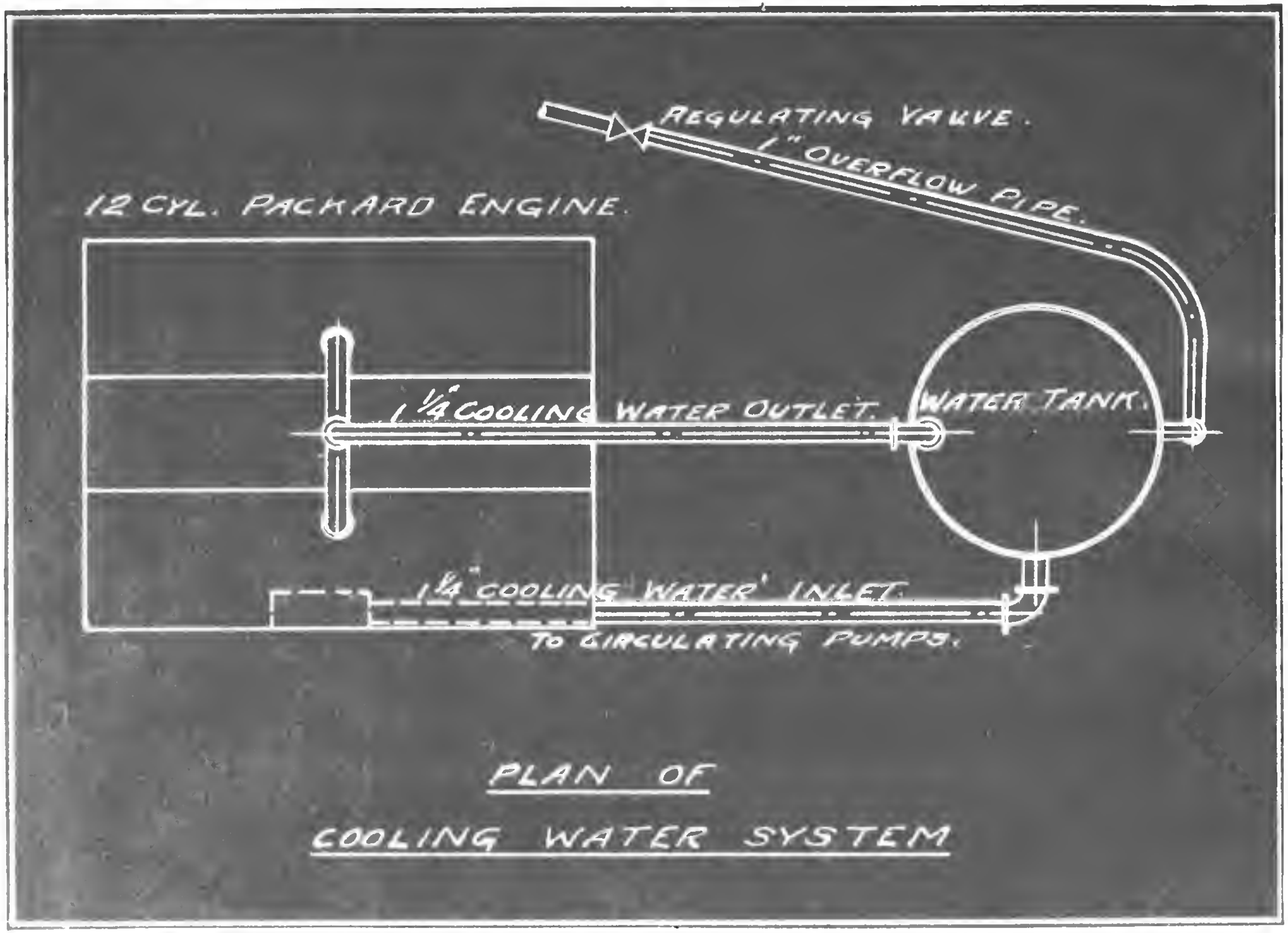

REGULATING VALVE.
1" OVERFLOW PIPE.
12 CYL. PACKARD ENGINE.
1 1/4" COOLING WATER OUTLET.
WATER TANK.
1 1/4" COOLING WATER INLET.
TO CIRCULATING PUMPS.
PLAN OF
COOLING WATER SYSTEM

Figure 4.

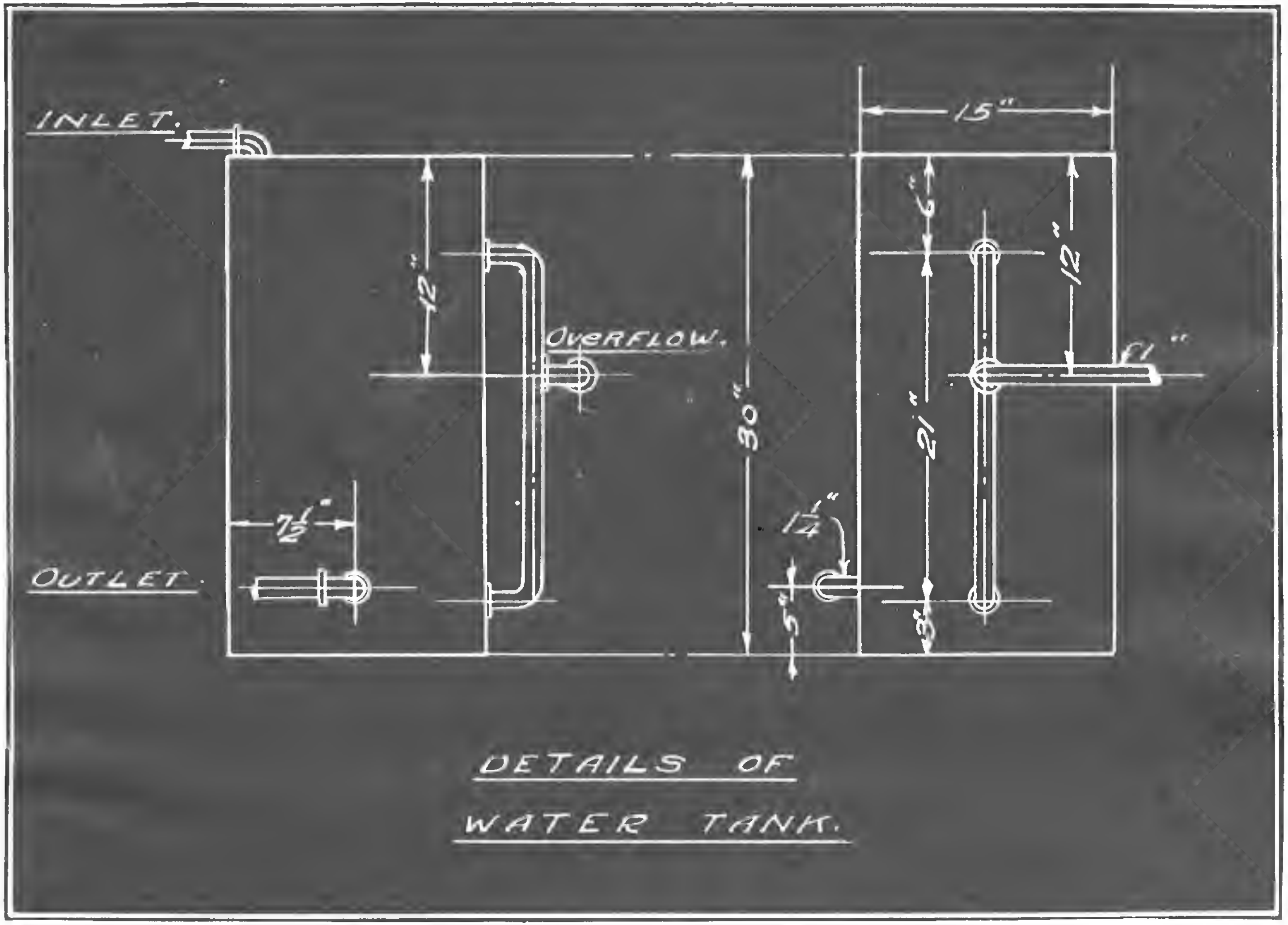

INLET.
OUTLET.
OVERFLOW.
12"
7½"
30"
15"
6"
12"
21"
3"
1¼"
5"
1"
DETAILS OF
WATER TANK.

Figure 5.

of the water in the tank. By this method an effective thermo-syphon system was produced. The capacity of the cooling tank was about 20 Gallons. For the Low speed runs the temperature of the engine was permitted to remain about 210 degrees F. The same cooling system was used on all the engines tested.

Gasoline Weighing Equipment

In the first tests on the Packard engine, gasoline was measured by volume in the conical shaped vessel shown in figure 6. The piece of apparatus was made by the Holly Carburettor Company. The vessel is filled by gravity by some source of supply until the ball indicator is slightly above the top of tube in which it moves. The stopwatch is started when the indicator sinks to the level of the top of the tube and is stopped when the gasoline level reaches the predetermined

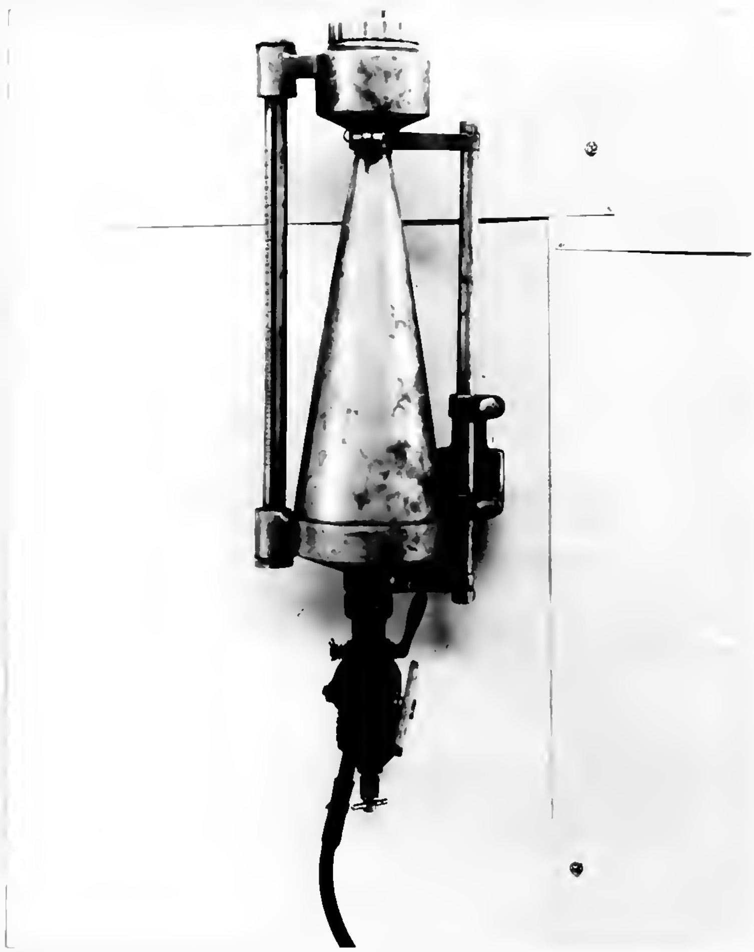


Figure 6.

mark in the gage glass. This Gage is calibrated in varying fractions of a gallon so that very accurate readings on fuel consumption are possible.

However, this method of measuring fuel was found inconvenient because of its limited capacity and because of the fact that it necessitated gravity feed to the carburettor. Moreover, all volumes thus measured had to be converted to weights before the results could be plotted. In order to overcome these objections, the method shown in figure 7 was used.

Here the gasoline supply is a five gallon tank (closed) placed on a small platform scale and delivering fuel, to the carburettor through a rubber tube. The gasoline in the tank was subjected to air pressure maintained by an air pump driven from the timing gears on the front of the engine; thus

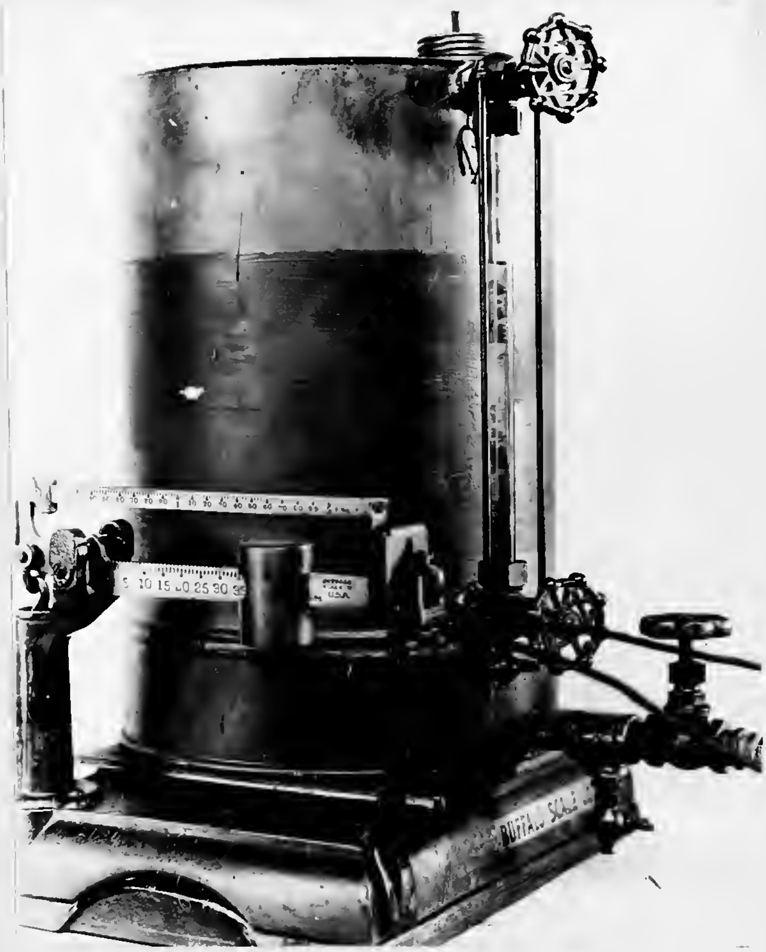


Figure 7.

gravity need not be depended upon for feed. The scale beam was provided with two connected metal points which complete the circuit between two mercury wells when the beam fell. The closing of the circuit rang a bell thus indicating the instant the scale was balanced.

This method was found to be quite satisfactory its only disadvantage being its susceptibility to vibration and an apparent inherent tendancy of the beam to stick an instant befor dropping. This weighing equipment was used in all the later tests.

Manifold Depression Measuring Equipment

For all tests of each engine the pressure in the intake manifold was measured, and recorded. A 1/8" brass pipe screwed into the intake manifold was connected by means of a rubber tube to a Bourdon gage shown in Fig. 8. This measured depressions as small as .05" mercury.

Figure 8.

Spark Advance

The Packard Engine is equipped with both hand and automatic spark advance. However, it was found that the automatic advance was not reliable so that hand regulation was used entirely. The spark advance lever was set approximately correct and the beam on the dynamometer scale overbalanced a trifle. The spark lever was then moved slowly either backwardor foreward until the beam raised. This assured proper advance for maximum torque.

Speed Counting Device

Attached to the dynamometer shaft through a pair of reduction gears were two speed counters. These speed counters were started and stopped by push button switches which closed and opened the circuitsto two magnetically operated clutched. These counters were allowed to run for one, two or three minutes depending upon the time of the test. This

provided a very accurate means of determining the revolutions per minute. Figure 9 illustrates the counter.

Figure 9.

Part III. Preliminary Observations

Before any tests were made on the Packard engine, the cylinder heads were removed and all carbon scraped from the valves and cylinders. The valves were then carefully ground into their seats and the cylinder heads replaced. The valve tappets were so adjusted as to give .015" play on the intake valves and .025" play on the exhaust valves.

The spark plugs used in the first part of the test were AC and adjusted with .015" gap. Later a new set of AC "Titan" plugs were substituted and their gap adjusted to .025". However, this gap was soon reduced to .014 " which seemed to give more satisfactory results.

Previous to each test the engine and dynamometer were given a thorough inspection and all parts were properly lubricated. It was particularly important to note that the

engine was securely bolted down to the supports and that the coupling between the engine and dynamometer was secure. The gear shift lever was always kept in direct drive position.

All instruments were inspected and adjusted, particular attention being paid to the contacts on the gasoline scale weighing beam. It was found necessary to keep the mercury in the wells clean and free from oil add water to insure proper contact.

The engine was always allowed to warm up to normal operating temperature of about 150 degrees F,before any tests were started. The carburettor adjustment on the Packard was never changed, all tests being run with the carburettor as adjusted by the factory. On the other engines the carburettors were adjusted so as to give good economy, fair accereration and low throttling ability*

* See Fritze, King and White thesis.

Part IV. Test Proceedure

As soon as the engine reached normal temperature the tests were begun. These runs were always started with wide open throttle and the load made sufficient to bring the engine down to the speed at which the test was to be run. This speed was then maintained constant and the load varied within the limits of the engine operating range.

The duration of each run was determined by the time required for the combustion of the fuel allotted to the particular run. Two-tenths of a pound of gasoline was used for all low speed light load runs, while one pound or even two pounds were used on the high speed heavy torque runs. This meant that the duration of the runs was between 45 seconds and three minutes.

The method of weighing the fuel was as follows: The fuel scales were approximately balanced, the load on the platform being slight-

ly heavier than the counterweight on the scale beam. The stopwatch was started the moment the bell indicated that the beam was balanced. The rider was then set back an amount equal to the weight of the fuel to be used in the test. When the bell again showed the beam to be balanced, the watch was stopped.

The method of adjusting the spark advance and counting the speed was given in the description of the apparatus.

All runs for the same speed were made without stopping the engine. Its temperature was kept constant by a careful regulation of the cold water supply.

On the low speed heavy torque runs, it was found necessary to run the engine muhh hotter than for the higher speed tests. In some such cases the temperature was allowed to reach 210-212 degrees F. If tests at a higher speed were to follow, the engine was allowed to run

idle at a slow speed until the temperature had again become normal.

The following data was tabulated fbom the Packard tests: R.P.M., torque, horse power, pounds of gasoline, time for consumption of same, intake manifold depression(inches бf mercury), and temperature of outlet jacket water. This data is given in tables 1to 16 inclusive. The specific Gravity (degrees Baume') and the temperature of the gasoline was taken for all tests. From the data so obtained, the pounds of gasoline per hour, and the pounds of gasoline per horse power per hour were calculatdd. As the speed varied slightly during a run, all power developed was corrected to the specifbed speed. When the torque as read on the scale beam varied, the average value was always taken.

In addition to the above constant speed tests made on the Packard, Fritze, King

and White made tests on the Chalmers engine maintaining a manifold depression of 27" mercury absl., constant and operating the engine at all speeds within its range. Subsequent series of runs were made at manifold depressions of 12", 15", 18", 21", and 24" mercury respectively. The results of these constant manifold depression tests are not given in this thesis. Fritze, King and White also made constant speed tests on the Chalmers engine, the data from which was used in this thesis in the construction of the Chalmers performance surfaces.

Similar data was taken from tests made on the Ford engine By professor Roesch of Armour Institute of Technology.

The friction horse power was obtained by shutting off the ignition to the hot engine and driving it by the dynamometer now used as a motor. Seven sets of runs were

taken in this manner, each being made at nearJy a constant speed. The readings taken for each run were: R. P. M., horse power to drive, and intake manifold depression. as the throttle was gradually closed more power was required to drive the engine, so that there was a resulting decreacs in speed. However, by increasing the armature current, the speed was always brought back to approximately the original value. The data obtained from these tests is given in tables 17 to 20 inclusive, while their graphical representation is given on page

Part V. Construction of Economy Surfaces

As stated in the beginning the object of this thesis is the presentation of a new method of representing automobile engine economy performance, the testing itself being but a means to this end.

Gas Per Horse Power Per Hour Surfaces

The results of all tests were first plotted with reference to two coordinate axes in the usual manner, ordinates representing horse power and abscissa pounds of gasoline per horse power per hour. Each test comprisdd all the runs made at that particular speed. Curve sheets 1 to 5 inclusive give the graphical results of the Packard tests for speeds from 150 to 2200 R.P.M. The curves for the Ford test are given on sheets 6 and 7 while Those for the Chalmers are given on sheets 8 to 16 inclusive.

All curves were then replotted on

paper to a larger scale(ordinates 2" equal 10 B.H.P., abscissa 2" equal one pound gasoline per horse power per hour) and cut out thus giving a set of patterns having the same contour as the original curves.

If these paper patterns were now placed two inches apart and parallel to each other with the abscissa and ordinates in the same horizontal and vertical planes respectively, we would have the skeleton of a warped surface representing the economy at all speeds. See figure 10. A surface tangent at all points to all these contour lines is the economy surface of the engine. Since the patterns were made from the results of tests 200 R.P.M. apart and are separated from each other by two inhhes the scale of R.P.M. is 1" equal 100 R.P.M.

As the surface described is only imaginary, a form or model was made up of wooden pieces two inches thick so shaped that its

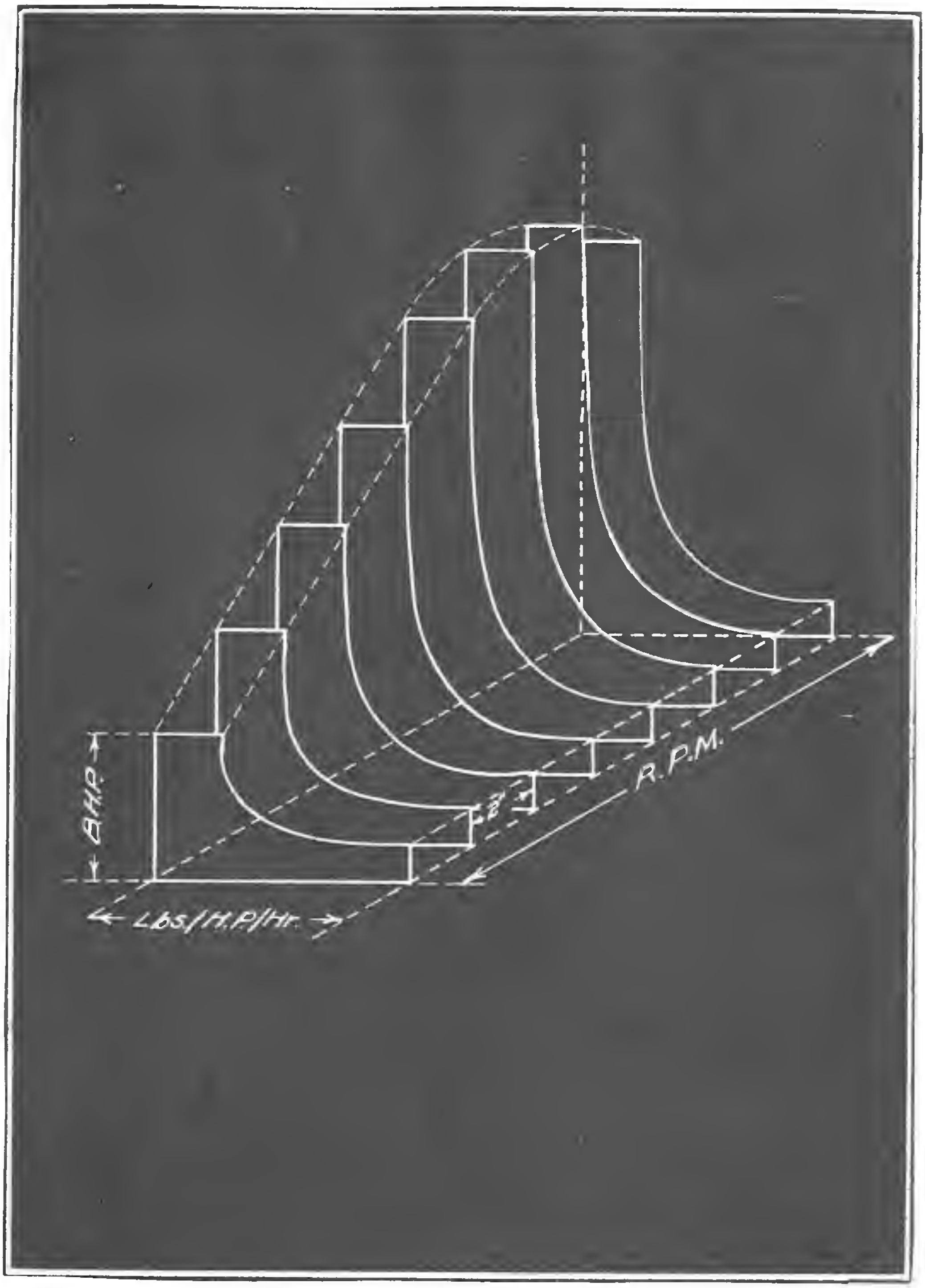


Figure 10.

opposite faces correspond with the contour curves of two adjacent patterns. The wood between the two faces was then cut away so as to form a smooth curved surface boundded by the above mentioned curves, the ordinate, the abscissa and the third coordinate axis. These were then placed side by side in the proper order and glued together. This gives a complete wooden model of the economy surface.

Total Gasoline Surface

As in the previous case curves were plotted for each engine at all speeds, representing now the total gasoline consumption(ordinates for horse power and abscissa for total pounds of gasoline). Curve sheets 17 to 22 inclusive give these curves for the Packard, while sheets 23 to 33 show the curves for the Chalmers. The total gasoline consumption curve for the Ford is shown in curve sheet 7.

Paper patterns were again made of these curves using a scale of 2" equal 10 "B.H.P.

and 4" equal one pound of gasoline for ordinate and abscissa respectively. The method of constructing the wooden model was identical with that described above. The surface so formed represents the total gasoline consumption of the engine at all operating conditions.

These surfaces, both the total gasoline and gasoline per brake horse power per hour, are shown in figures 11 to 19 inclusive.

Figure 11.

Figure 12.

Figure 13.

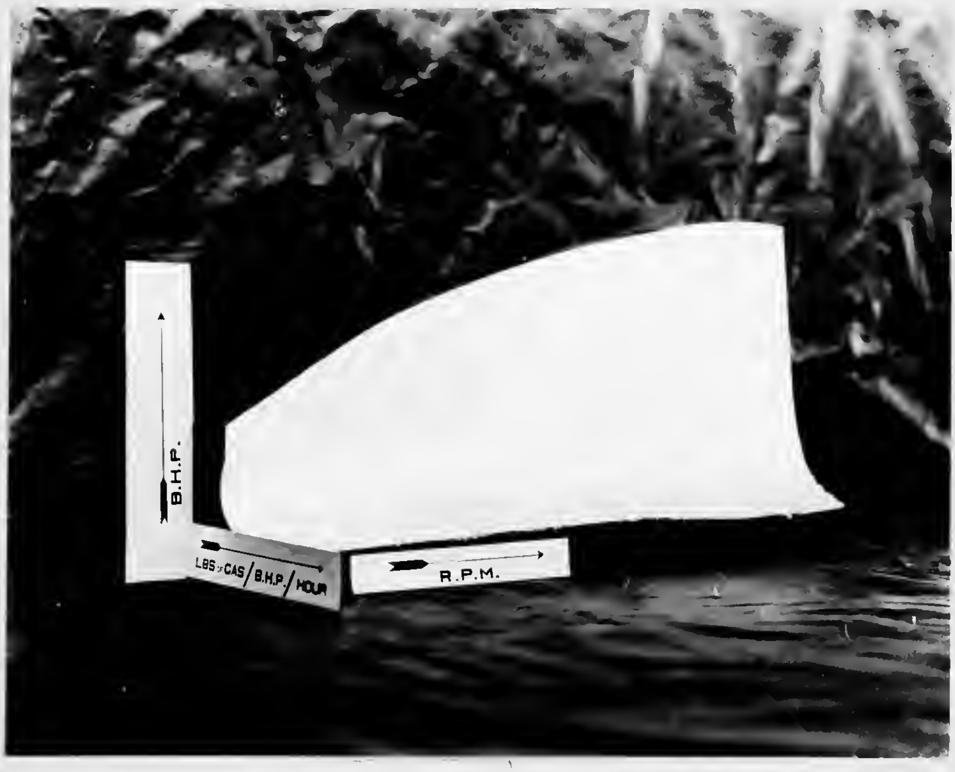


Figure 14.

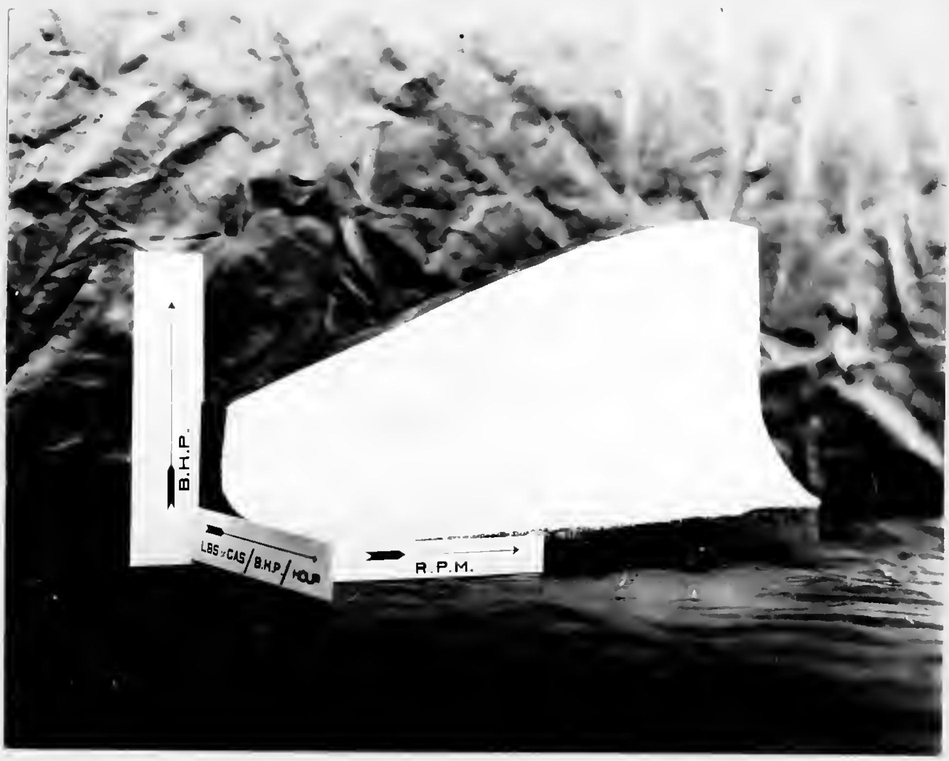


Figure 15.

Figure 16.

Figure 17.

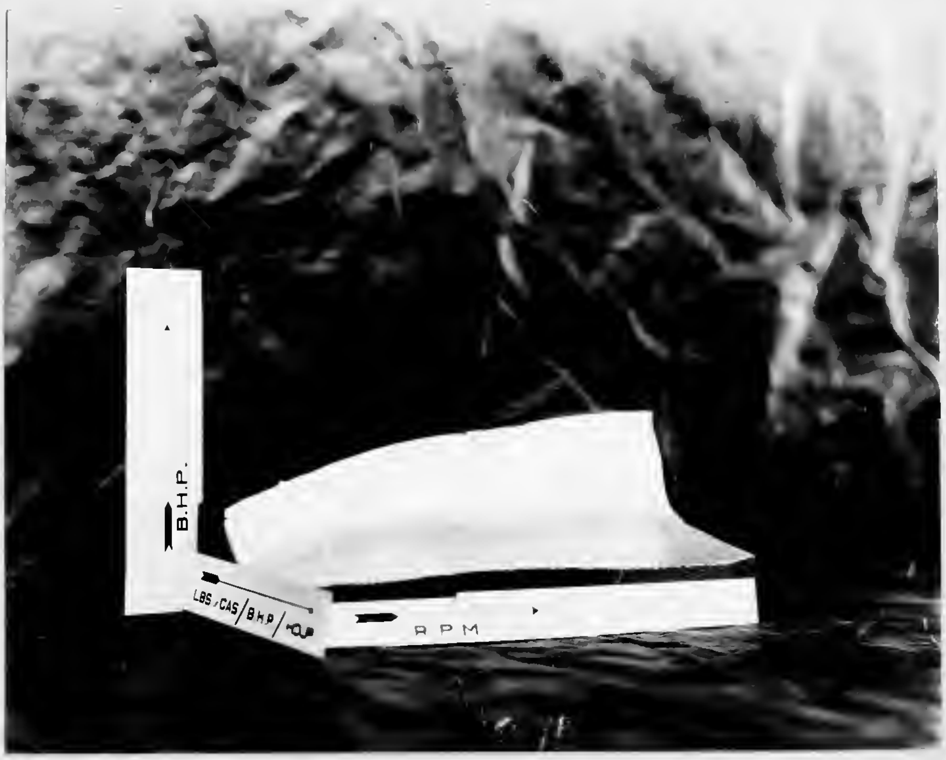


Figure 18.

Figure 19.

Packard Engine Test

R.P.M.	Torque	H.P.	H.P. at 150 R.P.M.	Gasoline Lbs/H.P./Hr.	Gasoline Total Lbs	Suction In. Hg.
156	97.0	5.04	4.84	1.013	5.12	–
155	96.0	4.96	4.80	.967	4.75	–
155	96.5	4.99	4.83	.801	4.00	–
153	95.0	4.85	4.76	.784	3.80	0.1
149	92.5	4.60	4.60	.860	3.96	0.4
141.5	90.0	4.25	4.25	.845	3.63	.79
153	86.0	4.38	4.38	.948	4.15	1.80
141	82.5	3.88	3.88	1.005	3.82	2.35
150.5	61.0	3.06	3.06	1.332	4.07	5.80

Table 1.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 200 R.P.M.	Gasoline		Suction In. Hg
				Lbs/H.P./Hr.	Total Lbs.	
207	105.5	7.29	7.04	1.11	8.11	.02
224	113.0	8.44	7.53	1.58	8.75	.03
225	111.5	8.36	7.45	1.04	8.65	.035
221	110.5	8.15	7.38	1.07	8.75	.035
219	109.0	7.96	7.27	.964	7.69	.16
217	107.5	7.78	7.17	1.02	7.94	.30
211	105.5	7.43	7.04	1.01	4.47	.60
203	99.0	6.70	6.60	.979	6.56	1.55
203	90.5	6.13	6.04	.984	6.04	3.15
205	78.0	5.33	5.20	.846	4.51	5.30
196	62.0	4.05	4.14	.935	3.79	7.8
213	50.0	3.55	3.33	1.03	3.65	10.0
217	35.0	2.53	2.33	1.07	2.73	11.8

Table 2.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 300 R.P.M.	Gasoline		Suction In, Hg
				Lbs/H.P./Hr	Total Lbs.	
294	120.0	11.78	12.0.0	.921	10.84	.05
303	120.5	12.17	12.10	1.10	13.38	.05
311	121.0	12.54	12.10	1.21	15.12	.125
300	116.5	11.64	11.64	.825	9.60	.50
312	115.5	12.03	11.58	.738	8.88	1.0
306	100.0	10.20	10.00	.416	4.25	3.5
305	66.0	6.71	6.60	1.04	6.99	9.0
311	53.5	55.5	5.36	1.75	9.73	11.5
313	45.5	47.5	4.56	.878	4.17	12.95
305	39.0	39.7	3.91	.633	2.51	13.9
318	52.5	55.6	5.24	.802	4.46	1.18
305	77.5	7.88	7.75	.845	6.67	7.25
314	90.5	9.47	9.05	.895	8.49	5.20

Table 3.

Packard Engine Test

R.P.M.	Torque	H.P.	H.P. at 400 R.P.M.	Gasoline Lbs/HP/Hr.	Gasoline Total Lbs	Suction In. Hg.
412	132.7	18.20	17.7	.899	16.37	.15
383	128.5	16.40	17.2	.814	13.36	.04
405	125.2	16.92	16.7	.843	14.29	.95
412	118.2	16.25	15.8	.852	13.85	2.0
408	102.6	13.94	13.7	.884	12.33	3.9
421	93.2	13.10	12.45	.764	10.00	6.1
400	82.0	10.93	10.93	.818	8.95	8.2
408	74.2	10.04	9.90	.734	7.40	9.9
413	61.4	8.45	8.20	1.09	9.23	11.85
407	46.0	6.25	6.14	1.02	6.40	14.0
414	32.4	4.47	4.32	7.36	3.29	15.85

Table 4.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 600 R.P.M.	Gasoline		Suction In. Hg
				Lbs/H.P./Hr.	Total Lbs	
588	137.0	26.8	27.3	.795	21.3	0.20
610	138.0	28.0	27.5	.792	22.2	0.20
600	129.2	25.8	25.8	.756	19.5	0.50
600	122.0	24.4	24.4	.788	19.2	1.0
600	110.0	22.0	22.0	.868	19.1	2.05
611	97.7	19.9	19.5	.870	17.3	6.00
601	84.7	17.0	17.0	.877	14.9	8.00
601	71.7	14.4	14.4	.958	13.8	9.95
604	58.5	11.8	11.70	.984	11.6	12.00
605	46.7	9.40	9.30	1.007	9.47	14.10
606	34.6	6.99	6.83	1.15	8.02	15.95
601	17.1	3.42	3.42	1.39	4.74	18.1
613	136.6	27.8	27.2	.855	23.8	0.10

Table 5.

Packard Engine Test

R.P.M.	Torque	H.P.	H.P. at 600 R.P.M.	Gasoline		Suction In. Hg
				Lbs/H.P./Hr	Total Lbs	
614	133.0	30.0	29.3	.670	20.1	0.20
607	134.0	27.1	26.8	.760	20.6	0.20
617	131.0	26.9	26.2	.736	19.8	0.55
600	125.0	25.0	25.0	.728	18.2	1.30
620	101.5	21.0	20.3	.842	17.7	3.10
616	97.5	20.0	19.5	1.00	20.0	5.50
614	82.5	16.9	16.5	.850	14.4	8.00
619	63.0	13.0	12.6	.953	12.4	10.90
621	41.0	8.5	8.2	1.25	10.6	14.2
616	20.5	4.2	4.1	1.71	7.2	16.9
645	5.5	1.8	1.7	2.88	5.3	18.4

Table 6.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 800 R.P.M.	Gasoline		Suction In. Hg
				Lbs/H.P./Hr.	Total Lbs.	
799	133.7	35.6	35.6	.768	27.4	0.4
799	34.15	9.08	9.08	.850	7.72	16.0
814	7.6	2.06	2.04	3.76	7.75	18.8
795	15.3	4.05	4.08	2.25	9.10	18.0
807	47.4	12.70	12.6	.984	12.5	14.0
800	58.0	15.50	15.5	.897	13.9	12.0
811	71.55	19.40	19.1	.860	16.7	10.0
801	88.45	23.80	23.8	.782	18.6	8.0
794	98.70	26.10	26.3	.819	21.4	6.0
806	114.90	30.80	30.6	.754	23.2	4.0
800	128.2	34.20	34.2	.684	23.4	2.0
795	134.6	35.70	35.9	.703	25.1	1.0

Table 7.

Packard Engine Test

R.P.M.	Torque	H.P.	H.P. at 1000 R.P.M.	Gasoline		Suction In. Hg.
				Lbs/H.P./Hr.	Total Lbs.	
1001	135.9	45.3	45.3	.726	32.9	0.5
1013	134.5	45.5	44.9	.667	30.8	0.95
1006	127.5	42.8	42.7	.670	28.7	2.05
1010	114.7	38.8	38.2	.743	28.7	4.0
1001	101.5	33.9	33.9	.787	26.6	6.0
1008	88.8	29.8	29.6	.775	23.1	8.0
999	75.2	25.0	25.0	.795	19.9	10.1
1014	61.0	20.6	20.3	.918	18.9	12.0
1005	49.5	16.6	16.5	.934	15.5	14.0
1010	34.5	11.6	11.5	1.18	13.7	16.1
1008	17.1	5.75	5.70	3.49	20.0	18.2
1020	6.5	2.20	2.16	3.44	7.56	19.2
1028	136.4	46.7	45.5	.722	33.7	0.55

Table 8.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 1000 R.P.M.	Gasoline Lbs/H.P./Hr.	Gasoline Total Lbs	Suction In. Hg.
1006	128.3	43.9	42.7	.750	32.0	0.55
1013	130.5	43.9	43.3	.710	30.7	0.55
1026	131.1	44.0	42.8	.701	30.7	0.70
1006	128.0	42.9	42.7	.710	30.3	1.0
1032	123.0	42.4	41.0	.735	30.1	1.9
1019	111.0	38.7	38.0	.716	27.2	3.6
1009	92.5	30.8	30.8	.763	23.5	6.2
1011	78.5	26.5	26.3	.837	22.0	8.3
1013	65.5	22.2	22.0	.877	19.3	10.5
1006	42.5	14.25	14.23	1.01	14.35	14.2
1013	18.5	6.25	6.21	1.75	10.89	17.9
1020	4.7	1.57	1.54	5.67	8.73	19.4

Table 9.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P at 1200 R.P.M.	Gasoline		Suction In. Hg.
				Lbs/H.P/Hr.	Total Lbs.	
1191	130.5	51.8	52.1	.718	37.2	0.8
1213	135.3	54.7	54.1	.658	36.0	0.9
1192	132.1	52.5	52.8	.715	37.5	1.5
1200	129.5	51.8	51.8	.725	37.6	2.2
1222	114.5	46.7	45.8	.697	32.6	4.4
1195	101.8	40.6	40.8	.703	28.6	6.1
1202	88.5	40.1	40.0	.643	26.8	8.1
1202	72.0	28.9	28.8	.785	22.7	10.4
1195	60.0	23.9	24.0	.856	20.5	12.2
1196	46.5	18.6	18.6	.962	17.9	14.4
1199	34.5	13.8	13.8	1.17	16.1	16.1
1191	18.5	7.4	7.4	1.85	13.6	18.1
1228	6.2	2.5	2.4	4.44	11.3	19.2

Table 10.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 1400 R.P.M.	Gasoline		Suction In. Hg.
				Lbs/H.P./Hr.	Total Lbs.	
1403	119.5	55.9	55.8	.714	39.9	1.0
1431	120.5	57.5	56.2	.650	37.3	1.5
1436	114.0	54.5	53.2	.570	31.0	2.7
1402	106.1	49.6	49.5	.676	33.0	4.0
1366	83.9	38.2	39.2	.733	28.1	7.3
1425	77.8	37.0	36.4	.811	30.0	8.75
1438	62.1	29.8	29.0	.905	27.0	11.00
1441	51.3	24.6	23.9	.972	23.9	12.50
1390	41.7	19.3	19.4	1.09	21.0	14.00
1408	28.6	13.4	13.3	1.34	18.0	16.0
1389	12.2	5.6	5.7	2.48	13.9	17.9
1404	11.7	5.5	5.5	2.32	12.7	18.9

Table 11.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 1400 R.P.M.	Gasoline		Suction In. Hg.
				Lbs/H.P./Hr.	Total Lbs	
1409	127.0	59.6	59.2	.715	42.6	1.1
1405	132.0	61.8	61.6	.632	40.3	1.4
1397	128.3	59.8	60.0	.665	39.8	1.8
1400	123.4	58.5	58.5	.687	40.2	2.3
1397	113.0	52.6	52.7	.713	37.5	4.0
1399	98.5	45.8	45.8	.706	32.3	6.3
1390	88.5	41.0	41.3	.751	30.8	7.8
1413	72.5	34.2	33.9	.728	27.9	10.25
1399	59.0	27.5	27.5	.876	24.1	12.30
1390	47.5	22.0	22.2	1.01	22.3	13.9
1430	34.5	16.40	16.1	1.12	18.4	15.9
1380	20.0	9.2	9.3	1.67	15.3	17.85
1423	11.5	5.5	5.4	2.72	14.7	18.8

Table 12

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 1600 R.P.M.	Gasoline		Suction In. Hg
				Lbs/H.P./Hr.	Total Lbs.	
1640	122.0	66.7	65.0	.683	45.5	1.3
1619	125.5	67.4	66.6	.675	45.5	1.4
1610	123.0	66.0	65.6	.720	47.5	1.8
1580	119.0	62.7	63.5	.703	44.0	2.3
1601	108.0	57.6	57.6	.710	40.8	4.1
1581	95.5	50.4	51.0	.673	33.9	6.1
1615	78.5	42.2	41.8	.771	32.5	8.2
1601	69.0	36.8	36.8	.873	32.1	9.7
1591	52.0	27.6	27.6	.956	26.4	12.0
1603	37.0	19.8	19.8	1.27	25.15	13.8
1577	9.0	4.73	4.8	3.42	16.2	15.8

Table 13.

Packard Engine Test						
R.P.M.	Torque	H.P.	H.P. at 1800 R.P.M.	Gasoline		Suction In, Hg.
				Lbs/H.P./Hr.	Total Lbs.	
1785	126.0	75.0	75.5	.653	49.0	1.8
1768	123.0	72.4	73.7	.628	45.5	1.8
1844	118.0	72.5	70.7	.603	43.7	3.2
1800	112.8	67.8	67.8	.697	47.2	3.7
1843	96.0	59.0	57.6	.805	47.5	6.2
1802	71.1	42.8	72.8	.900	38.6	8.1
1849	66.5	40.9	39.8	.855	35.0	10.2
1803	51.5	30.9	30.8	.895	27.7	12.5
1852	39.0	24.1	23.4	1.19	28.7	14.3
1832	27.0	16.5	16.2	1.33	21.9	16.1
1805	9.0	5.42	5.4	3.36	18.2	17.3

Table 14.

Packard Engine Test

R.P.M.	Torque	H.P.	H.P. at 2000 R.P.M.	Gasoline		Suction In. Hg.
				Lbs/H.P./Hr.	Total Lbs	
1973	120.5	78.4	79.4	.736	57.7	2.15
1955	113.0	73.6	75.3	.691	50.8	3.7
2023	97.5	65.9	65.1	.684	45.1	5.6
2015	81.0	54.4	54.0	.784	42.7	8.0
1990	68.5	45.4	45.65	.755	34.3	10.1
2001	55.0	36.7	36.7	.926	34.0	12.0
2043	38.0	25.9	25.3	1.12	29.1	14.5
1975	30.0	19.8	20.0	1.33	26.2	16.2
2018	15.0	10.1	10.0	1.89	19.1	18.0
2030	9.0	60.8	5.99	3.11	18.9	18.5

Table 15.

Packard Engine Test

R.P.M.	Torque	H.P.	H.P. at 2200 R.P.M.	Gasoline Lbs/H.P./Hr.	Gasoline Total Lbs.	Suction In. Hg.
2230	99.5	74.0	73.0	.639	47.3	2.45
2159	103.5	74.4	75.8	.630	46.9	2.70
2164	103.0	74.5	75.7	.644	48.0	3.20
2191	97.0	70.8	72.0	.628	44.5	4.25
2192	91.0	66.5	66.8	.685	44.9	5.60
2209	74.5	54.9	54.7	.781	43.0	8.00
2177	61.5	44.6	45.1	.836	37.3	9.90
2197	48.6	35.6	35.7	.882	31.4	11.95
2206	36.3	26.7	26.5	1.19	30.5	13.80
2245	25.5	19.1	18.7	1.47	28.1	15.60
2182	9.3	6.76	6.81	3.15	21.2	17.80
2213	7.4	5.46	5.44	4.02	21.9	17.80
2200	7.0	5.14	5.14	3.94	20.2	18.00

Table 16.

Packard Friction Test			
R.P.M.	Torque	H.P.	Suction In, Hg.
110	13.6	.50	0.8
105	14.0	.491	1.5
100	15.7	.52	5.5
105	13.4	.47	—
100	15.2	.51	4.1
300	21.1	2.11	16.1
310	19.3	1.99	12.7
320	17.5	1.87	9.2
335	16.0	1.79	5.9
340	14.8	1.67	2.8
345	13.9	1.60	0.7
350	13.7	1.60	0.3
350	13.5	1.58	0.04

Table 17.

Packard Friction Test			
R.P.M.	Torque	H.P.	Suction In., Hg.
555	23.6	4.37	19.05
540	21.9	3.95	15.6
545	20.0	3.63	10.8
550	18.4	3.38	6.8
555	17.0	3.14	3.6
560	15.6	2.91	0.7
560	15.1	2.82	0.1
800	26.5	7.07	20.6
810	25.6	6.91	17.5
830	24.2	6.70	13.3
845	22.6	6.36	9.7
855	21.1	6.01	6.01
870	19.8	5.75	5.75
875	19.1	5.56	5.56
880	18.7	5.49	5.49

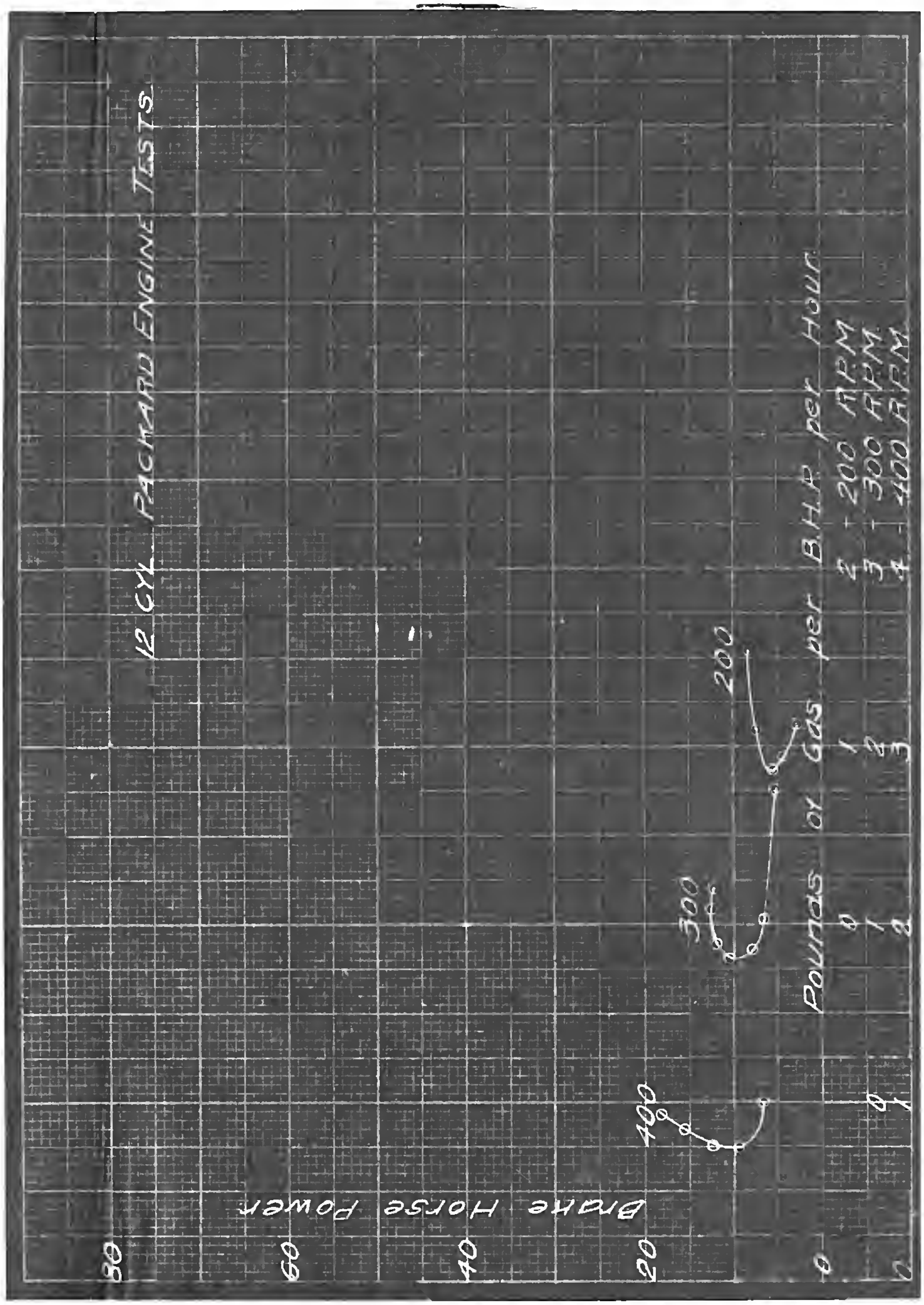
Table 18.

Packard Friction Test			
R.P.M.	Torque	H.P.	Suction In, Hg.
1120	30.1	11.20	24.5
1120	29.3	10.95	20.0
1120	28.3	10.56	17.6
1120	27.0	10.07	14.0
1130	25.6	9.67	10.1
1140	24.0	9.12	6.0
1140	22.6	8.58	3.0
1140	22.0	8.35	1.5
1140	21.6	8.22	.65

Table 19.

Packard Friction Test			
R.P.M.	Torque	H.P.	Suction In., Hg.
1410	34.0	15.95	22.4
1415	32.7	15.45	19.6
1415	31.4	14.81	16.4
1420	30.0	14.20	12.8
1425	28.5	13.54	9.3
1430	27.3	13.10	6.2
1440	26.2	12.60	3.4
1445	25.7	12.38	2.4
1450	25.0	12.08	1.0
1645	35.5	19.45	22.7
1645	35.0	19.20	20.8
1650	34.3	18.87	18.5
1660	32.5	17.97	13.5
1670	31.0	17.25	10.1
1670	29.8	16.60	7.1
1670	28.3	15.75	4.2
1675	27.8	15.50	3.0
1675	27.0	15.08	1.4

Table 20.



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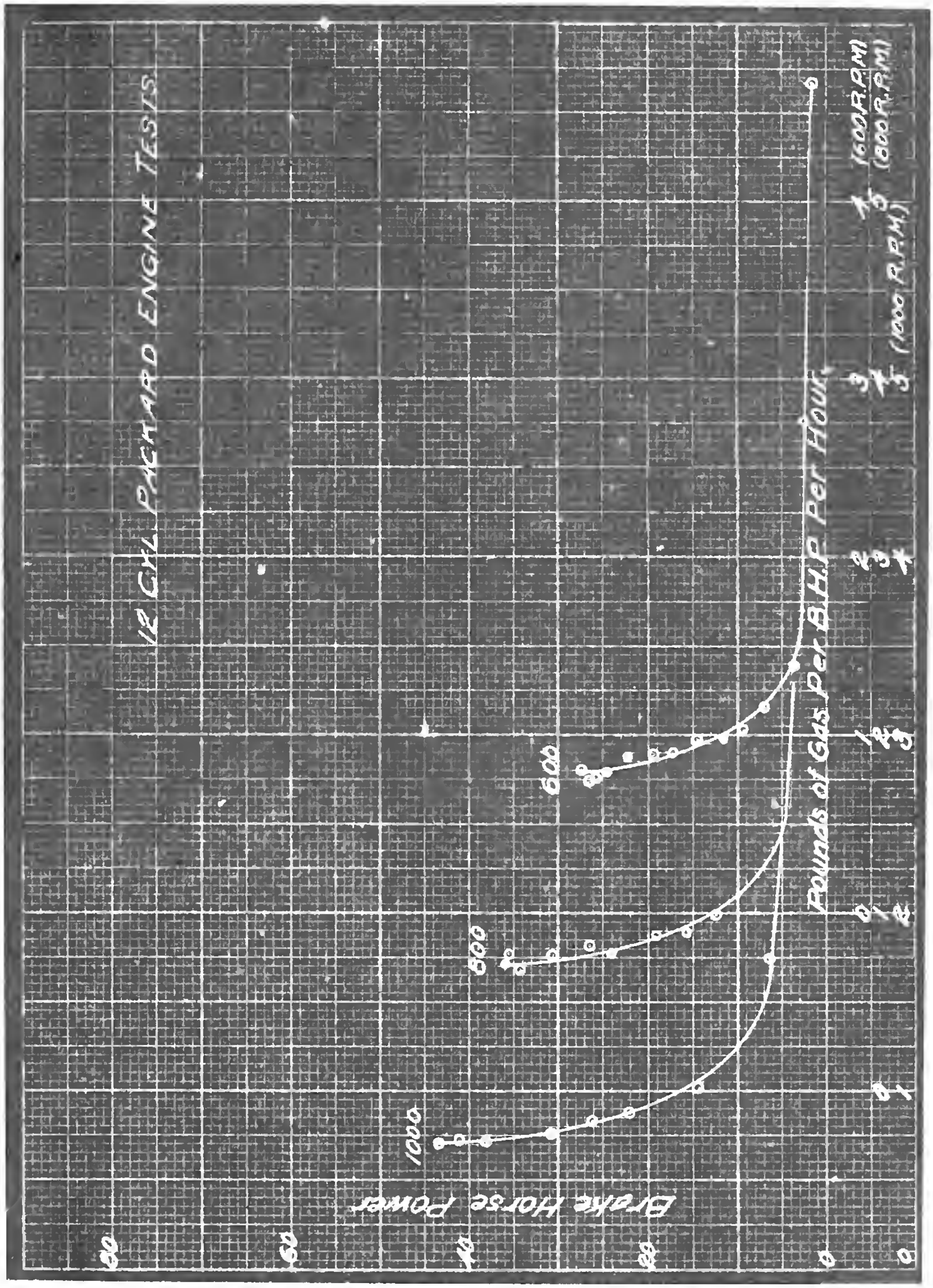

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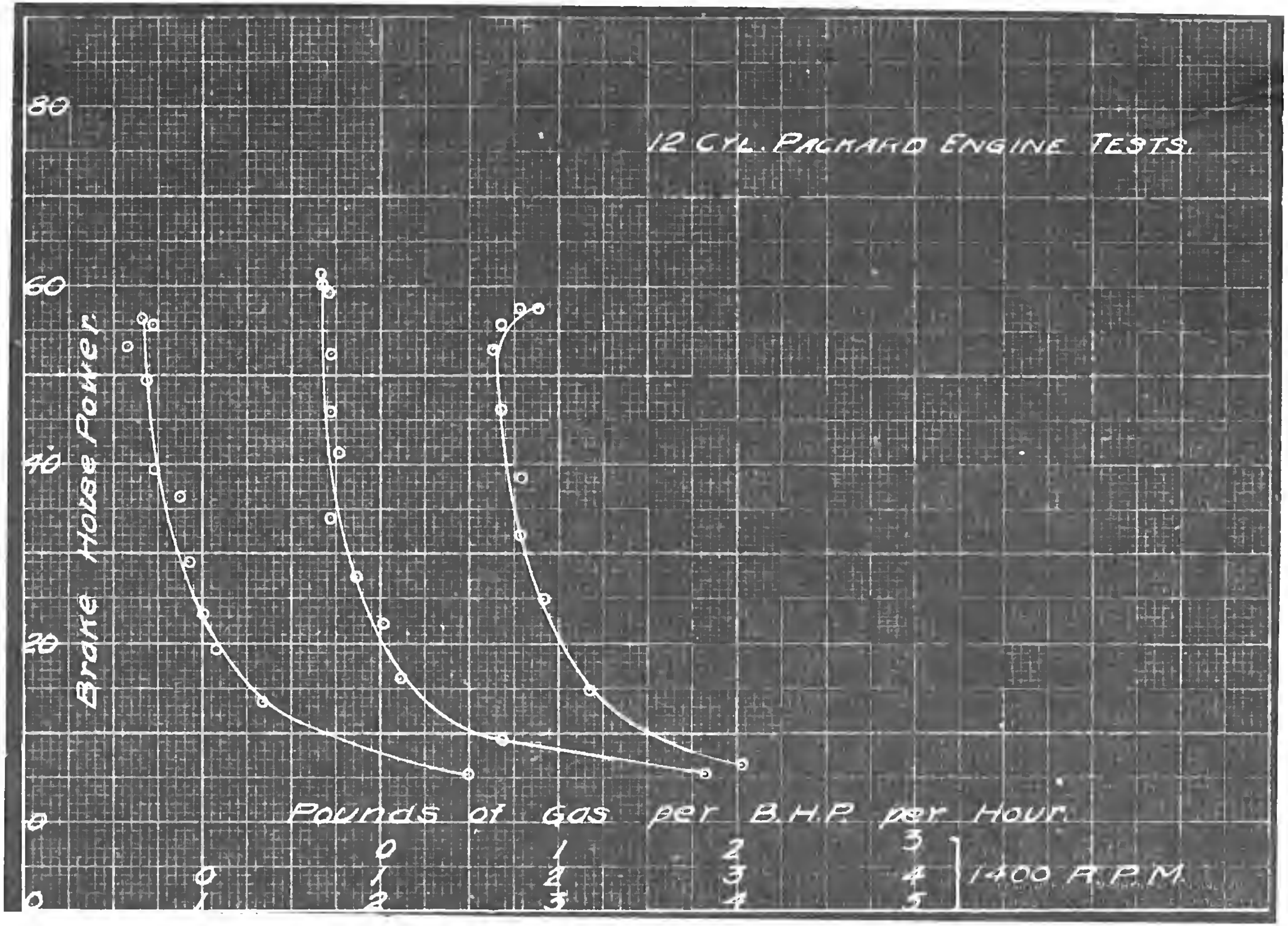

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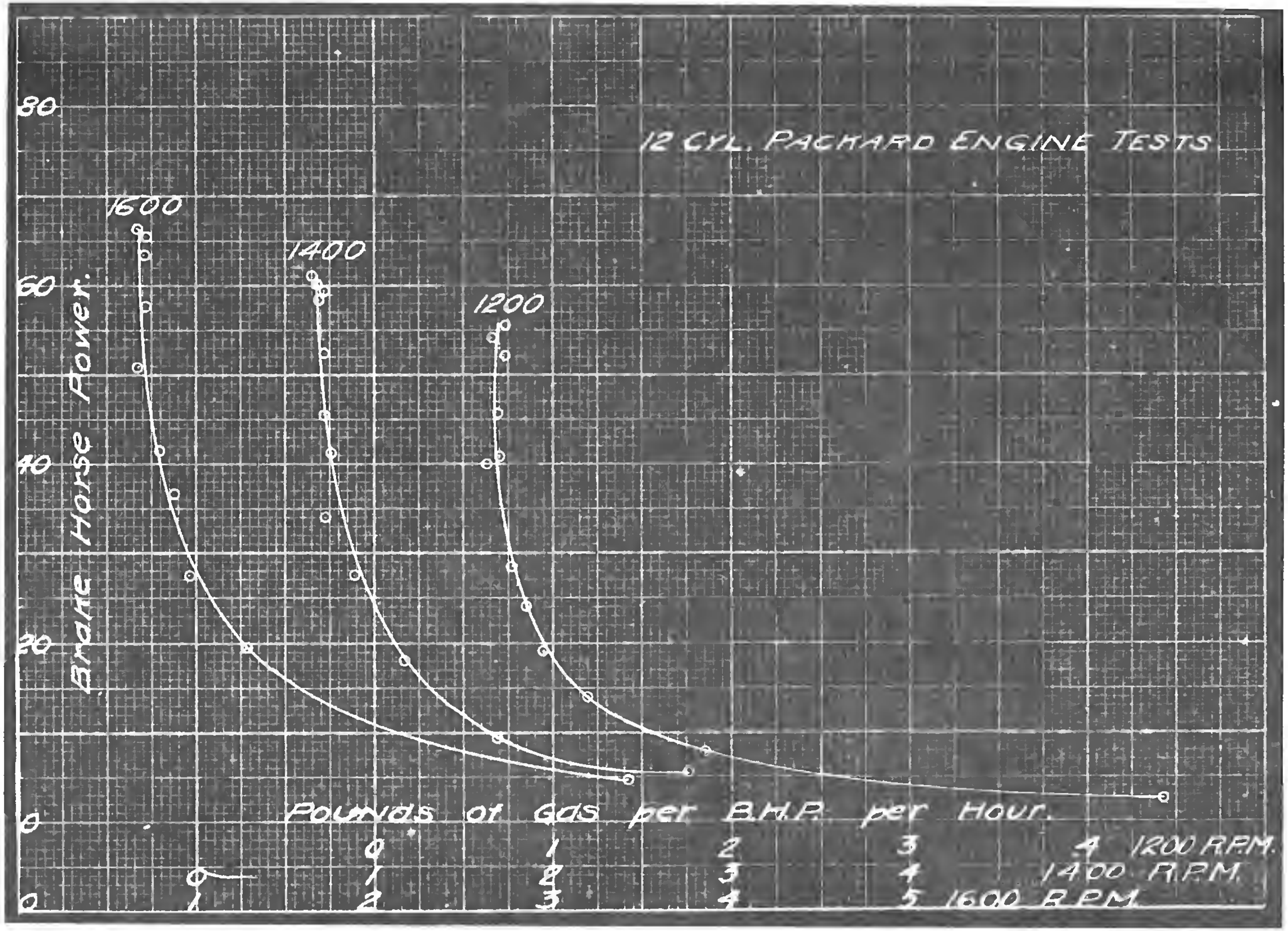

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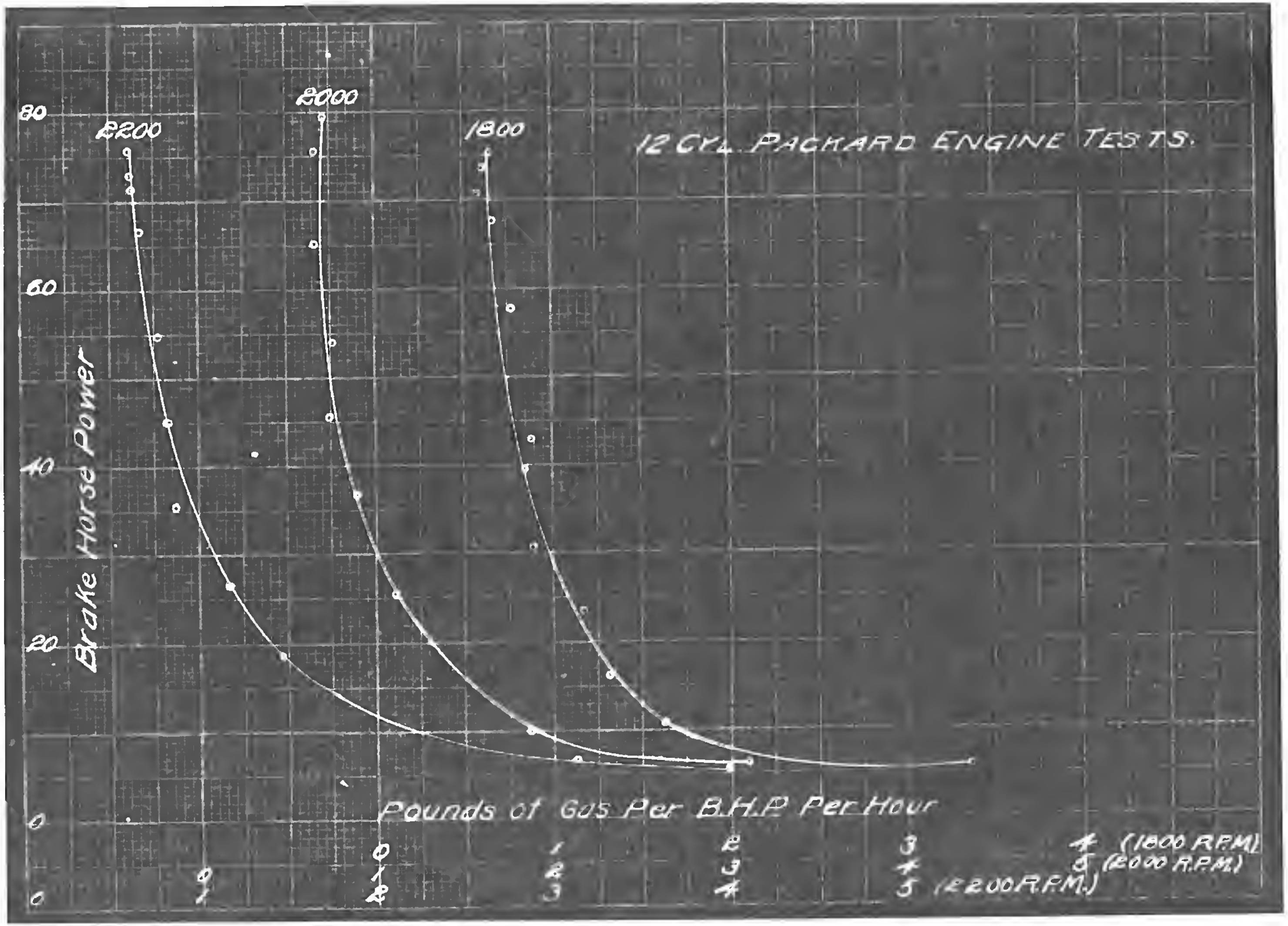

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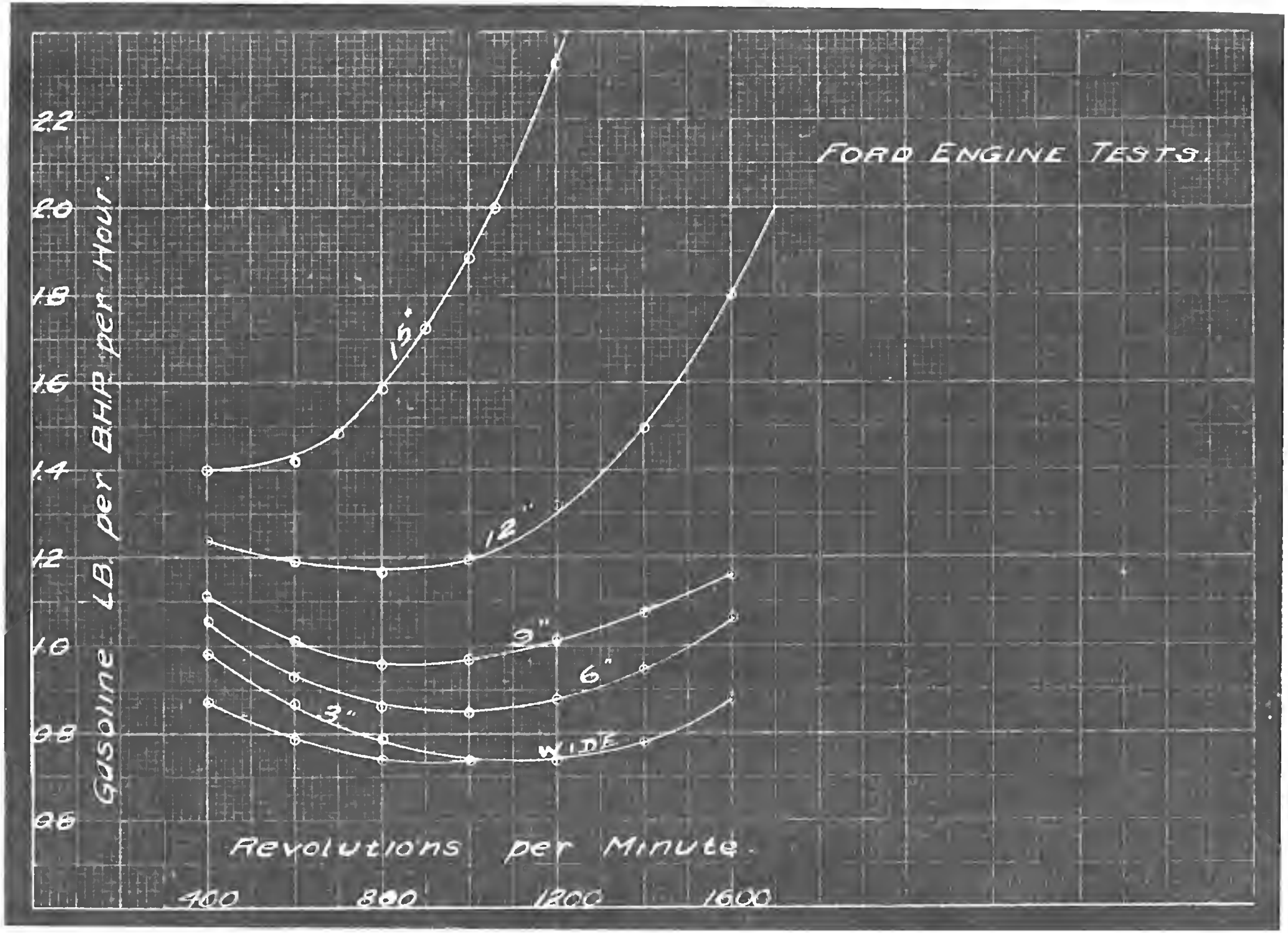

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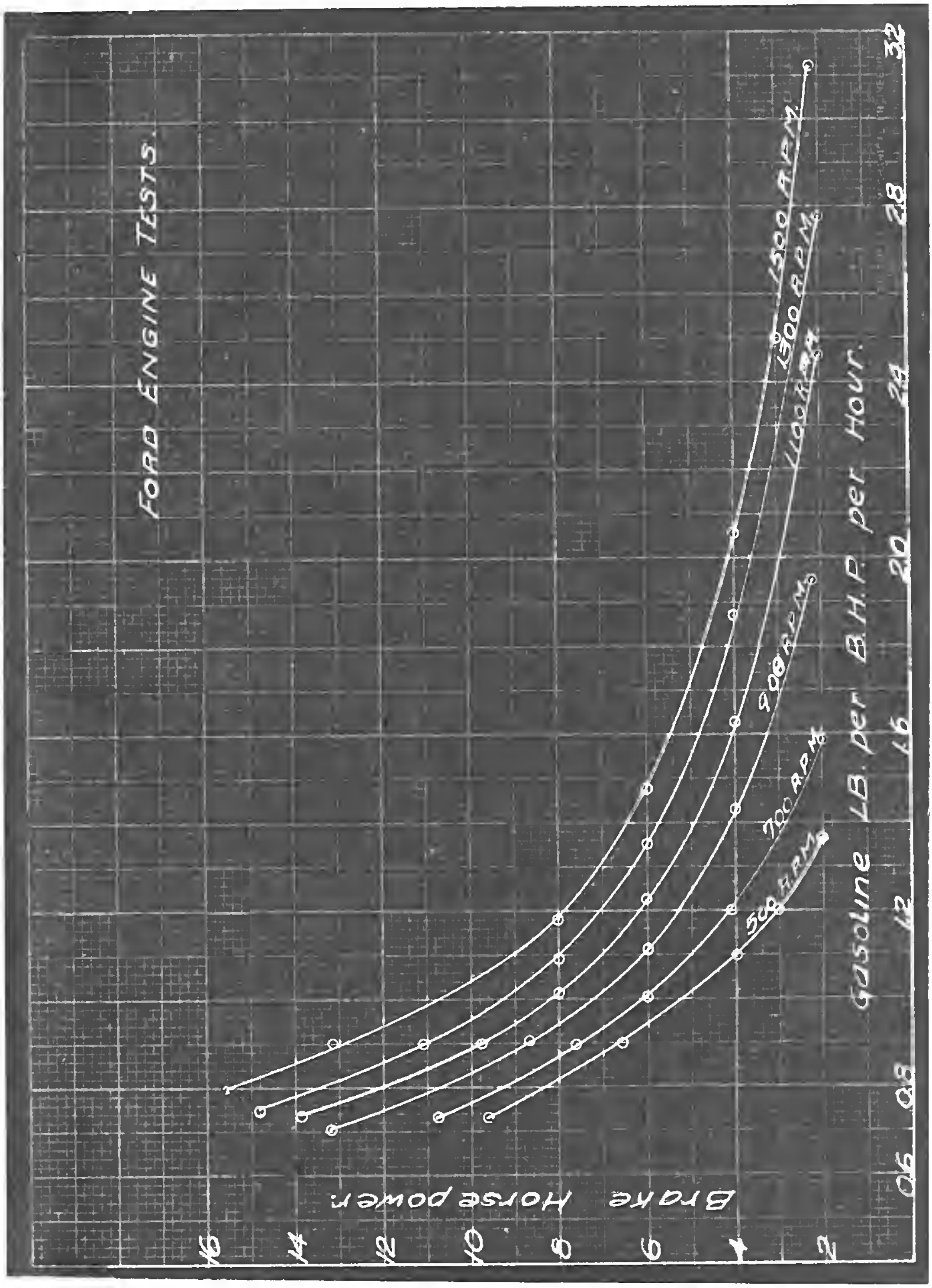

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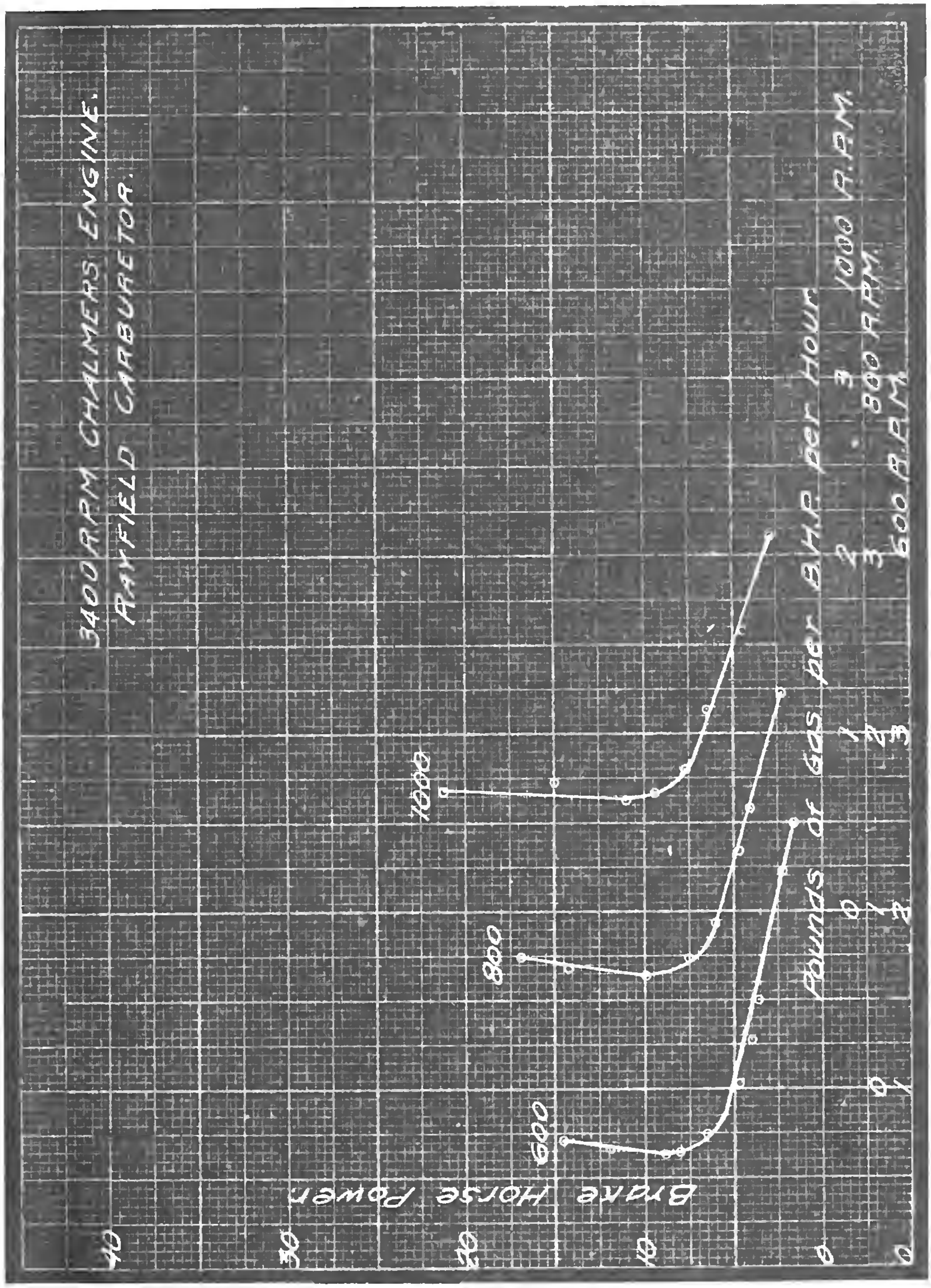

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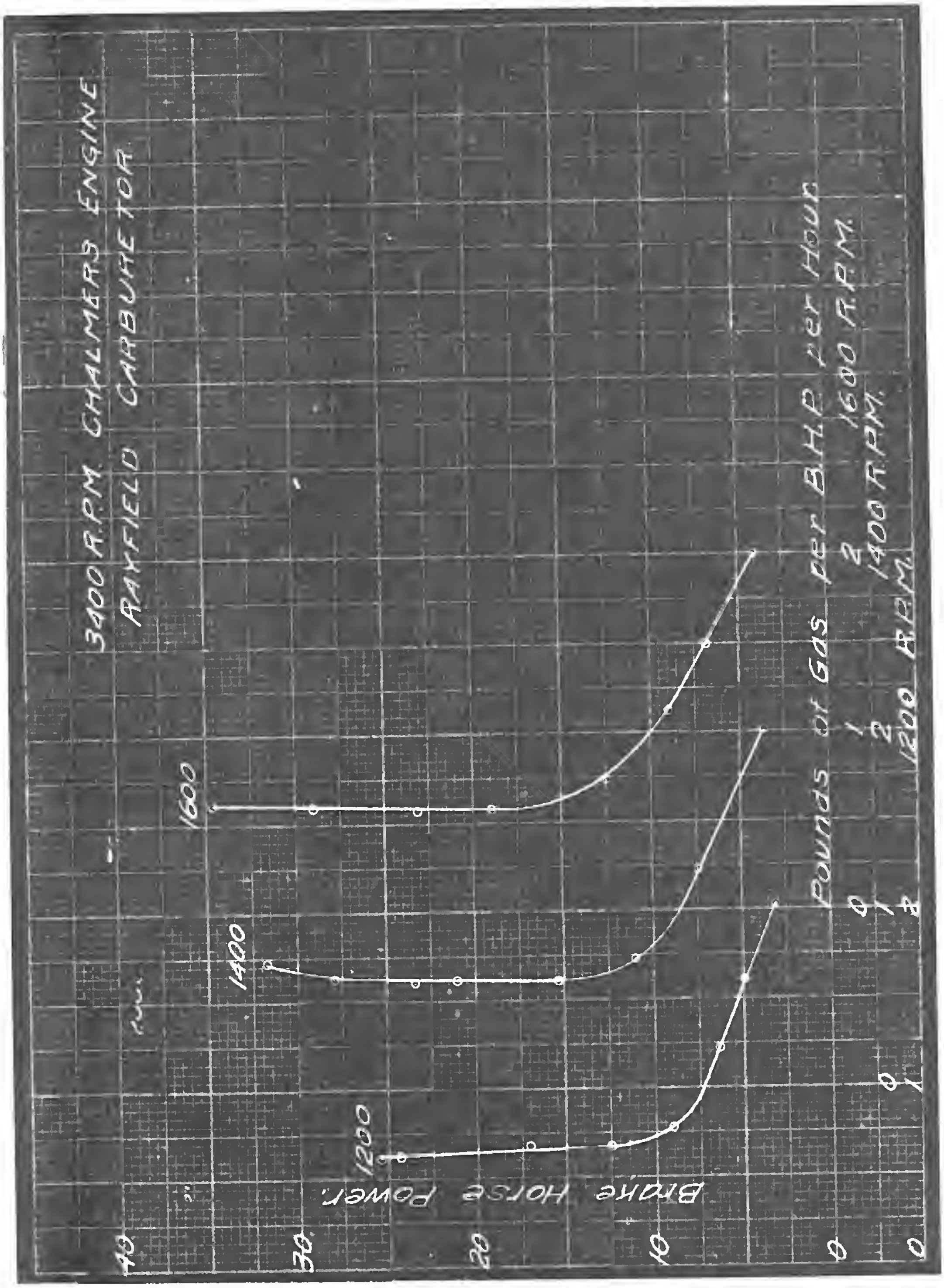

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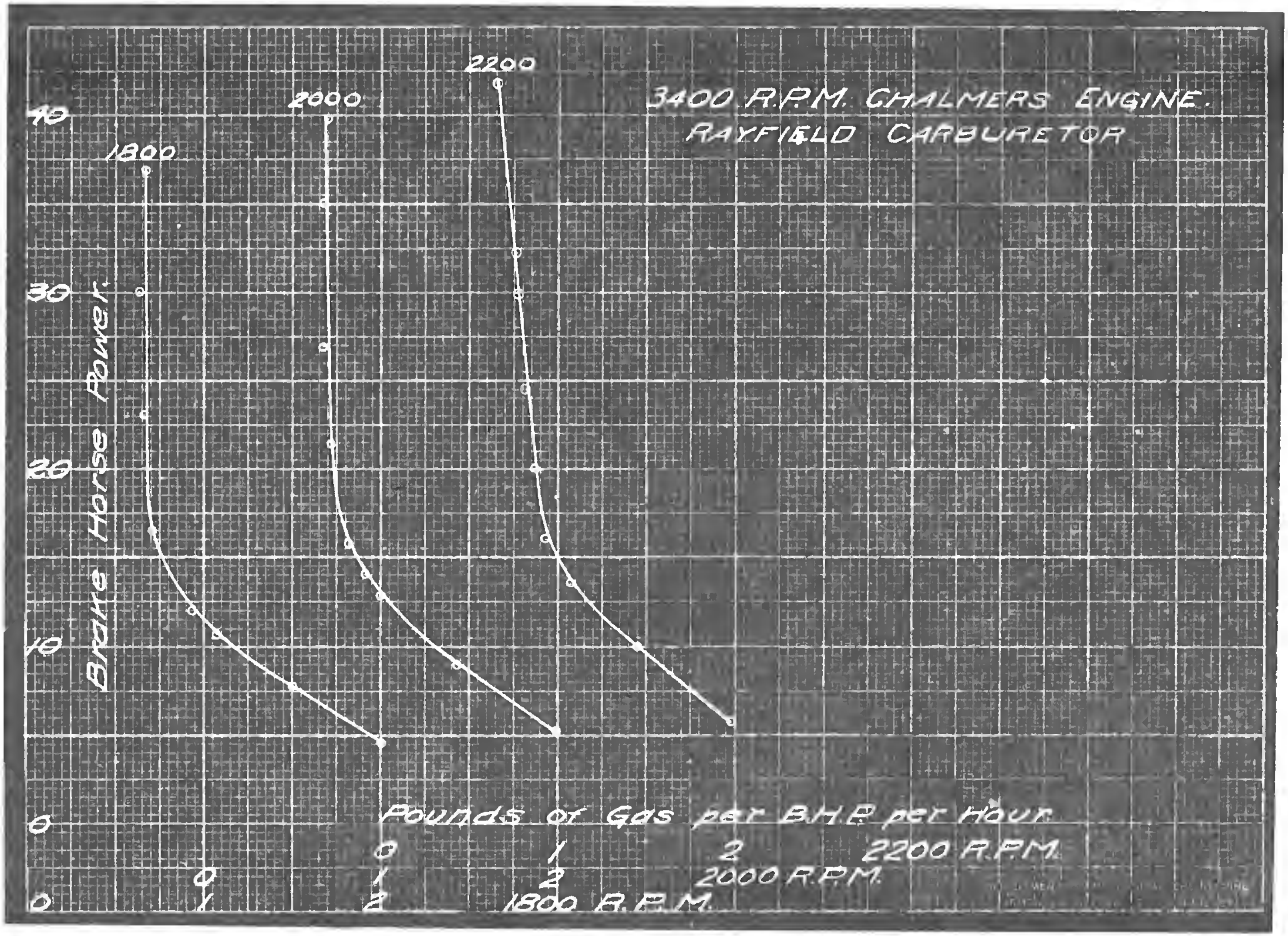

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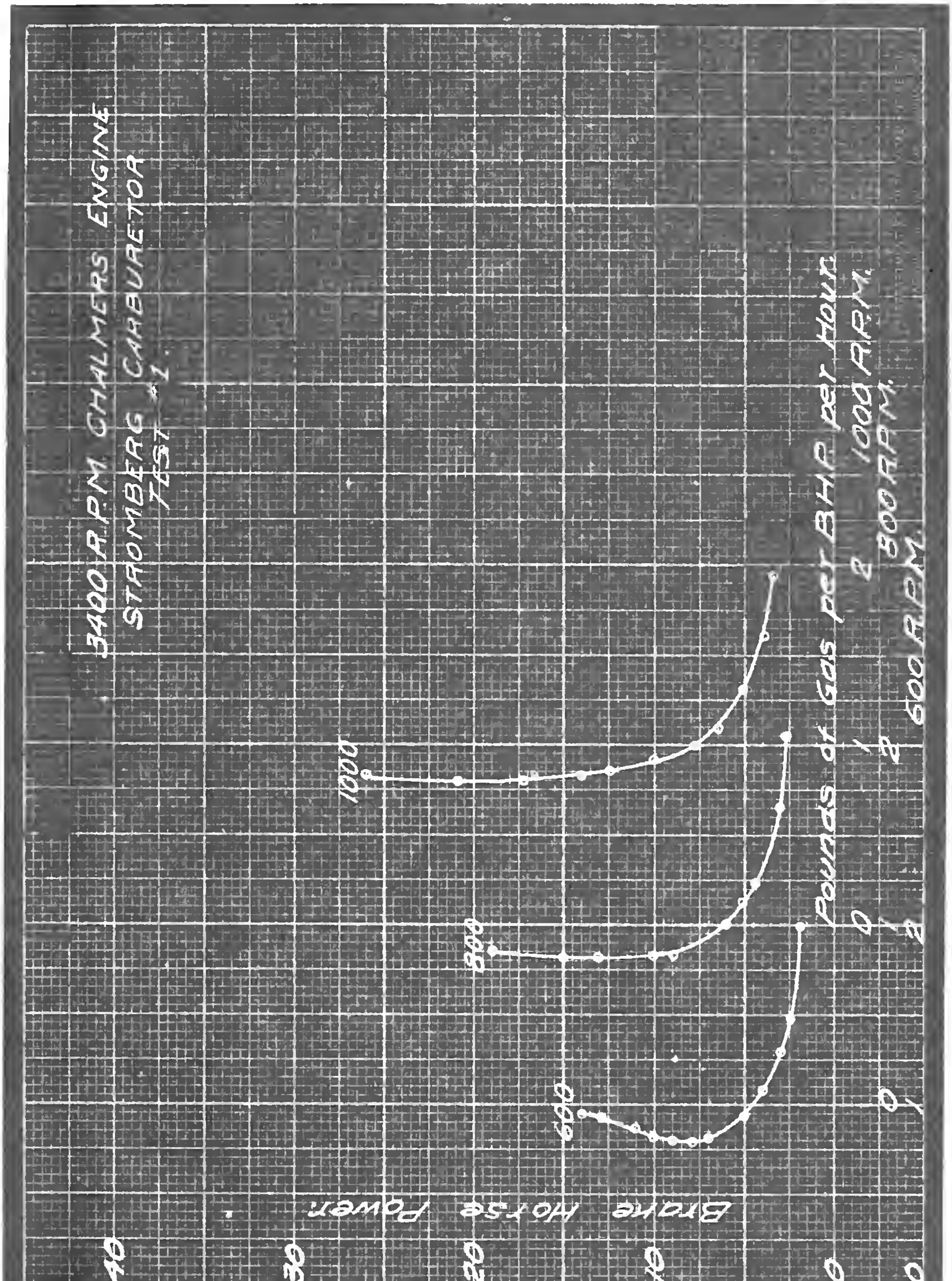

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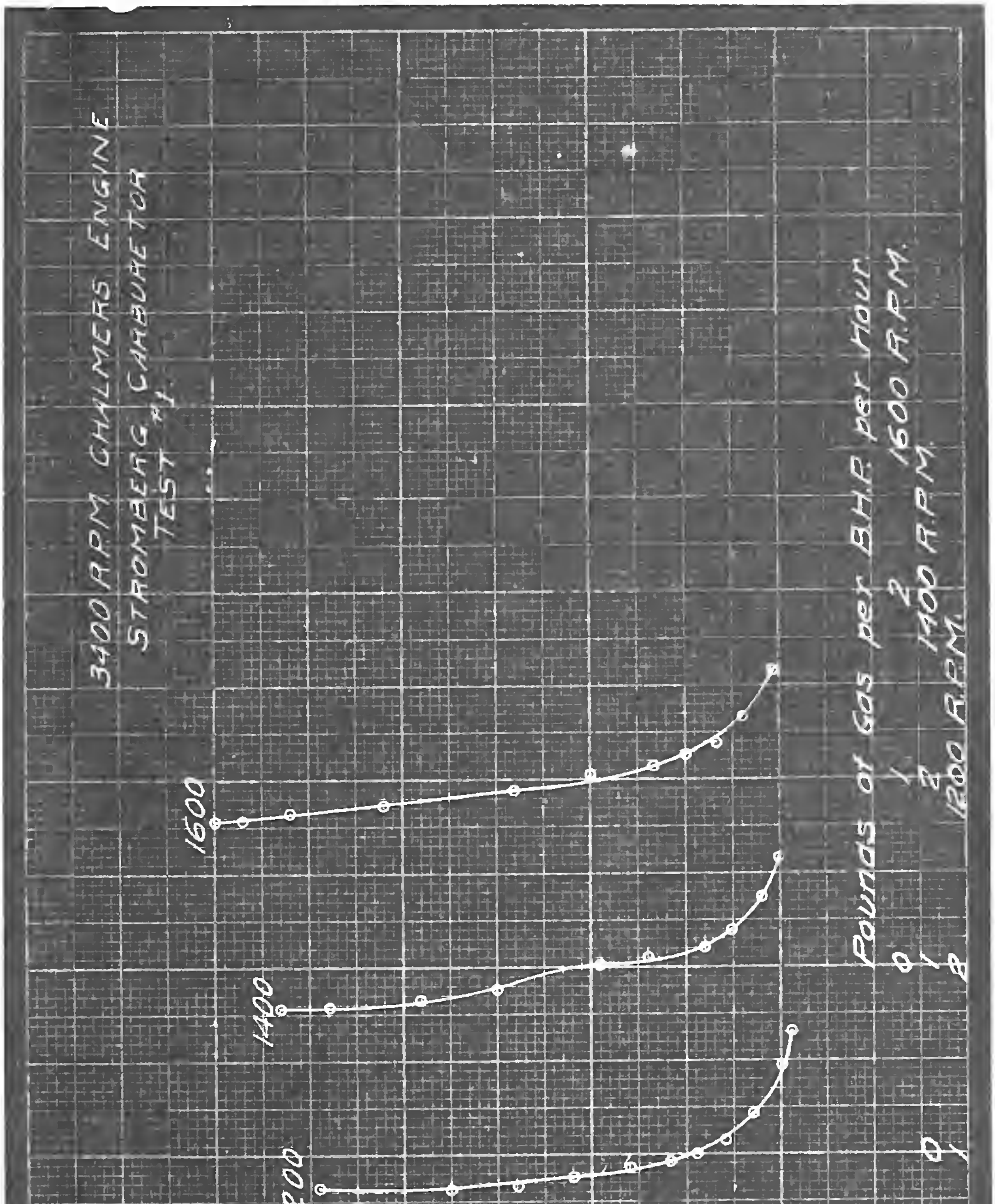

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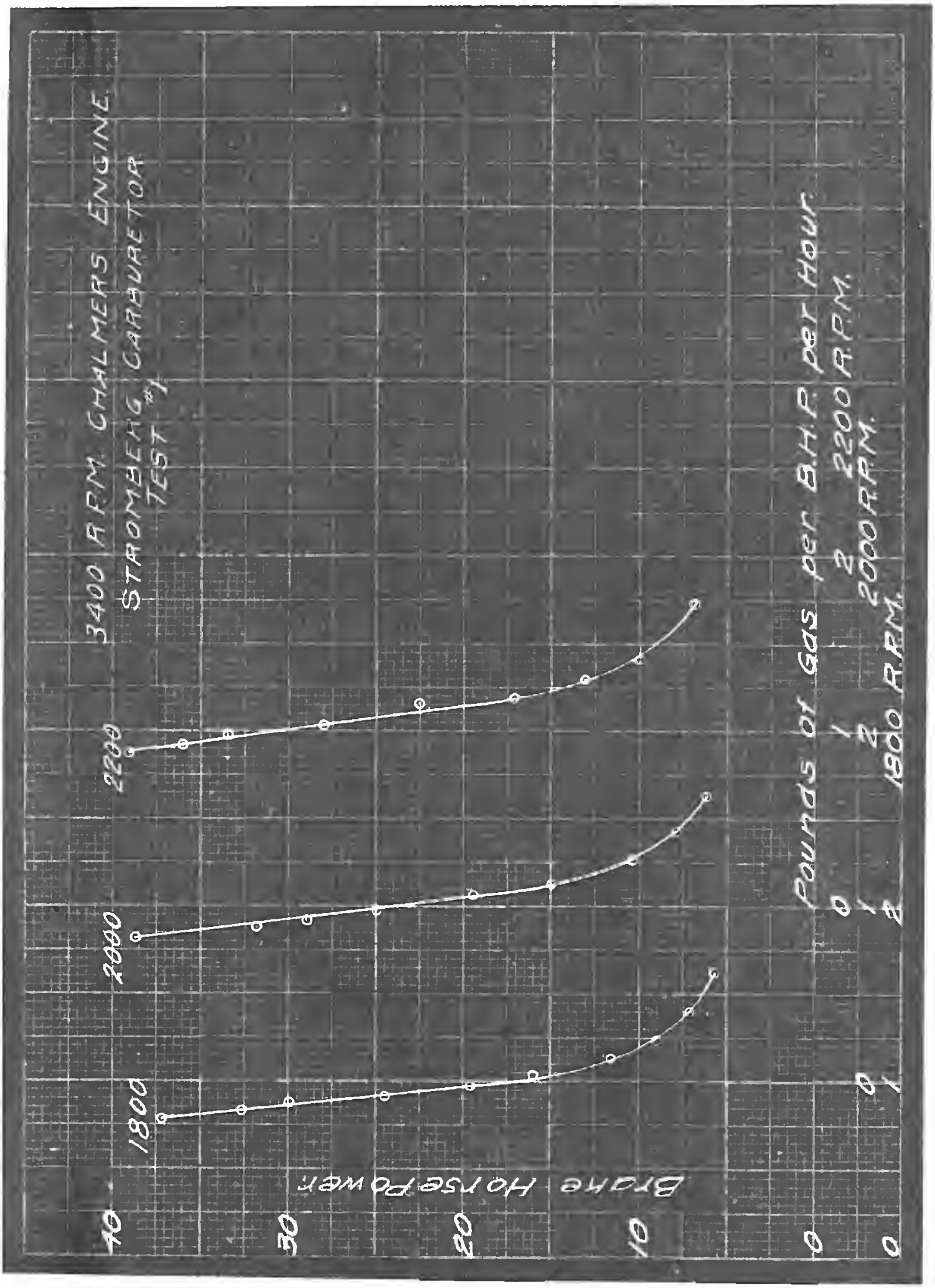

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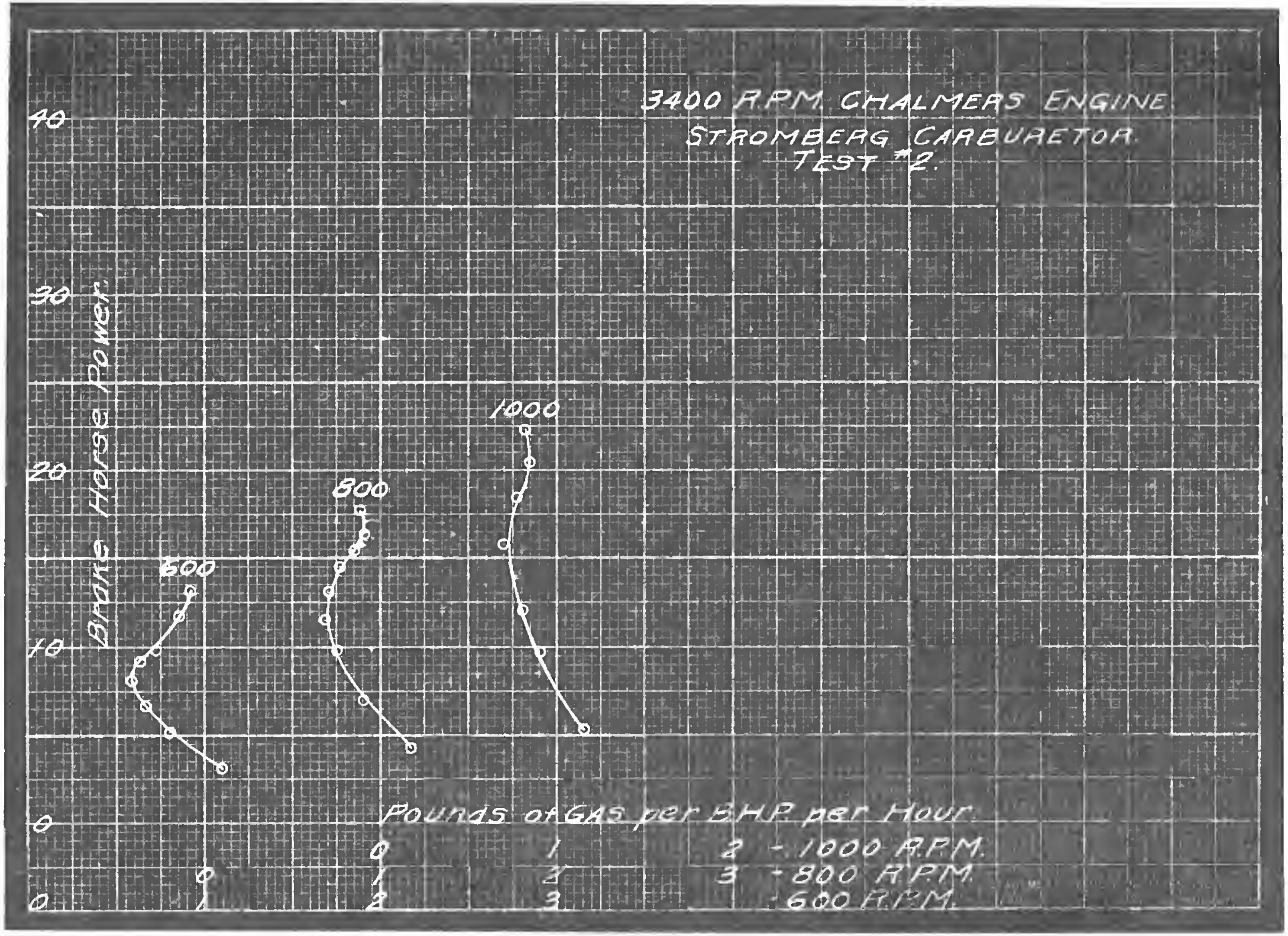

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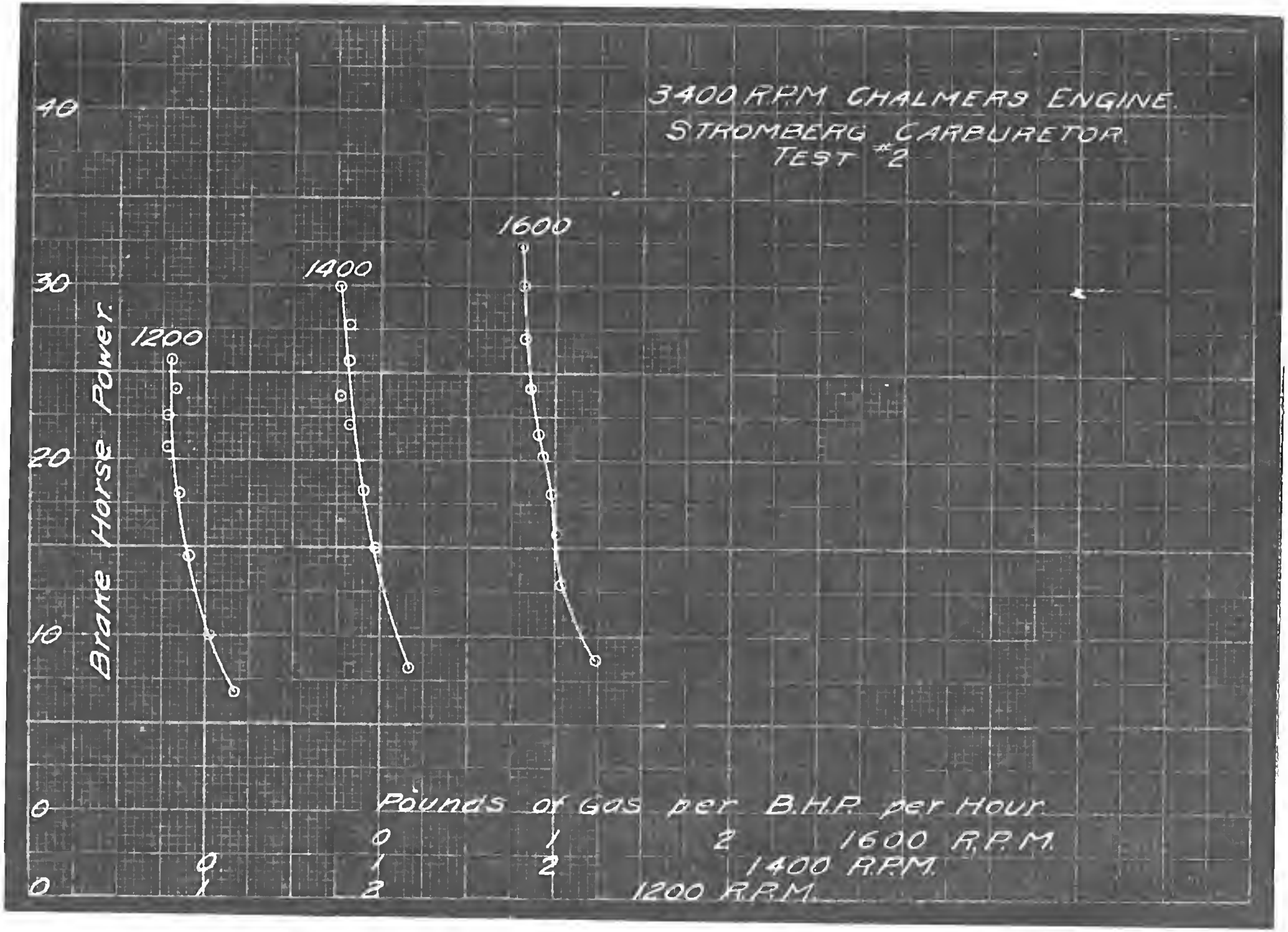

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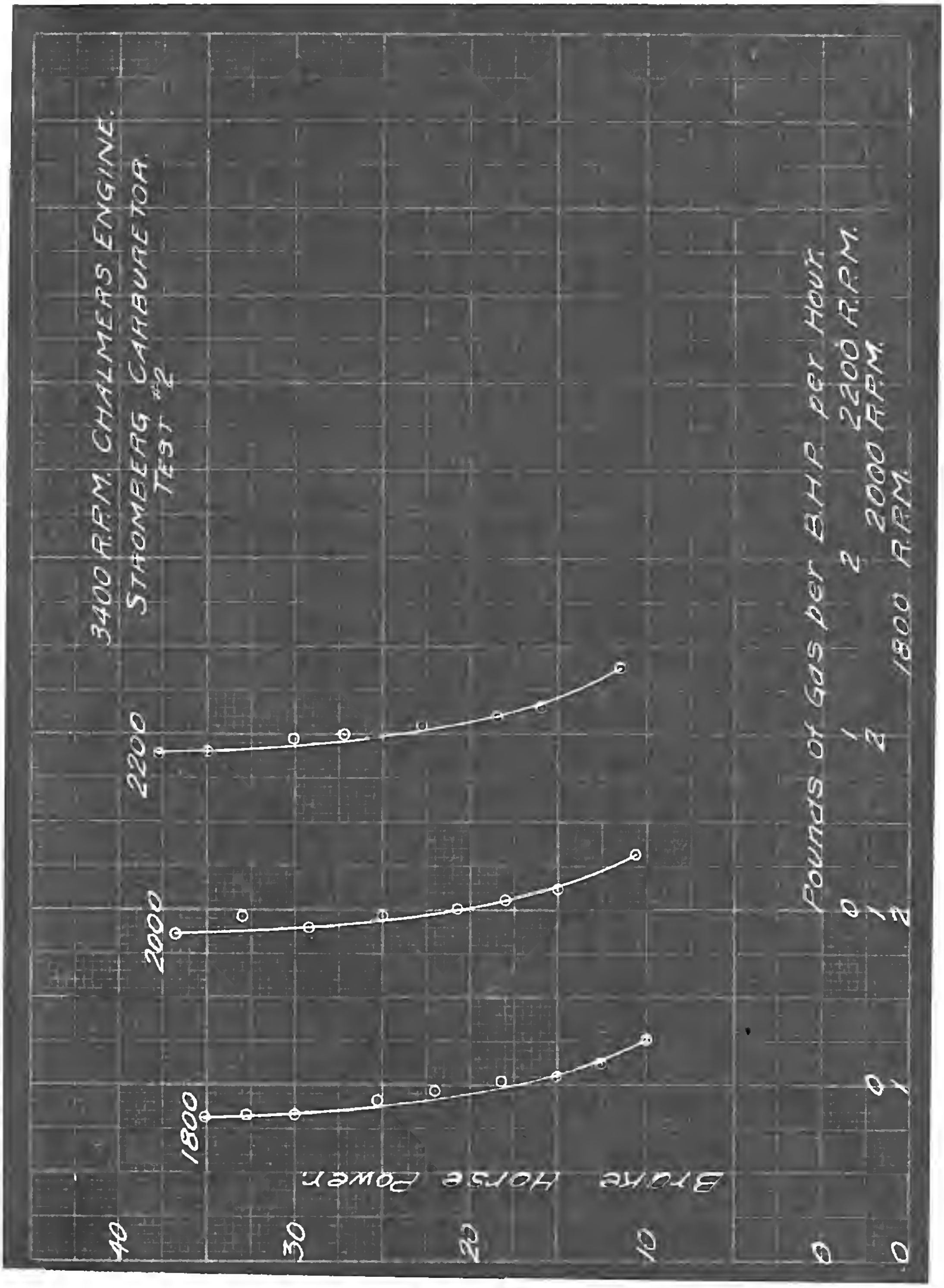

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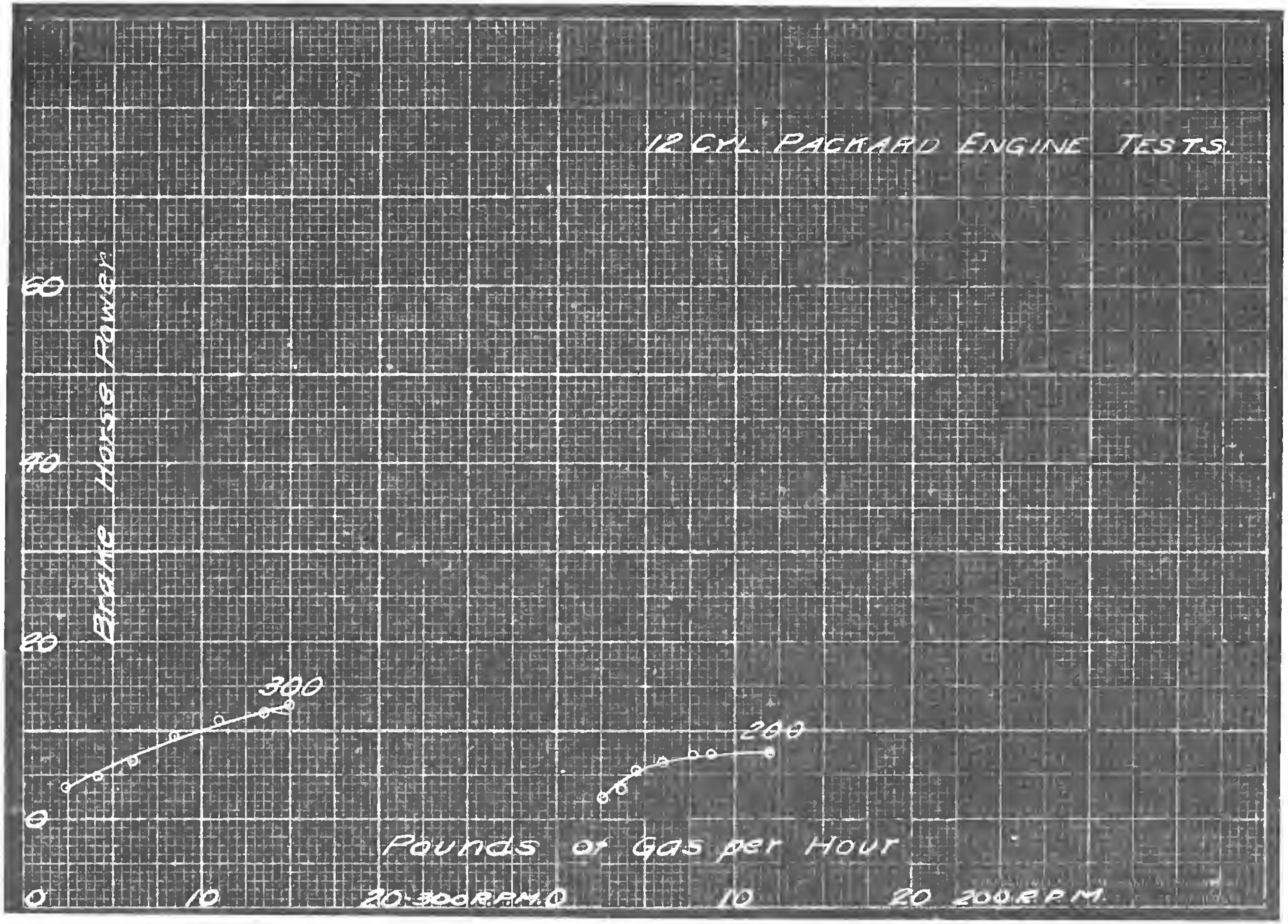

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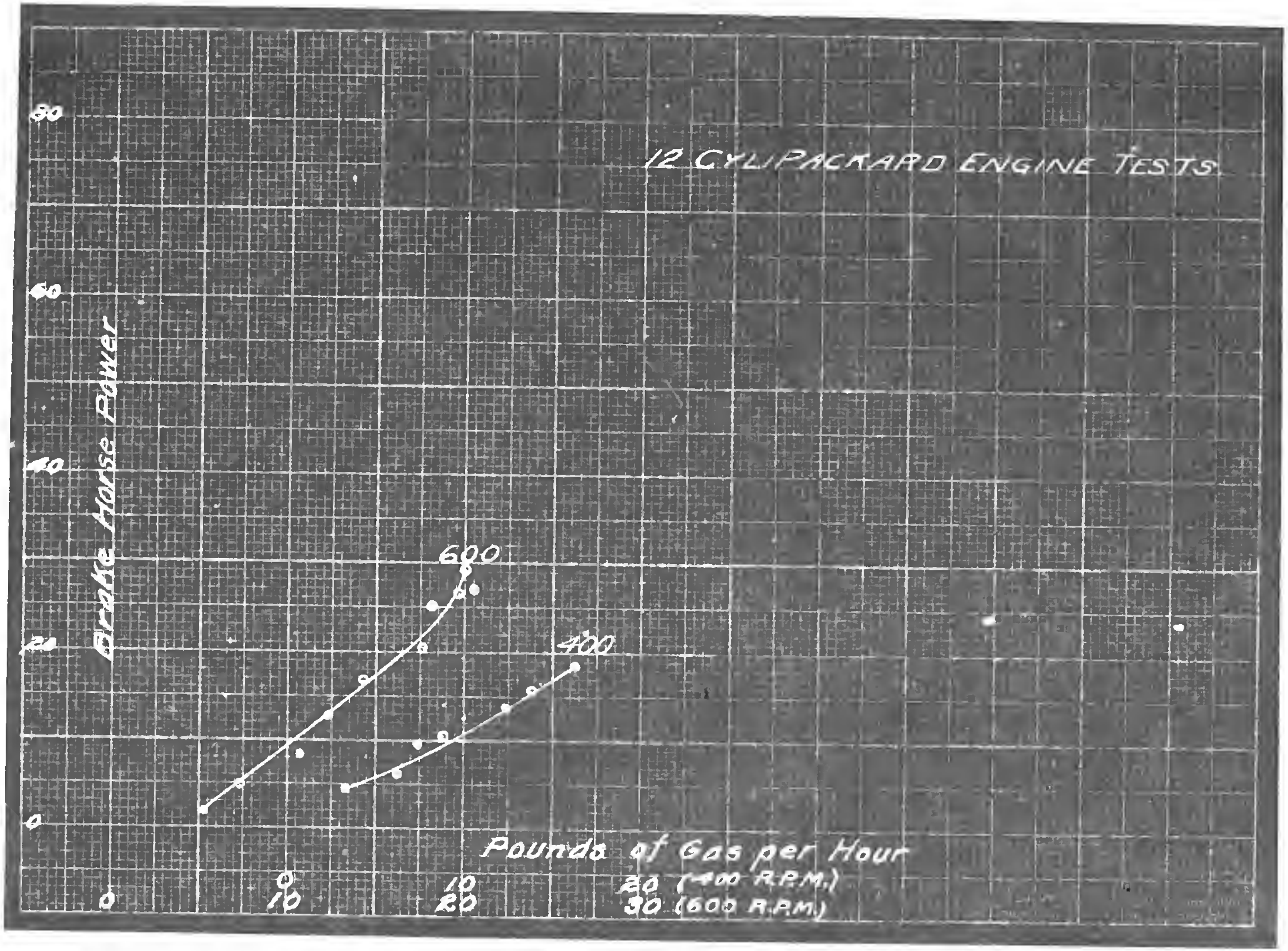

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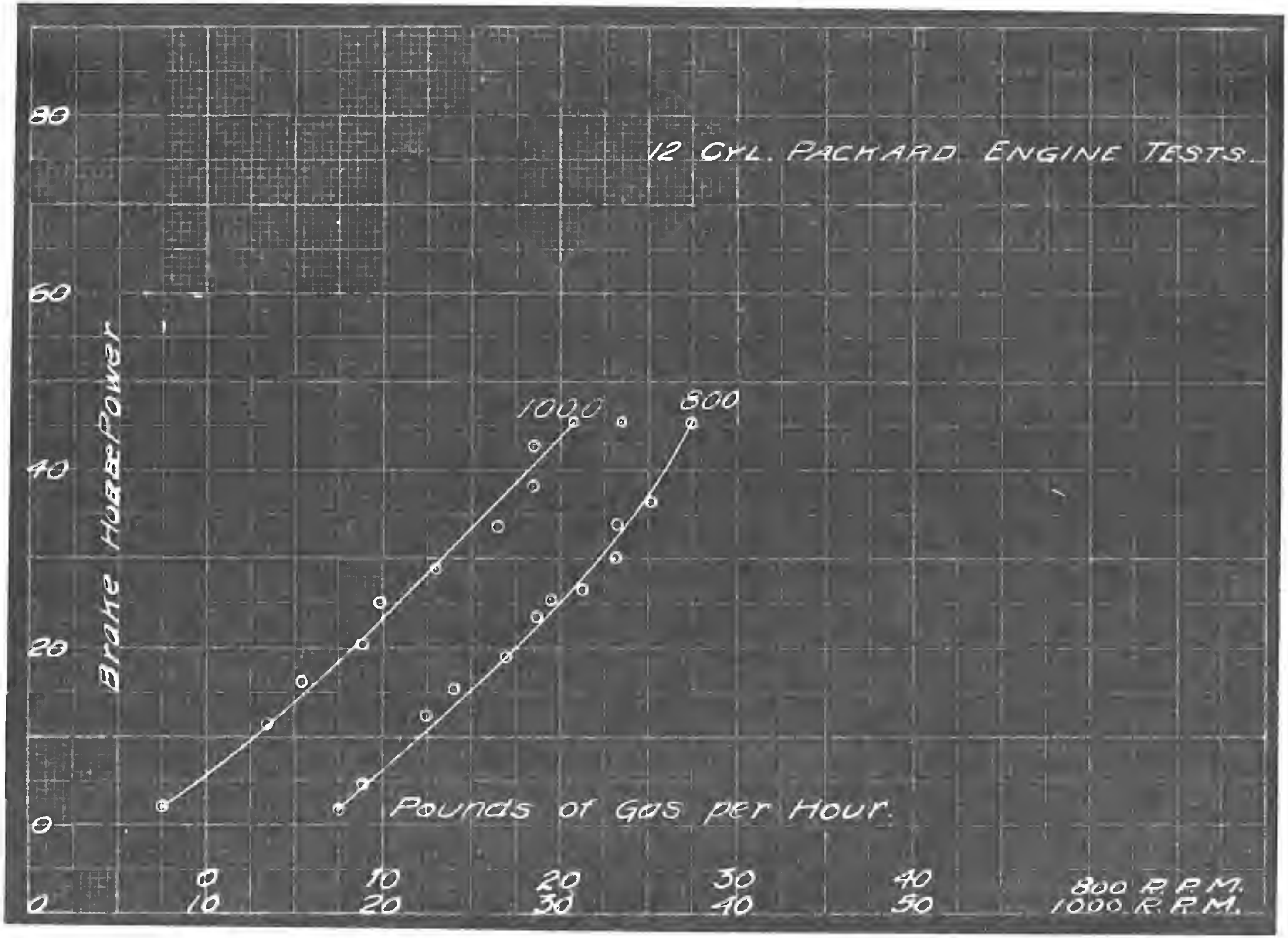

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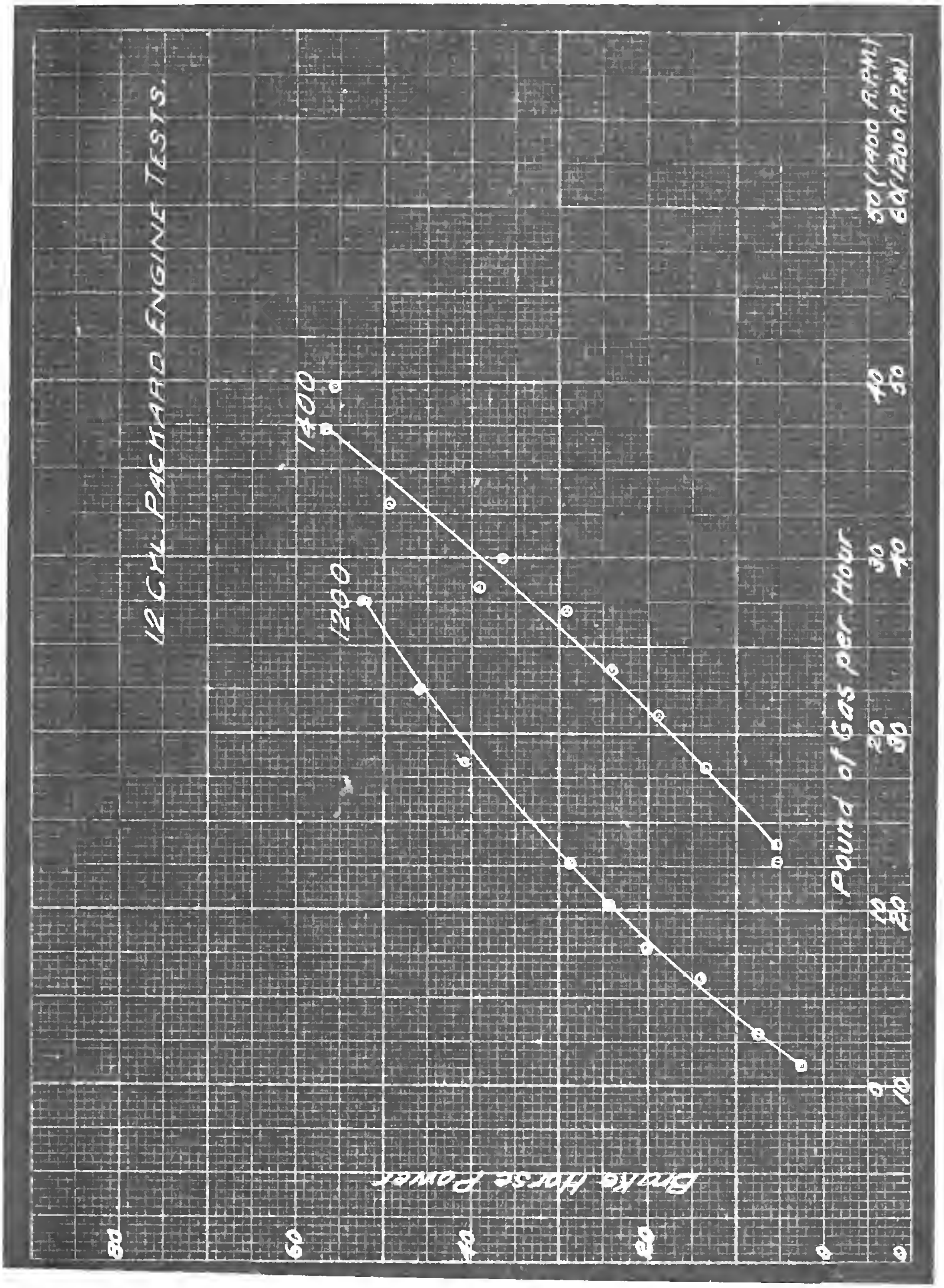

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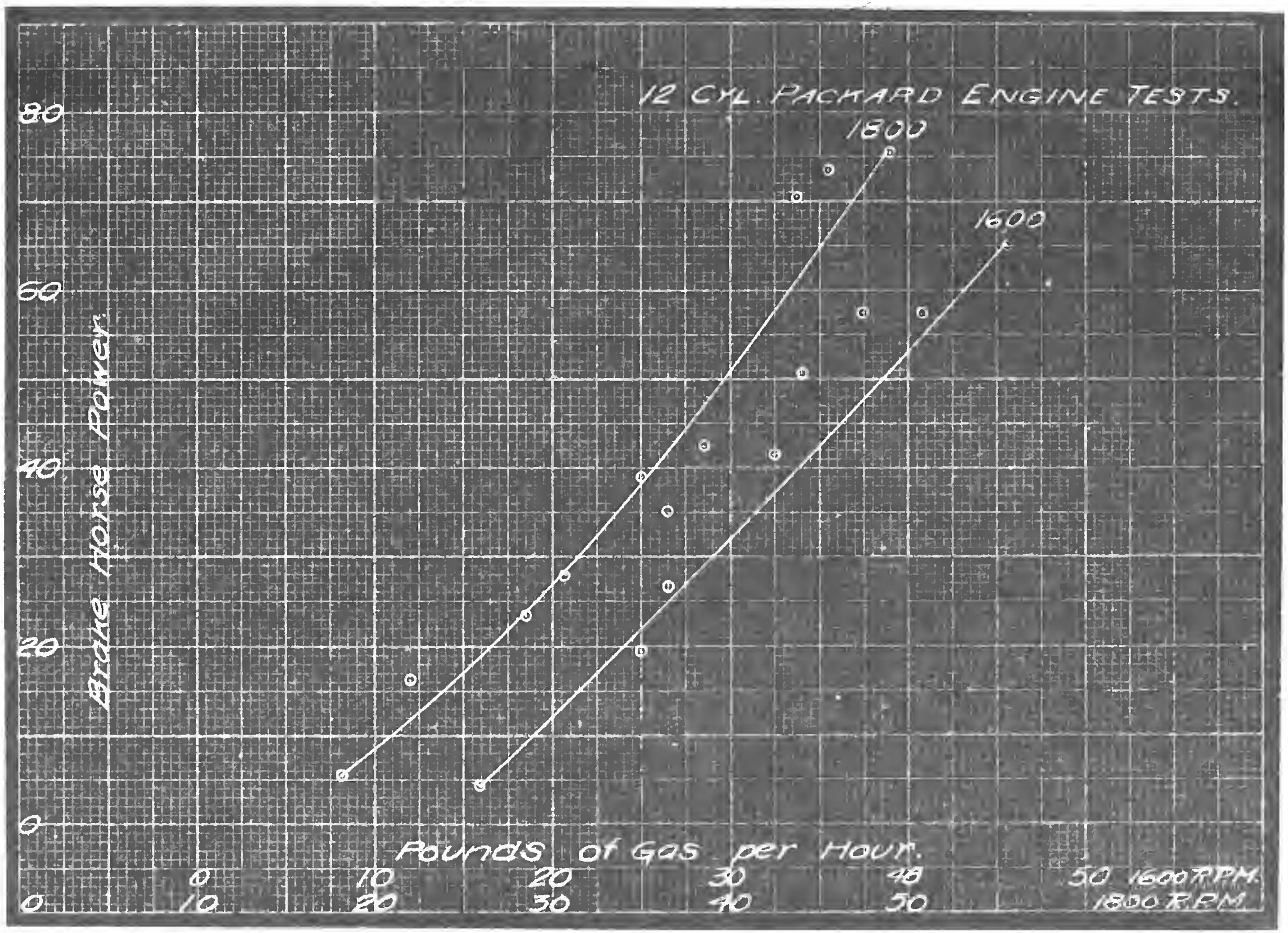

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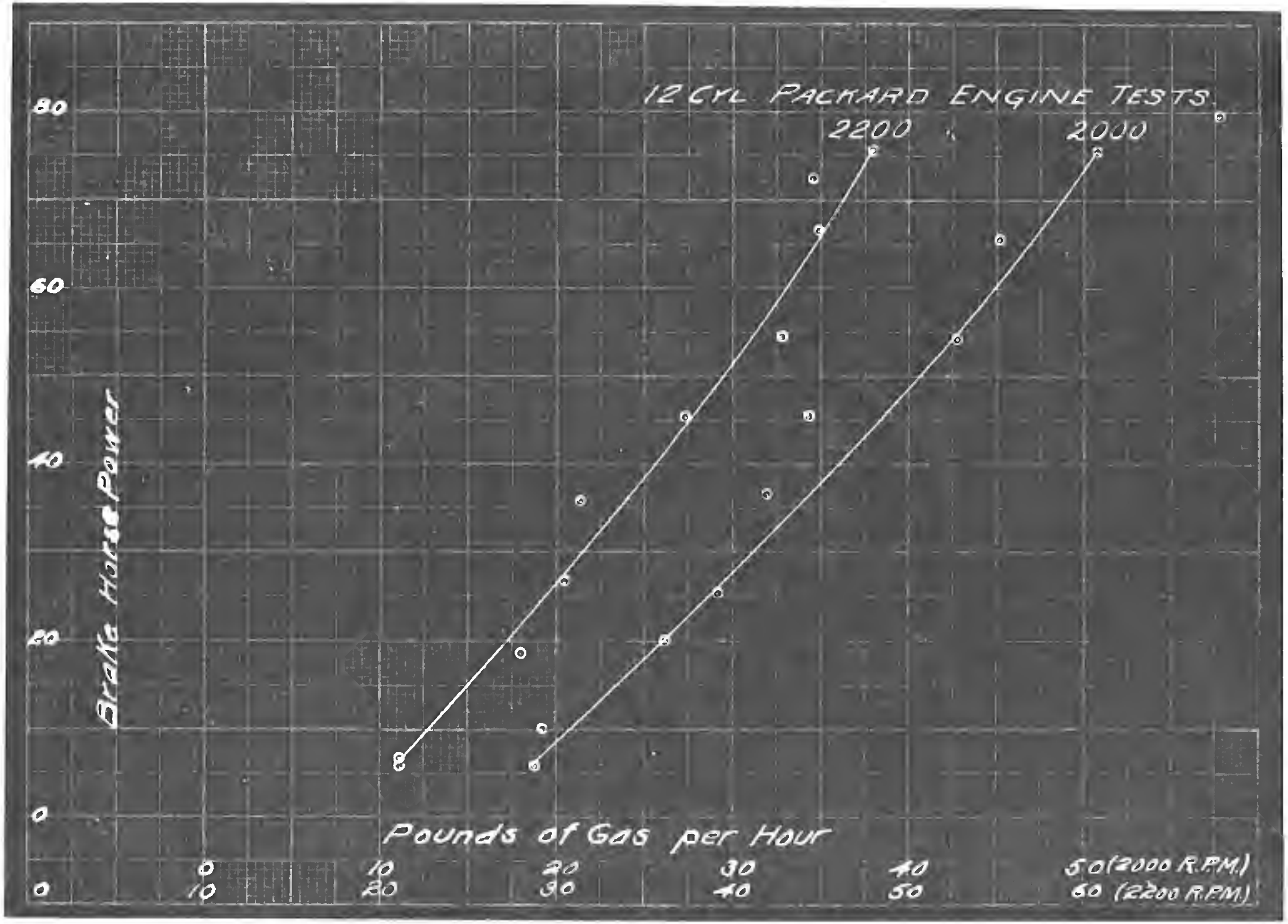

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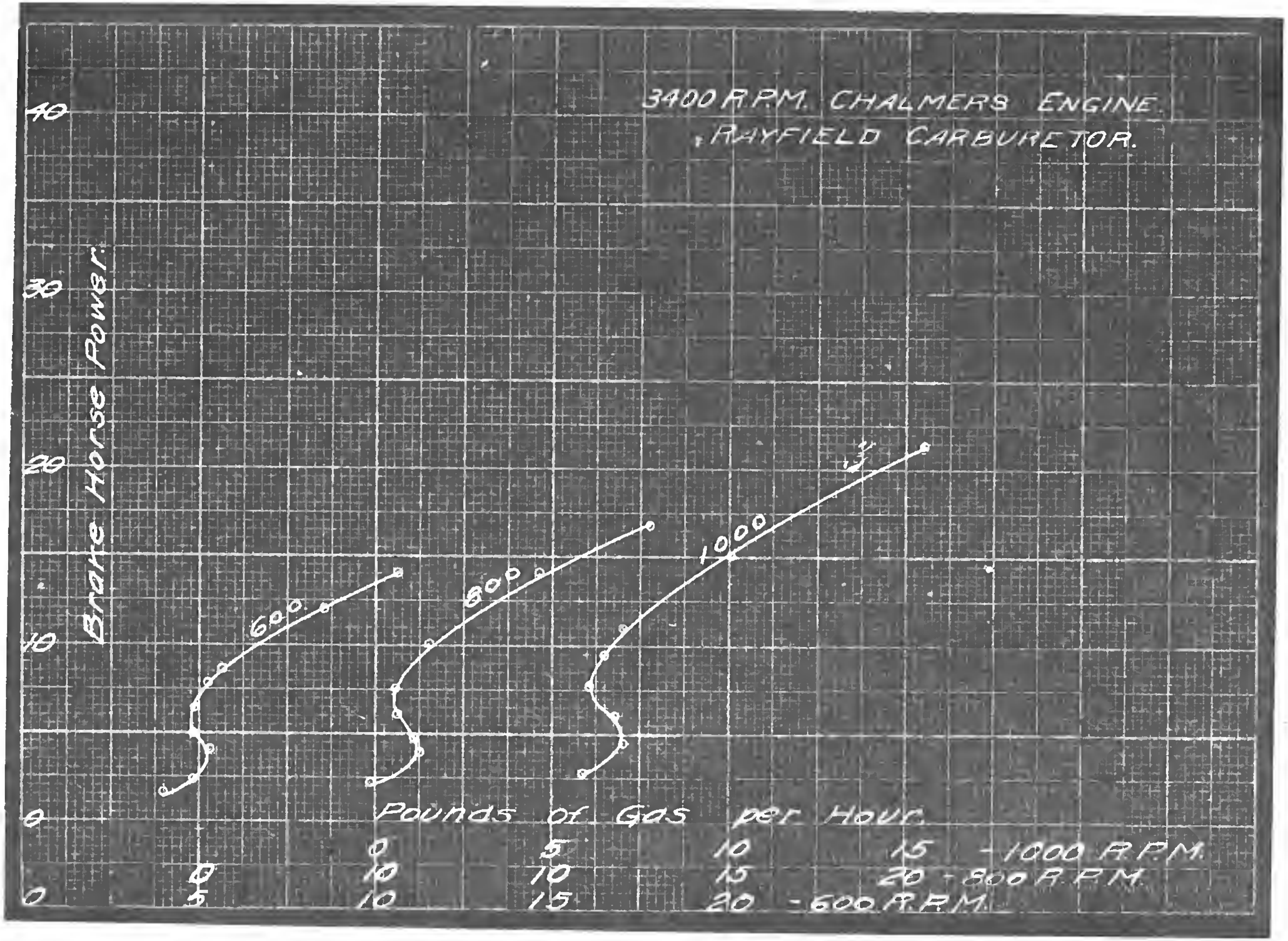

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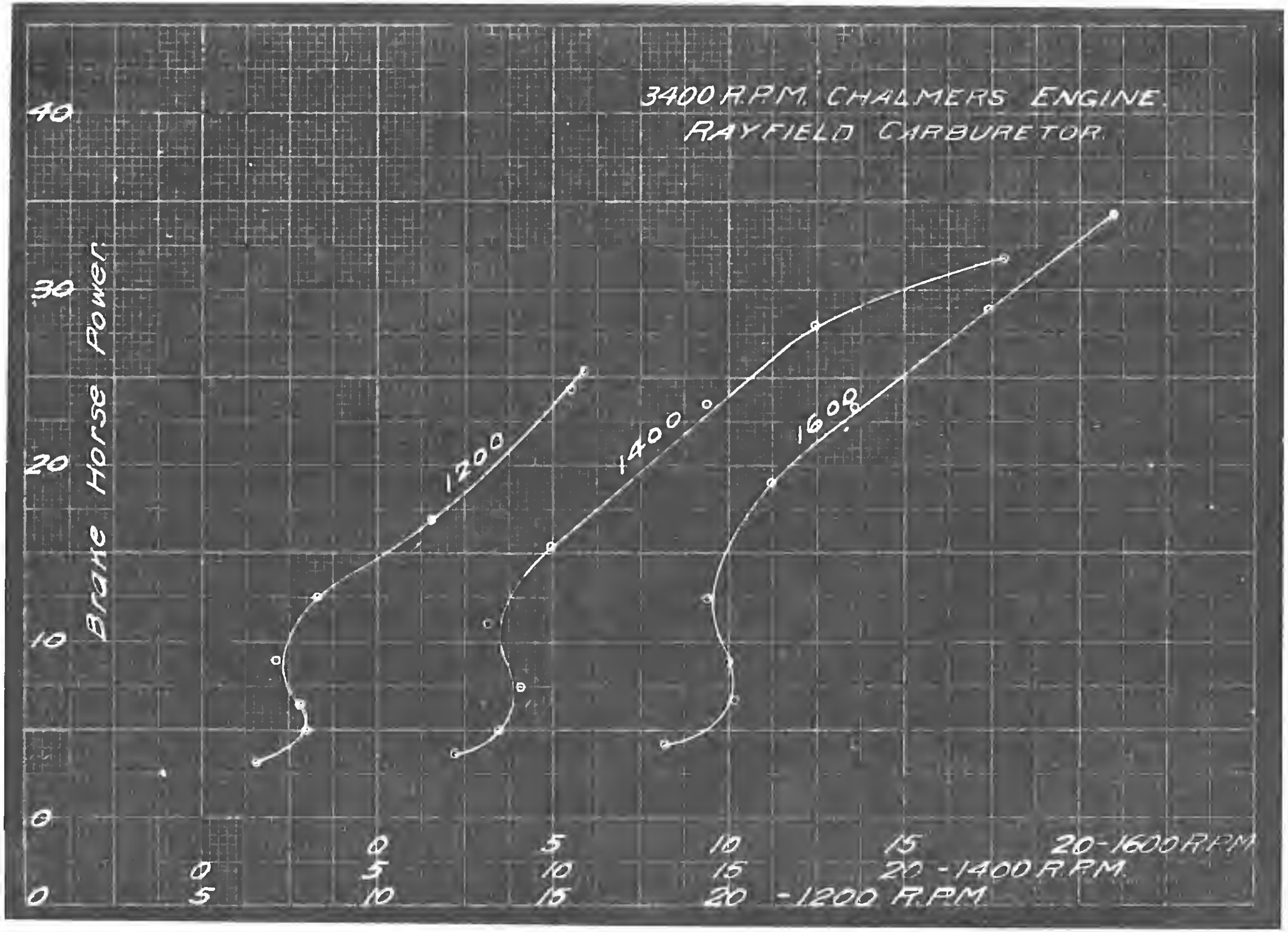

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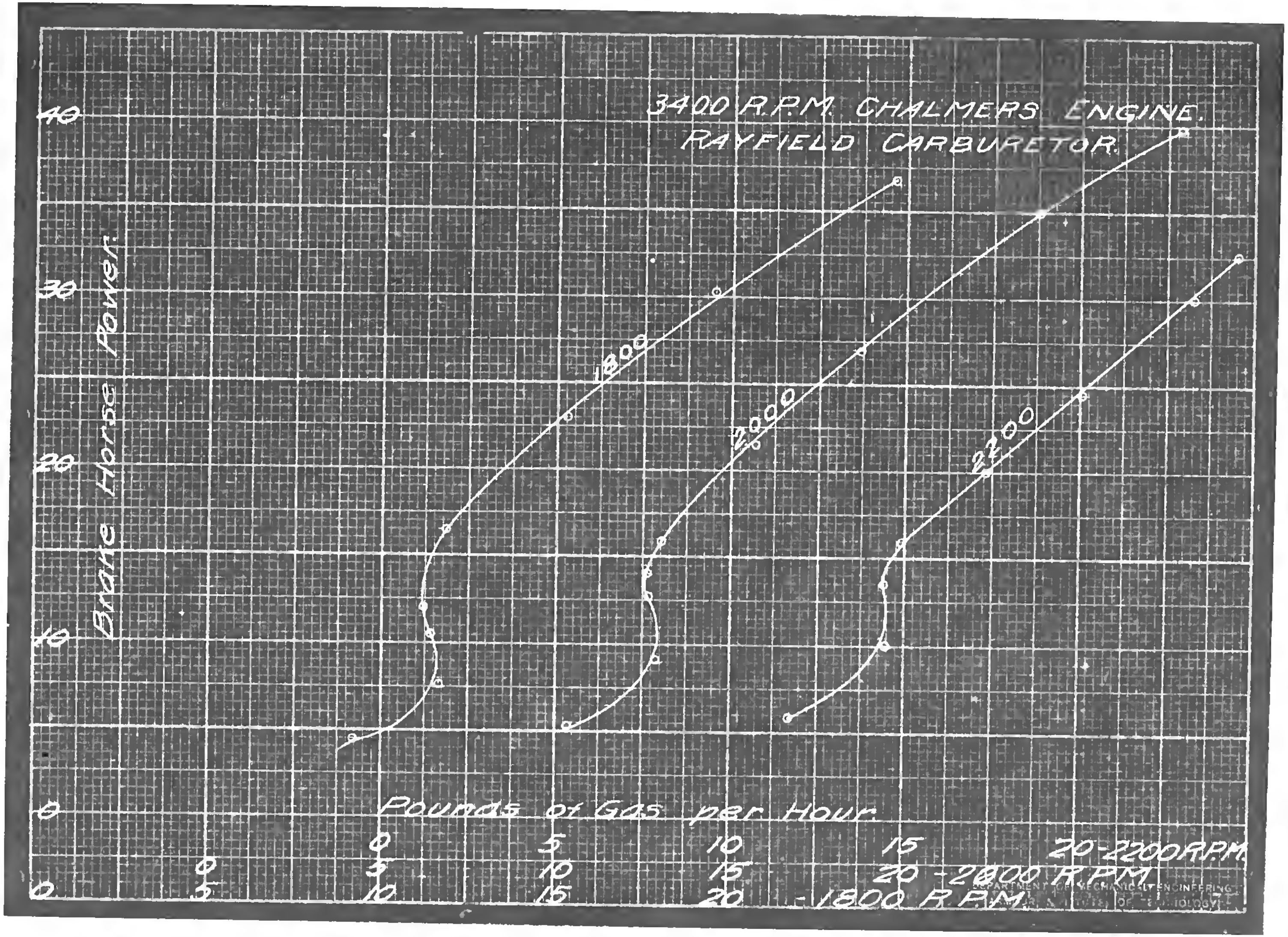

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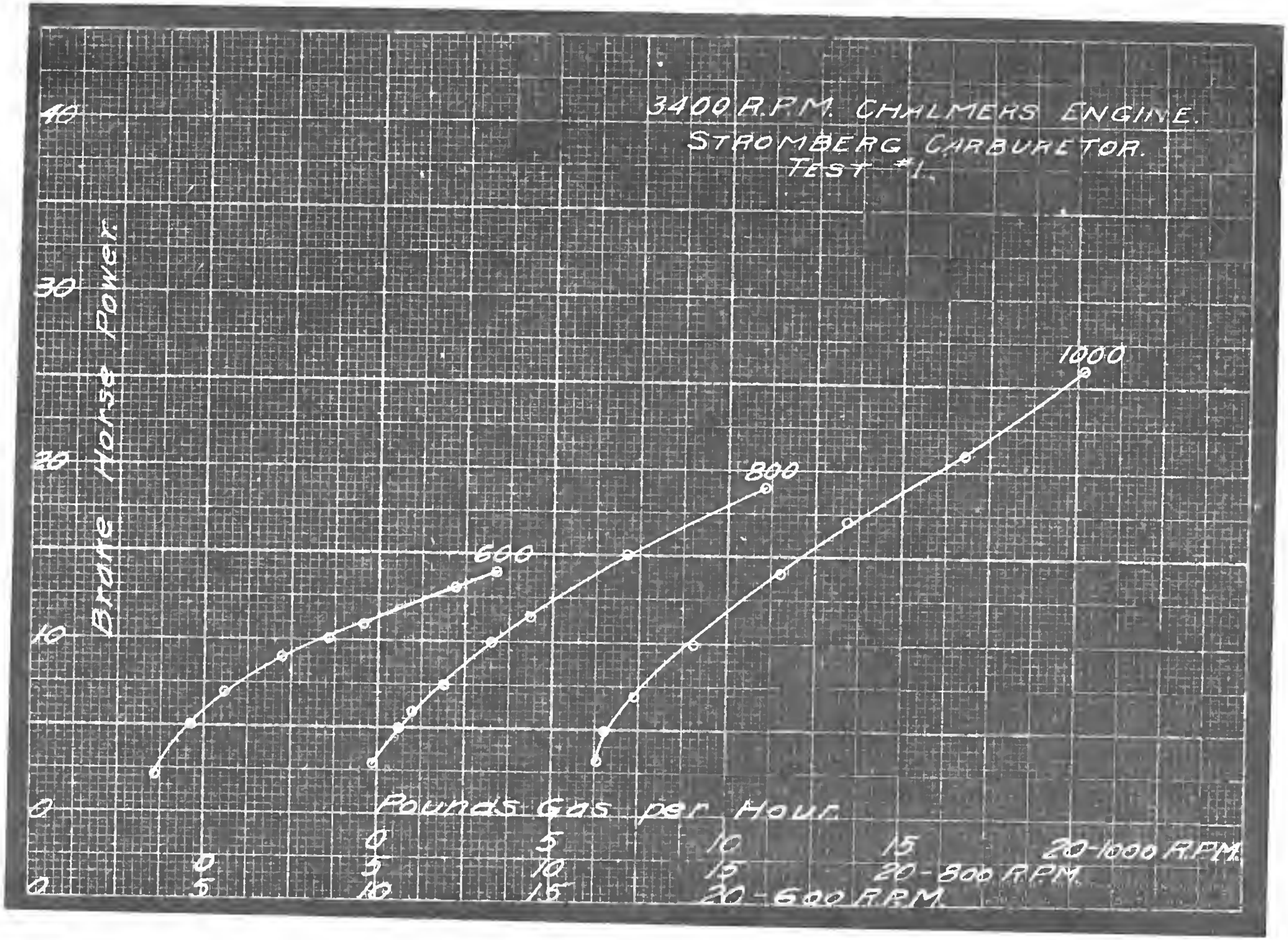

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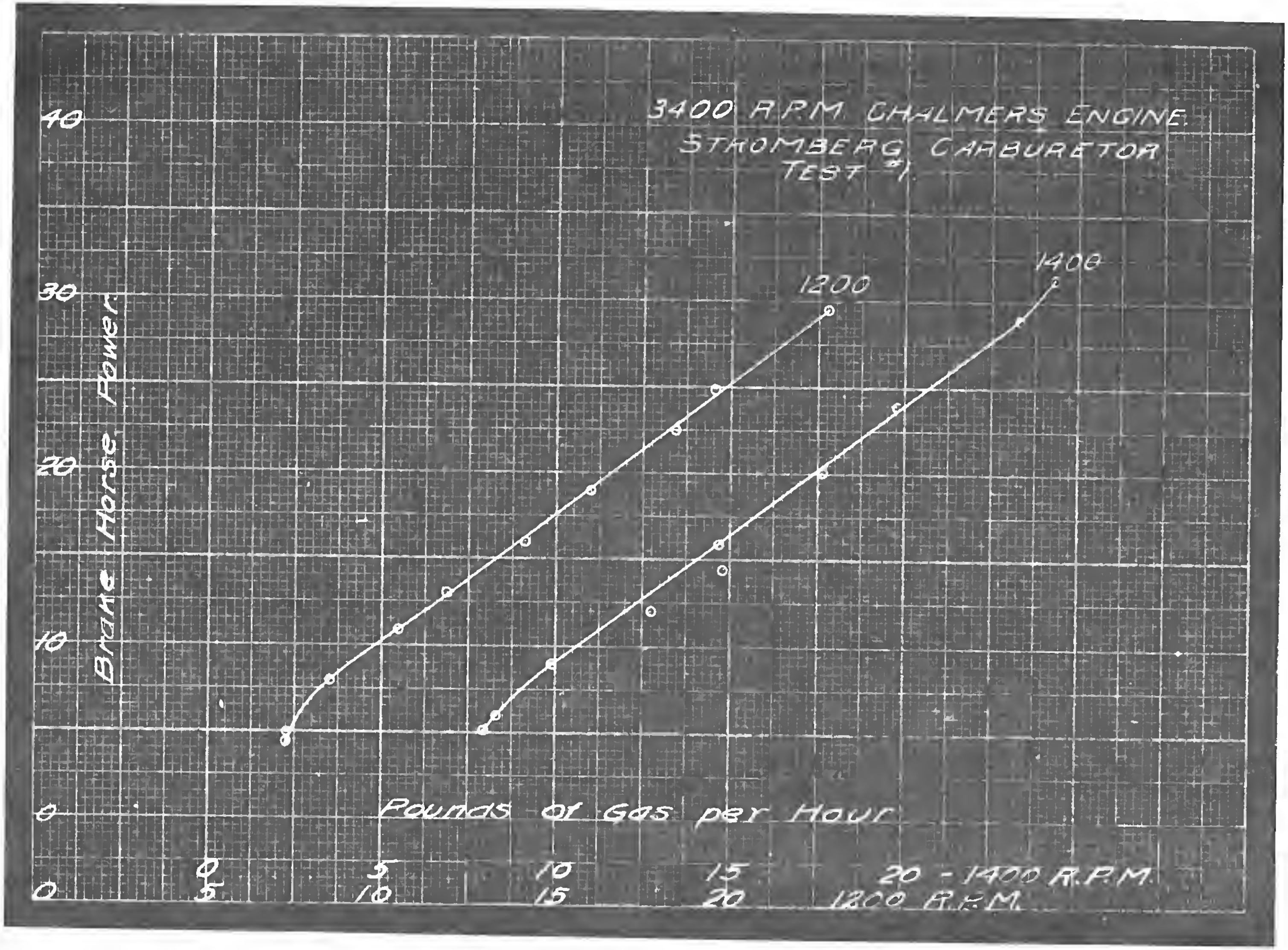

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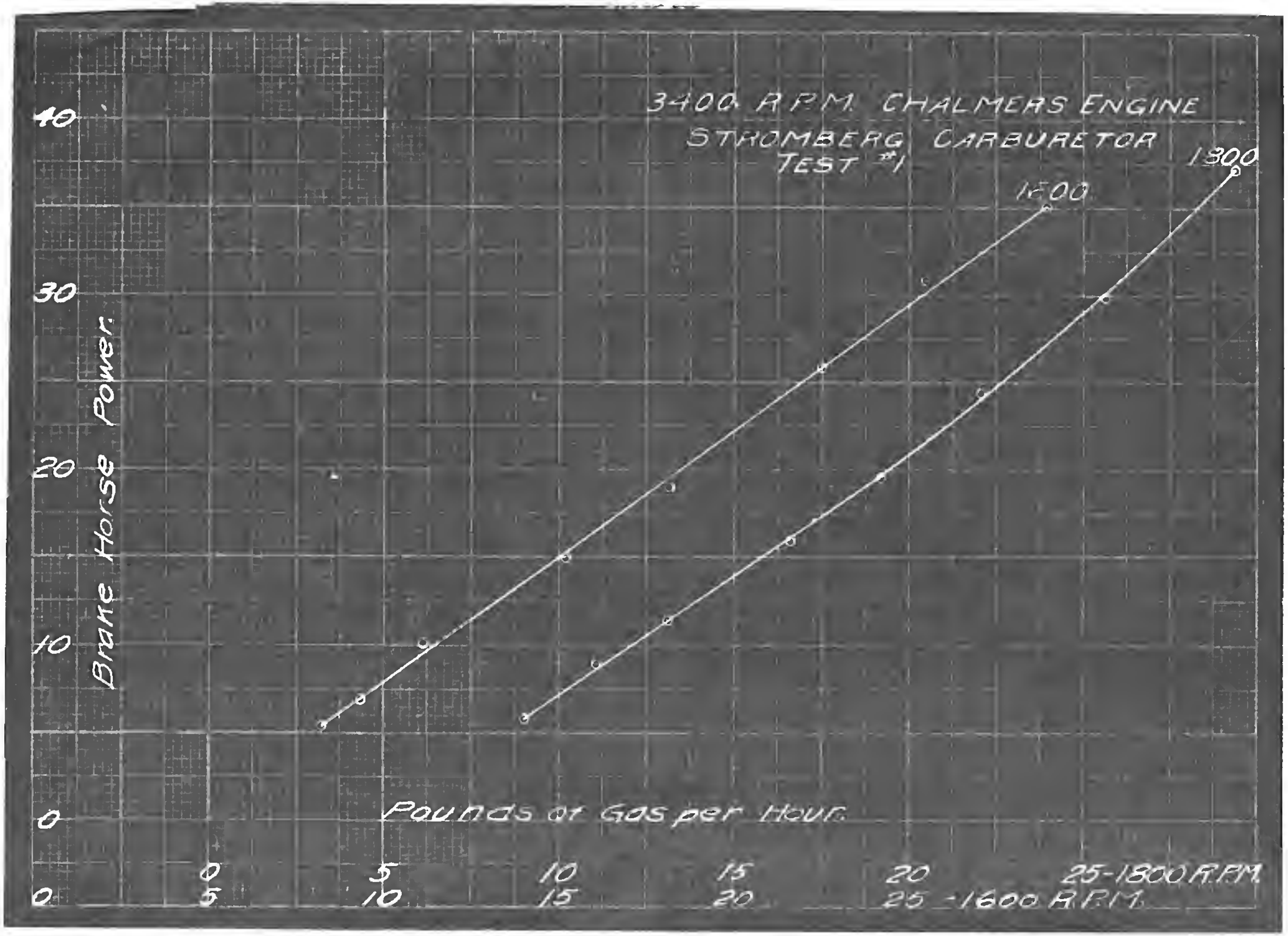

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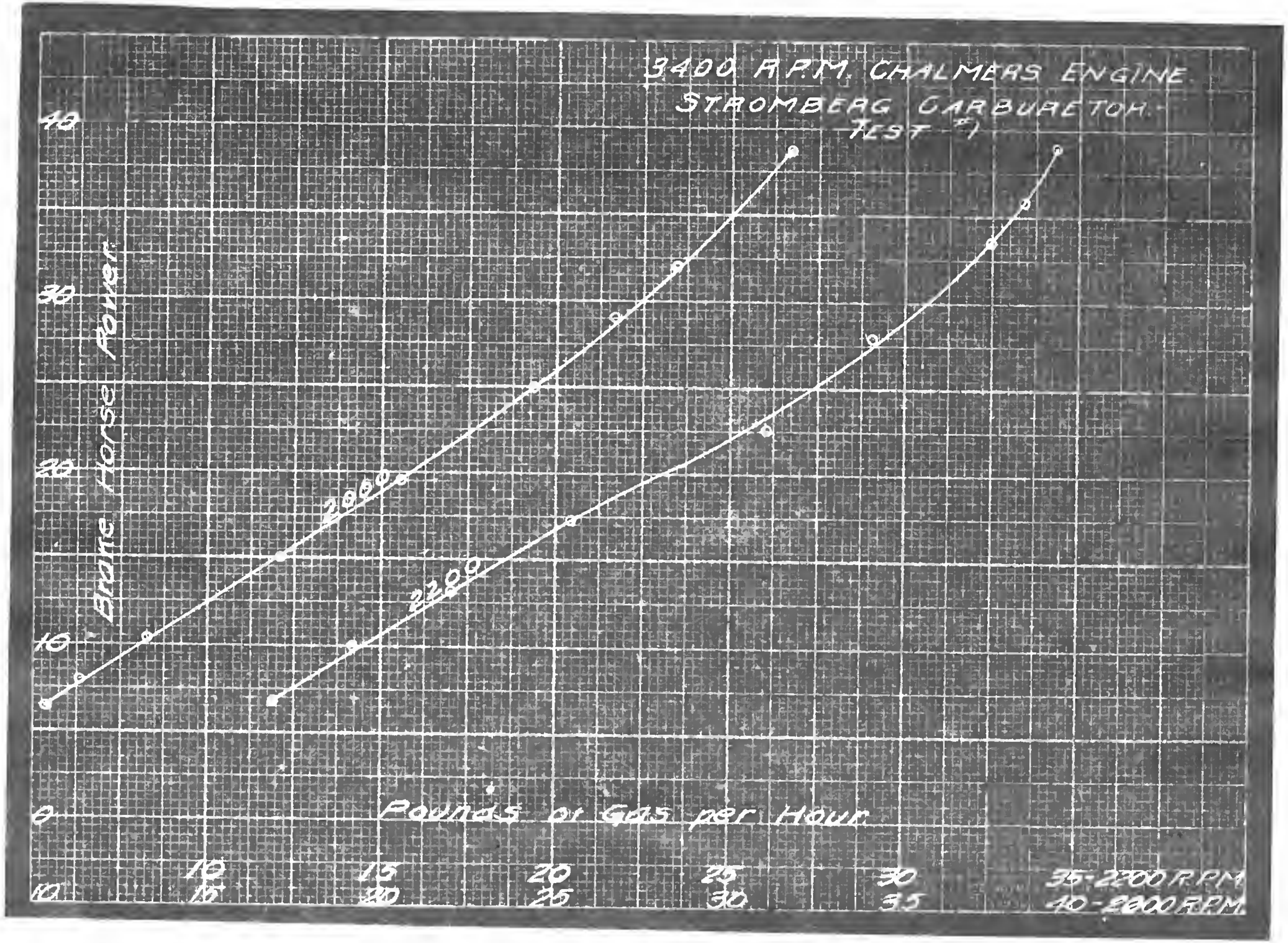

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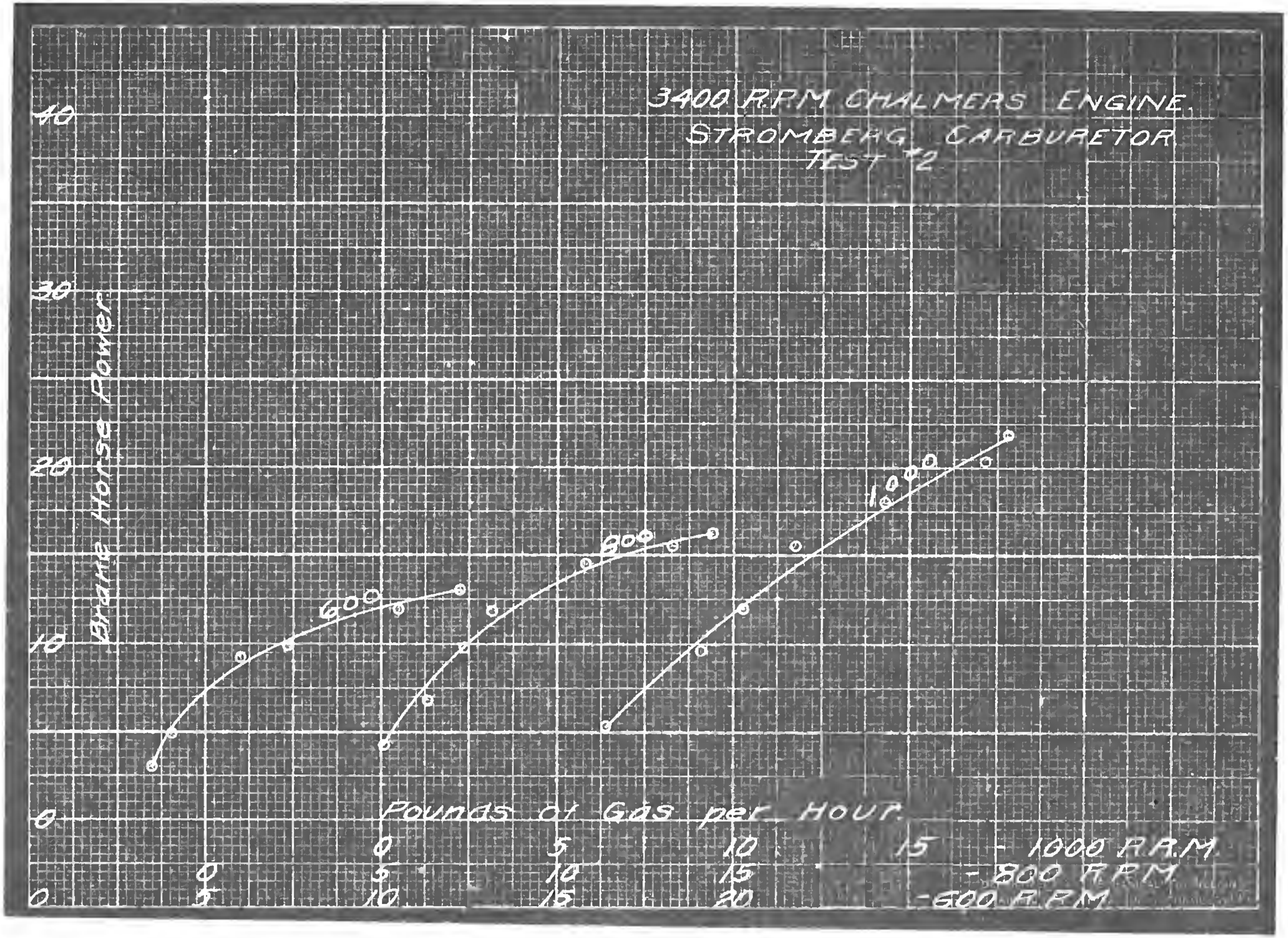

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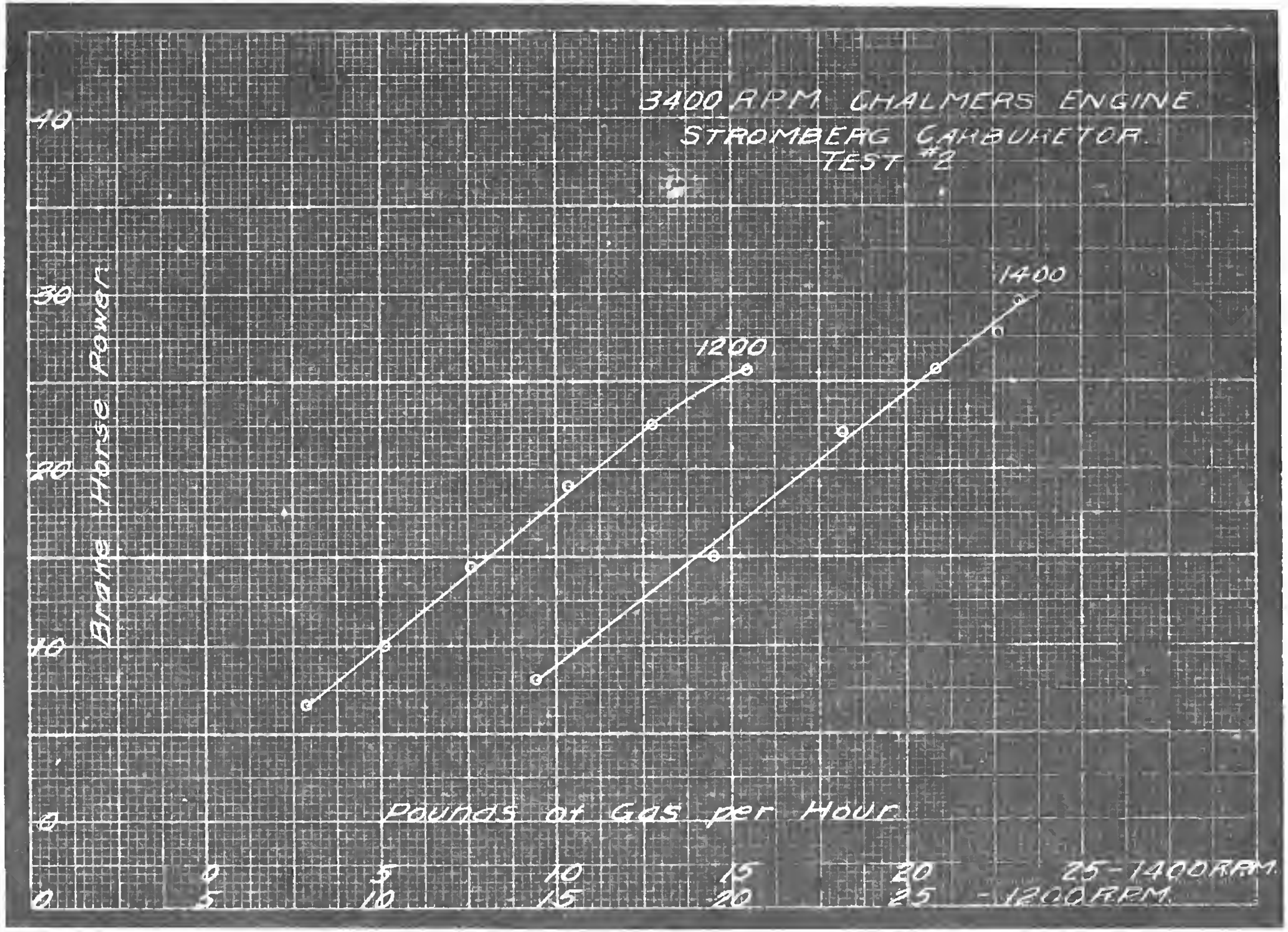

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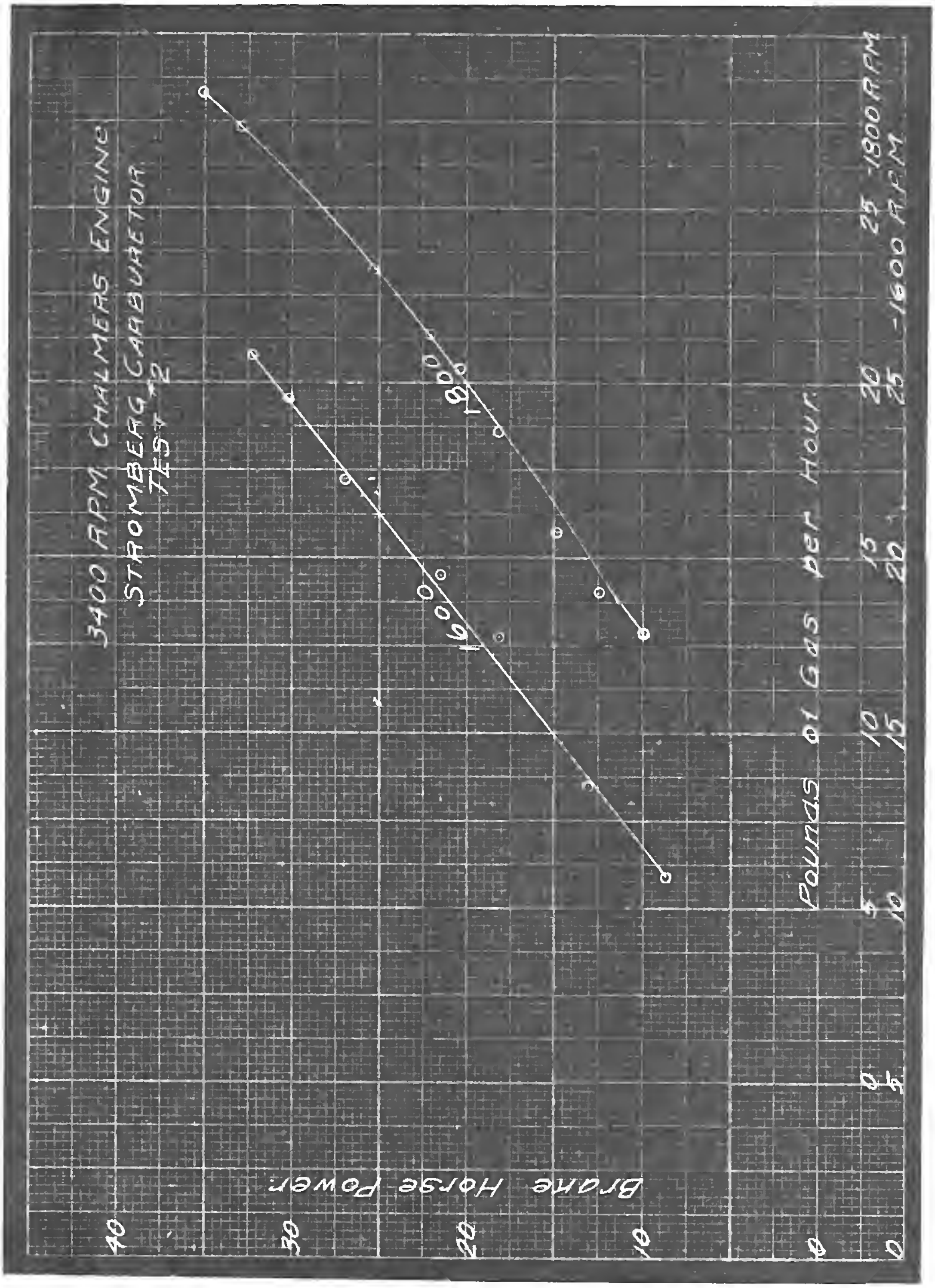

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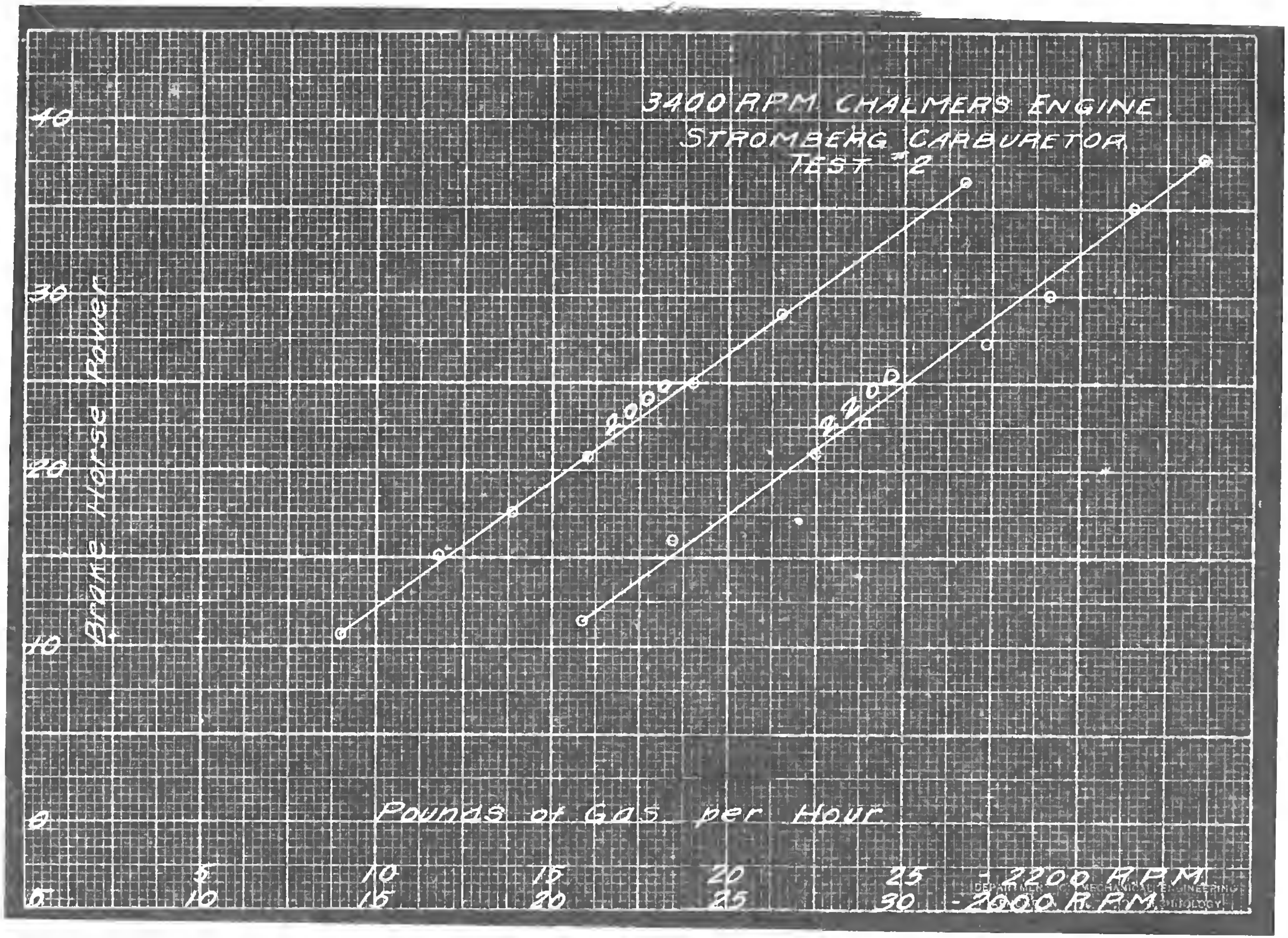

Curve Sheet 33.

Part VIII. Discussion

The surfaces show clearly the most economical running conditions of the different engines tested. The surfaces ase plotted to the same scale for all engines, so that they present a goo means of comparison. On the gasoline per horse power per surfaces, the ideal condition would be represemted by a surface parallel to the B.H.P.-R.P.M. plane throughout the entire range ofmavailable power. This would indicate that for any horse power and for any speed the gasoline consumption per horsepower would be the same. This ideal condition is most closely approached on the Packard engine as shown in figure 11. It will be noted that for this engine the surface representing the amount af gasoline per B.H.P. per hour is practically a flat one parallel to the B.H.P.-R.P.M. plane except for the

lower 20-25% of the power variation. At high speeds and high powers, the curve is very good showing good running economy. As the horse power per hour decreases, the gasoline per horse power per hour increases and the curve flattens out. Two gasoline per B.H.P. per hour surfaces were made for the Packard engine. The one, figure 12, was made with all irregularities in it with the hopes that they would show some inherent features in the carburettor performance. However, as there seemed to be no definite system to these humps, it was concluded that they were due merely to lack of uniformity in test conditions. For this reason a new surface was made leaving out all such irregularities.

In testing the Chalmers engine, two makes of carburettors, Rayfield and Stromberg, were used. From the surfaces made from each test, a difference in economy at different speeds can readilly be noticed. Figure

15 represents the Gas per B.H.P. per hour surface of the Chalmers with a Rayfield carburettor while figure 14 shows the results with the Stromberg carburettor. The surfaces show that above 30% of maximum power, the Rayfield carburettor gives better economy, while below this power the Stromberg shower better economy. Both surfaces represent good engine economy and performanee as the amount of gasoline per B.H.P. per hour does not vary a great deal until the engine is developing less than about 30% of maximum power. For the higher powers it shows nearly as good economy as the Packard engine but it has considerably less range of such good economy.

Figure 18 is the surface for the Ford engine and represents very poor economy within the usual operating range. Almost immediately as the horse power falls from its maximum value, the pounds of gasoline per H.P. per hour increase very rapidly.

These surfaces presemt a means

of determining the economy of an engine at all speeds and powers at actual everyday running conditions. Knowing the weight of a car, the speed, the rolling resistance, the wind resistance can be calculated and finally the horse power to drive. These two items, horse power and speed, determine a particular point on the economy surface the abscissa of which at once indicates the economy of the engineat those particular conditions. This could be carried further by calculating the horsepower at all different speeds ordinarilly used in driving and plotting the limiting values on the surface. The study of the economy of the engine within this limited zone should prove to be invaluable in engine design work.

In order to get a better idea of the total cost of operation of the various engines, surfaces were made showing the total gasoline consumption per hour. Figure 13 rep-

resents the total gasoline consumption of the Packard engine. Again as in the gasoline per B.H.P. per hour surface, this curve shows very good performance. Theoretically, the total gasoline per hour should vary directly as the horse power thus giving a straight 45 degree surface when plotted. This is practically the case at the higher speeds and powers of all the engines tested.

Total gasoline per hour surfaces were also made on the Chalmers engine. Figure 16 is the surface obtained from the Chalmers test using a Rayfield Carburettor, while figure 17 is the surface obtained when using the Stromberg Carburettor on the same engine.

Figure 19 shows the total gasoline surface for the Ford. By mistake this curve was constructed just opposite of the other total gasoline surfaces.

Part IX. Appendix

Part I. Method of Calculating

Both the brake and friction horse power were calculated according to the formula

$$B.H.P. = \frac{T \times R.P.M.}{3000};$$

where T is the torque as read from the scale beam. The constant 3000 comes from $\frac{2\pi R}{3000}$ in which R, the radius of the brake or lever arm of the generator field, equals 1.75 feet.

The pounds of gasoline per hour were determined by the equation

$$Lbs./Gas/Hr. = \frac{W \times 3600}{t}$$

where W is the weight in pounds of the fuel used and t the number of seconds required to use that amount.

The pounds of gasoline per brake horse power per hour were obtained by dividing the total pounds of gasoline(see above)

by the total horse power developed.

The quotient of the brake horse power and the sum of the brake and friction horse power for the same condition of speed and manifold depressiom gives the mechanical efficiency of the engine.

The mean effèctive pressure net was obtained by multiplying the torque by the constant .662 which was obtained as follows:

$$B.H.P. = \frac{PLAN}{33000} = \frac{T \times R.P.M.}{3000}$$

where P is mean effective pressure (Lbs./Sq. inch)

L is length ofmstroke in feet

A is area of piston in square inches

N is number of explosions per minute (6 times the R.P.M.)

Whense substituting the values for the above in the equality, we have for the Packard

$$P = \frac{R.P.M. \times T \times 33000}{3000 \times LAN}$$

$$P = \frac{R.P.M. \times T \times 33000}{3000 \times 5/12 \times /4 \times 9 \times 6 \times R.P.M.}$$

$$= .622\ T$$

The horse power of the Packard engine at 1200 R.P.M. which is 1000 feet per minute piston speed may be determined by the A.L.A.M. formula

$$B.H.P. = \frac{d\ n}{2.5}$$

in which n is the number of cylinders and d the diameter of the cylinders in inches.

As stated before it was impossible to hold the speed absolutely constant during any set of runs so that it was necessary to correct the brake horse power as measured to the mean speed at which the test was made. This was done according to the equation

$$B.H.P.(Cor.) = B.H.P. \times \frac{\text{mean } R.P.M.}{\text{actual } R.P.M.}$$

Part II. Sample Calculations

All calculations are carried thru for the first run of the 2200 R.P.M. Packard test.

$$B.H.P = \frac{99.5 \times 2230}{3000}$$

$$= 74.0$$

Corrected to 2200 R.P.M.

$$B.H.P. = 74.0 \times \frac{2200}{2230}$$

$$= 73.0$$

$$Lbs./\ Gas/\ Hr. = \frac{1 \times 3600}{76}$$

$$= 47.3$$

$$Lbs./Gas/B.H.P./Hr. = \frac{47.3}{74.0}$$

Mean effective pressure = .622 x 99.5

= 61.9 Lbs./Sq.In.

A.L.A.M. Rating

$$B.H.P. = \frac{3 \times 3 \times 12}{2.5}$$

= 43.2 at 1200 R.P.M.