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THESIS

ENGINE TEST AND STUDY OF THE VALVE ACTION
OF A WILLYS-KNIGHT MOTOR

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1918

Engine Test

and

Study of the Valve Action

of a

Willys-Knight Motor.

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by

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INTRODUCTION.

The double-sleeve type of valve for gasoline engines was invented by Charles Y. Knight in Chicago in 1903 and was patented in the United States in 1912. A test car was built in the Garford factory in Elyria, Ohio in 1905, and the motor was used in the cars manufactured by the Daimler Company in England in 1906. Altho it differed radically from all other valve forms that were used up to that time, it has been adopted and has remained in continued use by several automobile manufacturers both in Europe and in this country. While the Knight valve is, in effect, a hollow-piston valve type, it has distinguishing characteristics, in that it is made to surround the main engine piston instead of being located in a separate valve chest, and in that it is built in two separate cylindrical parts. By using two sleeves, necessary freedom in securing a desired timing of events is secured with the simple use of eccentrics instead of cams. A single sleeve may be used if a cam or other suitable mechanism is designed to operate it. Mr. Knight's first sleeve-valve patent, taken out in 1910, was for a single sleeve valve. Several single-sleeve valve engines are now being built both in this country and abroad.

PURPOSE AND EXTENT OF INVESTIGATION.

This analysis of the valve action and the engine test were undertaken in order to determine the advantages of this type of motor and to obtain a comparison with other types.

The motor was a stock four cylinder, four-cycle automobile motor manufactured by the Willys-Overland Co. and used in the Willys-Knight automobile, Model 88-4. It was a 4 1/8" by 4 1/2" motor with double sleeve valves.

This type of valve consists of two sleeves surrounding the engine piston which are moved vertically by connecting rods from a single eccentric shaft. This eccentric shaft is driven thru silent chain drive at half the crankshaft speed and is made with 70 degrees as an angle of advance between the eccentrics of the two sleeves of each cylinder. Ports are cut opposite to each other in each sleeve, one of which serves as an intake port and the other as an exhaust port. The positions and widths of these ports correspond to the determined best valve action. The valve action is obtained by the ports in the sleeves passing each other and the cylinder wall port at the desired time. The purpose of the study of the valve action is to become acquainted with the original methods of determining these positions and to check the results obtained from the theoretical design.

The engine test was necessarily reduced due to the fact that the maximum speed that the dynamometer could be driven was about 1400 r.p.m. This resulted in the curves being only partially drawn and deteriorated the extent of the comparison with other types of motors. The test was run to obtain curves between the Brake Horsepower and the Fuel Economy, and the R. P. M., and these were compared with those of motors with other types of valves. Tests were run with four carburetor settings to correspond approximately to 1/4, 1/2, 3/4, and maximum throttle opening at 1200 r.p.m. Tests were run with lower throttle settings but they are invaluable since they could be used at only two or three of the lower speeds. The time for the occurence of the spark was set at the point of maximum advance during all of the tests. Also the frictional horsepower could be obtained at but one point, 700 r.p.m., which was due to the fact that the dynamometer when used as a motor did not have a variable speed. This allowed the Mechanical Efficiency to be computed at but the one speed of the engine.

SPECIFICATIONS.

Name and Model	Willys-Knight, Model 88-4, #A11146.
Manufacturer	Willys-Overland Inc., Toledo, Ohio.
Number of cylinders	Four.
Bore and Stroke	4 1/8" -- 4 1/2".
Piston displacement	240 cubic inches.
Type of cylinder casting	Block casting, 3/8" offset.
Type of valve	Double sleeve.
Cooling system	Thermo syphon.
Pistons	Cast iron.
Piston rings	Two, eccentric type.
Connecting rod	Drop forged, 10" cc
Crankshaft bearings	Three, plain.
Valve timing	Inlet opens 8 degrees after upper dead center.
	Inlet closes 37 degrees after lower dead center.
	Exhaust opens 48 degrees before lower deadcenter.
	Exhaust closes 5 degrees after upper dead center.
Carburetor	Tillotson.
Heating	Air from exhaust stove.
Principle of operation	Single nozzle with steel spring air valve in inlet.

Ignition	Conneticut distributor and coil.
Firing order	1-3-4-2.
Type of breaker	Closed.
Spark plugs	Champion, 1/2" regular.
Location	Center of combustion chamber.
Oiling system	Splash-pressure, with plunger pump.

STUDY OF THE VALVE ACTION.

The valve action and the effect of various factors upon the valve timing can best be studied by means of timing and sealing diagrams. To construct these diagrams it is first necessary to construct a sinusoidal diagram for each sleeve.

To construct the sinusoidal diagrams, the eccentric radius and the connecting rod length must be known. This was obtained from blue prints loaned by the manufacturers. Twelve inches was laid off on the paper on which the diagram was to be made and this distance was divided into twenty-four equal parts. Ordinates were erected through these points. The eccentric circle was drawn and placed .4375 inch to the left of the first ordinate as the eccentric shaft or cam shaft is offset this amount from the connecting rod pins in the sleeves. This circle was divided into twenty-four parts and the corresponding positions of the connecting rod and the sleeve found. From these points lines were drawn to the corresponding ordinates and the sinusoidal curve drawn through these points. Each diagram for the two sleeves was constructed by the same method except that the different lengths of the connecting rods made it necessary to find the various positions of the sleeves and the connecting rods in each case.

The sinusoidal curve for each sleeve having been drawn a piece of tracing cloth was placed over the curve and the curve was traced through the tracing cloth and extended to each side. A duplicate of the curve for the outer sleeve was drawn at a distance on the tracing cloth equal to the port widths in the outer sleeve. The same was done with the inner sleeve except that due to the exhaust and intake ports being of different widths, a curve had to be constructed for each of these widths.

The following dimensions were obtained from the blue prints:

Cylinder intake port width -----------------	.500	inch.
Cylinder exhaust port width ----------------	.500	"
Inner sleeve intake port width -------------	.391	"
Inner sleeve exhaust port width ------------	.500	"
Outer sleeve intake port width -------------	.469	"
Outer sleeve exhaust port width ------------	.469	"
Bottom of cylinder head ring to the bottom of the cylinder ports ---------------	.375	"
The travel of each sleeve ------------------	.9055	"
Angle of advance between the sleeves -------	70	degrees.

On a separate sheet of paper, two parallel lines were drawn at a distance apart equal to the port width in the cylinder wall. A third parallel line was drawn representing the bottom edge of the cylinder head ring which acts as a sealing surface and an inside cut-off edge. On these lines a length was laid off equal to one wave length of the sinusoidal curves. This was divided into twenty-four parts in the same manner that the curve was divided. This total length represents two complete revolutions of the crankshaft or 720 degrees and each division would represent 30 degrees. The eccentric arms being set with 70 degrees between them, this 70 degrees is the angle of advance by which the inner eccentric preceeds the outer eccentric. However, on the diagrams this appears as 140 degrees, since the eccentric shaft runs at half the speed of the crankshaft.

This angle of advance being known, together with the distances from the centers of the connecting rod pins in each sleeve to the bottom of each port in each sleeve, the timing diagram can be drawn. By marking these positions on the chart as zero degrees and then placing the two tracings on each other and on the chart, the correct positions of the curves were found. When found, the tracing cloth was fastened and the points marked on the ordinates of the chart. The solid lines represent the positions of the inner sleeve ports and the dotted lines the outer sleeve ports. The cross-sectioned areas show the amount of port opening and the period of the intake and exhaust openings.

From the diagram it is seen that the exhaust begins to open when the lower edge of the port in the inner sleeve, moving downwards, passes the lower edge of the cylinder head ring. The exhaust closes when the top edge of the port in the outer sleeve, moving downwards, passes the lower edge of the port in the cylinder wall. The exhaust opening extends over 233 degrees of crank motion. The exhaust begins to open 48 degrees ahead of the lower dead center and closes 5 degrees past the top dead center.

The intake begins to open when the bottom edge of the port in the outer sleeve, moving downwards, passes the top edge of the port in the inner sleeve, moving in a downward direction. The intake closes when the bottom edge of the inner sleeve port, moving upwards, passes the bottom edge of the cylinder head ring. The intake is open over a period of 209 degrees of crank motion, begins to open 8 degrees after top dead center, and closed 37 degrees after lower dead center.

The timing points for the diagram are as follows:

Exhaust opens	132	degrees.
Exhaust closes	365	"
Intake opens	368	"
Intake closes	577	"

The sealing diagram was next to be constructed and is useful in showing the aggregate of the overlapping edges which tend to prevent leakage. The diagram is taken from the timing diagram above it. Any total ordinate included in the cross-sectioned area above the line shows the amount of sealing of the intake port at that crank position. At zero degrees, for example, when the explosion is about to take place, the bottom port edge of the inner sleeve is above the cylinder head ring by the amount that the sinusoidal of the inner sleeve

intake port is above the line representing the bottom edge of the cylinder head ring in the timing diagram. The same method is used in finding the amount of sealing at each of the other ordinates both for the intake and the exhaust sides. The exhaust seal, however, is shown below the line and it will be seen that the seal at zero degrees crank position is made up of three distinct lappings. First, the amount the lower port edge of the inner sleeve is above the top edge of the outer sleeve; and second, the amount the lower port edge of the inner sleeve is above the edge of the cylinder head ring. It will be noticed that the greatest seal occurs at 640 degrees of crank travel during compression, when there is a triple seal of the exhaust composed of the cylinder, sleeves and the cylinder head ring.

Another was drawn showing the relation between the intake and exhaust port openings and the rate of change of the piston displacement. Where the double sinusoidal curve crosses the horizontal line there is no change in the piston displacement, which would happen at upper and lower dead centers. The other curves give the amount of the valve openings and are the same as the port opening curves shown on the sealing lap diagram. They were obtained by transferring the ordinates of the exhaust and intake openings from the timing diagram.

The exhaust valve opening occurs 48 degrees before lower dead center, and has its maximum opening during the maximum rate of change in the piston displacement. The amount of opening of the intake valve and the rate of change in the piston displacement are approximately proportional, except that the intake closes 37 degrees after dead center or during a part of the intake stroke the piston is traveling in an upward direction.

ENGINE TEST.

The motor was run with a direct connected cradle dynamometer with a water rheostat to vary the load. Runs were made at 450, 700, 950 and 1200 r.p.m. for horsepower and fuel economy. The duration of the runs was the time required to consume five pounds of gasoline. The frictional horsepower tests were run through a period of five minutes. The dynamometer allowed only one frictional horsepower test to be run which was at 700 r.p.m.

The horsepower constant of the dynamometer was computed and found to be .0003163. The brake load readings were taken on platform scales every five minutes during the tests. The engine speed was kept constant and the load allowed to vary to obtain this constant speed. Approximate readings on the speed were taken from a tachometer and accurate readings were taken with a speed indicator from the eccentric shaft every five minutes. The load was varied by means of a water rheostat connected with the dynamometer.

The fuel consumption was measured by taking the time, with a stop watch, during the period in which the weight of the gasoline tank decreased five pounds. From this time the number of pounds of fuel used per hour can easidy be obtained. The fuel used in pounds per Brake Horsepower per hour can be computed by dividing the number of pounds of fuel used per hour in any test by the Brake Horsepower during that test. The time was taken when a pointer on the scale beam passed a line on the frame of the scales.

The temperature of the air entering the carburetor was taken every five minutes with a 400 degree straight stem thermometer. The temperature of the water was taken at the inlet to the cylinders and at the outlet with thermometers placed in oil wells in the water pipes. The outlet temperature was kept as near as possible to 150 degrees Fahrenheit. The fan was removed during all the tests.

The frictional horsepower was measured by using the dynamometer as a motor, which made it necessary to measure the torque on the opposite side of the dynamometer. These tests were run immediately after the horsepower tests and the motor was unchanged, except for shutting off the water to prevent cooling.

RULES OF TESTING.

Society of Automotive Engineers

Transactions XII, Part I.

During the complete test, control of the engine shall be by means of throttle and spark only. Engine adjustments shall be made for best horsepower output (that is, carburetor setting, spark plug gaps, etc.,) and in no case are such adjustments to be changed during the complete test. Test runs should not be made until the engine has been run-in sufficiently to show no appreciable difference in friction before and after a run of 30 minutes at the speed of maximum torque with the throttle wide open. Before beginning any run, the engine should be brought to a condition of sustained operation under the conditions of the run and it is imperative that in every case the r.p.m., brake loads, rate of fuel consumption, cooling-water temperatures, oil temperature, etc., remain substantially constant, steady and sustained throughout the run.

In every test, enough runs should be taken throughout the speed range so that the points therefrom when plotted will indicate clearly the shape and characteristics of the curves. For horsepower and fuel economy tests, it is recommended that runs be made at intervals of approximately 200 r.p.m. A run should be made at the lowest steady operating speed of the engine. The duration of Brake-horsepower tests shall not be less than three minutes. Where

fuel consumption is measured, the duration of the tests shall not be less than five minutes. The duration of the frictional horsepower tests shall not be less than one minute. The above stated times are the minima. In most cases it is desirable to make the runs of longer duration, and it is imperative that in every case r.p.m., brake loads, etc., remain substantially constant and steady throughout the run.

Readings for Brake Loads should be taken with accurately calibrated platform or beam scales. During any run, the platform or beam scales are kept balanced, and the loads registered thereby must be substantially constant throughout the run.

Speed in revolutions per minute should be invariably taken from positively driven counters which engage at the beginning of the run and disengage at the end. The difference between the two readings, divided by the duration of the run in minutes, then gives the true average speed. Tachometers, even though carefully calibrated, are not sufficiently reliable for r.p.m. readings. In connection with the speed counters mentioned, however, the tachometer may be used as an approximate check on the average speed, also as an indication of variation in speed before or during the run. It is recommended that the maximum allowable variation is speed during a run be 50 r.p.m.

The method recommended for measuring fuel consumption is by noting the decrease in weight of a tank from

which the fuel is being fed to the carburetor. The tank should be placed on sensitive platform scales at a proper level above the carburetor, and connected to the fuel supply pipe by s short horizontal length of rubber tubing. This tubing should be very flexible and should not be drawn taut, to avoid interference with the weighing. Weighings should be made as follows: Set the counterpoise so that the scale beam will fall just as the run is started. Note the setting and the time at which the beams fall. Move the counterpoise to some point such that it will fall just before the end of the run, and note carefully the time it falls again. From the difference between the two times and the two weights recorded, the fuel consumption per hour can easily be determined.

All temperatures are to be given in degrees Fahrenheit. A reliable glass straight-stem thermometer should be placed near the carburetor intake in order to measure the temperature of the entering air. This thermometer should be read at least three times during each run. Thermometers should be placed also in suitable wells or sockets, one near the inlet and another as close as possible to the water outlet of the engine. These wells or sockets should be in pipes that run full, so that water continually circulates about them. They should be filled with oil or mercury, and careful readings should be taken atleast three times during each run. It is recommended that the maximum allowable temperature change shall be ten

degrees Fahrenheit. During the frictional horsepower runs, the test must be made immediately after the corresponding brake-horsepower test, before the engine has cooled, the water should be shut off.

The approximate frictional horsepower of an engine can be measured best by means of an electric dynamometer, preferably of the cradle type. The dynamometer is used to drive the engine usder the test at various speeds, and the torque reaction is measured. This will be in the opposite direction to that obtained while the engine is driving the dynamometer, or else suitable linkage must be provided to change the direction of the pull. The test for frictional horsepower should be made immediately after the brake horsepower test, before the engine has cooled, in order to keep the condition of the lubricating oil and the friction of the parts the same during this test as during the brake horsepower test. Compression-relief cocks should remain closed and all accessories, such as magneto, generator, pumps, etc., used during the brake horsepower test, should remain in operation.

Approximate indicated-horsepower is obtained by adding to the brake horsepower at any given speed the frictional horsepower obtained at the same speed.

LOG SHEETS OF ENGINE TEST.

1st Carburetor Setting.

Tacho-meter	Speed Indic ator	Diff-erence	True RPM.	Brake Load	Temperatures Water In	Out	Carb. Air	Time
	9886							
150	107	221	442	62.0	56	140	161	
150	557x	225	450	62.0	56	142	161	
150	782	225	450	62.0	56	142	161	
150	1009	227	454	62.0	56	142	161	
150	1235	226	452	62.0	56	143	162	
150	1467	232	464	62.0	56	150	162	
150	1697	224	448	62.0	56	158	162	35.55
		x-----	332					
	9628							
235	9950	322	644	56.0	60	144	168	
240	497x	357	714	56.0	60	132	168	
238	848	351	702	56.0	60	150	168	
238	1197	349	698	56.0	60	160	168	
238	1905	354	708	56.0	60	146	168	23.05
		x-----	140					
	3466							
320	3932	466	932	35.5	56	143	148	
318	4401	469	938	35.5	57	160	150	
318	4870	469	938	35.5	57	142	150	
318	5341	471	942	35.5	57	128	150	
320	5812	471	942	35.5	57	128	150	23.43
	1814							
400	2403	589	1178	35.5	58	142	176	
400	4172x	591	1182	35.5	58	145	184	
400	4766	594	1188	35.5	58	143	185	
400	5364	598	1196	35.5	58	147	186	
400	5962	598	1196	35.5	58	148	186	21.58

2nd Carburetor Setting.

Tacho-meter	Speed Indicator	Difference	True RPM.	Brake Load	Temperatures Water In	Out	Carb. Air	Time
	1691							
150	1912	221	442	69.0	56	138	160	
150	2136	224	448	69.0	56	156	160	
150	2356	220	440	69.0	56	160	160	
150	2798	221	442	69.0	56	158	158	
150	3019	221	442	69.0	56	155	158	
150	3240	321	442	69.0	56	160	160	
150	3464	224	448	69.0	56	144	160	33.65
	1905							
233	2237	332	664	67.0	60	168	170	
235	2579	342	684	71.5	60	146	176	
232	2920	341	682	68.0	60	148	176	13.40

Only three pounds of gasoline used in this test.

Tacho-meter	Speed Indicator	Difference	True RPM.	Brake Load	Temperatures Water In	Out	Carb. Air	Time
	5812							
320	6275	463	926	49.5	57	140	145	
320	6749	474	948	49.5	57	142	148	
320	7223	474	948	49.5	57	142	148	
320	7697	474	948	49.5	57	142	148	
320.	8172	475	950	49.5	57	142	148	21.96
	5972							
400	6534	572	1164	50.5	58	148	186	
403	7128	594	1188	50.5	58	147	186	
405	7724	596	1192	50.0	58	148	184	
405	8325	601	1202	50.0	58	148	184	17.77

3rd Carburetor Setting.

Tacho-meter	Speed Indic ator	Diff-erence	True RPM.	Brake Load	Temperatures Water In	Out	Carb. Air	Time
	6432							
150	6651	219	438	74.0	56	150	152	
150	6871	220	440	74.0	56	146	150	
150	7096	225	450	74.0	56	144	150	
150	7317	221	442	74.0	56	144	150	
150	7542	225	450	74.0	56	144	150	
150	7765	223	446	74.0	56	144	152	
150	7985	220	440	74.0	56	146	148	32.62
	4666							
238	5014	348	696	80.0	62	161	166	
239	5356	342	684	80.5	62	154	168	
238	5698	342	684	80.0	63	148	167	
241	6045	347	694	80.0	63	156	166	18.76
	8172							
318	8639	467	934	78.5	56	155	144	
320	9112	473	946	78.5	57	160	166	
321	9587	475	950	78.5	57	146	168	
323	64	477	954	78.5	57	154	170	16.10
	8325							
405	8922	597	1194	75.5	58	149	180	
405	9522	600	1200	75.5	58	148	180	
405	120	598	1196	75.5	58	152	180	
405	716	594	1188	75.5	58	148	180	15.15

4th Carburetor Setting.

Tacho-meter	Speed Indicator	Diff-erence	True RPM.	Brake Load	Temperature Water In	Temperature Water Out	Temperature Carb. Air	Time
	6762							
160	6997	235	470	78.5	57	110	160	
155	7226	229	458	80.0	57	116	160	
155	7459	233	466	82.0	57	123	156	
160	7690	241	482	82.0	57	123	154	
155	7920	230	460	80.0	57	133	154	
155	8159	239	478	80.0	57	136	154	26.47
	6045							
238	6386	341	682	80.0	62	140	164	
237	6729	343	686	80.5	63	146	164	
236	7069	340	680	81.0	63	150	164	
236	7409	340	680	81.5	63	151	165	18.53
	49							
320	523	474	948	85.0	57	150	154	
324	998	475	950	85.0	57	152	144	
320	1469	471	942	85.0	57	149	163	
320	1939	470	940	85.0	57	148	164	
320	2109	470	940	85.0	57	148	165	[illegible].01
	716							
408	1316	600	1200	83.0	58	150	182	
408	1910	594	1188	83.0	58	142	170	
400	2498	588	1176	83.0	58	156	190	[illegible].35

Frictional Horsepower.

Tacho-meter	Speed Indicator	Diff-erence	True RPM.	Brake Load	Temperature Water In	Temperature Water Out	Temperature Carb. Air	Time
	6080							
[illegible]	6426	346	692	17.0		OFF		
	6455							
[illegible]	6805	350	700	17.5		OFF		

RESULTS.

Load	Torque	R.P.M.	B.H.P.	Fuel Consumption lb./hr.	[illegible] /B.H.P./hr.	[illegible]

1st Carburettor Setting.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	77.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	87.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2nd Carburettor Setting.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

3rd Carburettor Setting.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

4th Carburettor Setting.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1[illegible].0	[illegible]	[illegible]	[illegible]	[illegible]

[illegible] 700 [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].9

SUMMARY.

From the sealing lap diagram constructed in connection with the study of the valve action, it is seen that during compression, explosion, and most of the explosion stroke that the seal of the intake port is composed of a single lap only, which is the distance that the bottom edge of the inner sleeve intake port is above the lower edge of the cylinder head ring, which at its maximum is only 3/8 inch. It seems doubtful if this would serve as a sufficient retainer for the compression of the gases.

From the results obtained from the engine test, the gasoline used in Pounds per Brake Horsepower per Hour seems to be high for this size and type of engine. The lowest result obtained at maximum horsepower output was found to be .779 #/BHP/Hr. as compared to .61 of a 4 x 6" Moline Knight motor, .62 of a 3 3/4 x 5 1/8" White motor, and .77 of a 4 3/4 x 5 1/2" six cylinder Alco motor. From the curve sheet for maximum horsepower output the following facts can be noted from the curves: The horsepower curve increases at approximately the same rate from 450 to 1200 r.p.m. and would undoubtedly increase more with the speed; the torque curve increases slowly until the speed reaches 900 to 1000 r.p.m. at which point it starts to decrease slowly; the rate of fuel consumption in #/BHP/Hr. decreases slowly from the speeds of 450 to 1200;

and the thermal efficiency curve reaches its maximum at approximately 950 r.p.m.

A curve sheet is inserted with horsepower, torque, and the fuel consumption plotted to the r.p.m. as abcissae for a six cylinder Alco motor manufactured by the American Locomotive Co., Providence, R.I., which is 4 3/4" x 5 1/2", T-head type with a high tension magneto, and spark plugs placed over the inlet valves; a four cylinder White motor, 1913, which was L-head type with spark plugs placed over the inlet valves, size 3 3/4" x 5 1/8" and used a magneto for ignition; a four cylinder Moline-Knight motor of a size 4" x 6"; and this Willys-Knight motor which has the cylinder dimensions of 4 1/8" x 4 1/2". There is no important difference in the curves except that of position and that the larger Alco motor of the T-head type has its fuel economy curve increasing more rapidly and its torque curve decreasing more rapidly as the speed increases near the maximum speed.

ACKNOWLEDGMENTS AND TECHNICAL REFERENCES.

In our endeavors in this work, we are indebted to Prof. J. A. Polson for his advice and assistance; to "Valves and Valve Gears", Vol. II, Furnam, for the general construction and the study of the valve action; to Transactions XII, Part I, of the Society of Automotive Engineers, Inc., for rules and methods of testing; and to the "Gasoline Automobile", Heldt, for the history of the Knight motor.

REFERENCE FOR ENGINE DRAWING.

A --- Cylinder head.

B --- Cylinder head packing rings.

C --- Inner sleeve exhaust port.

D --- Cylinder exhaust port.

E --- Outer sleeve exhaust port.

F --- Piston rings.

G --- Cylinder and water jacket walls.

H --- Cooling water space.

I --- Outer sleeve connecting rod pin.

J --- Inner sleeve connecting rod pin.

K --- Eccentric shaft.

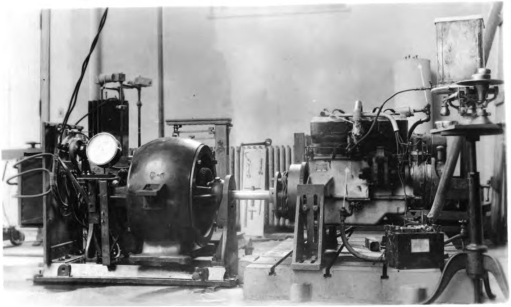
L --- Crankshaft.

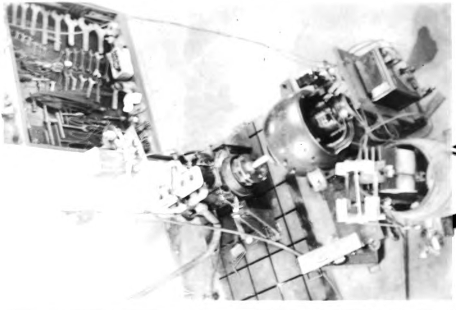
M --- Inner sleeve intake port.

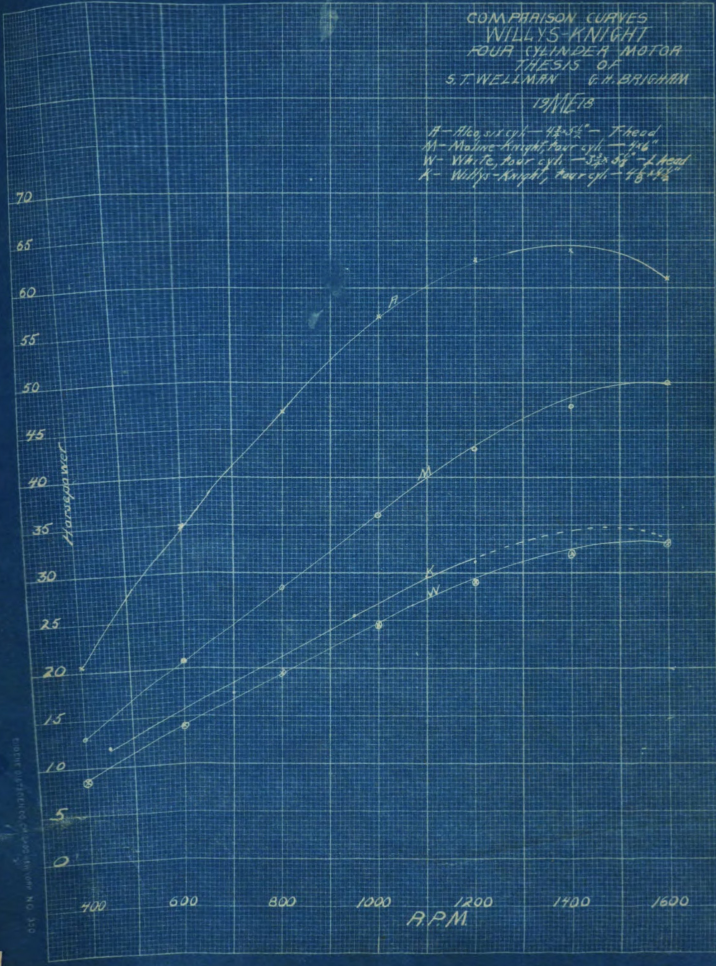
N --- Outer sleeve intake port.

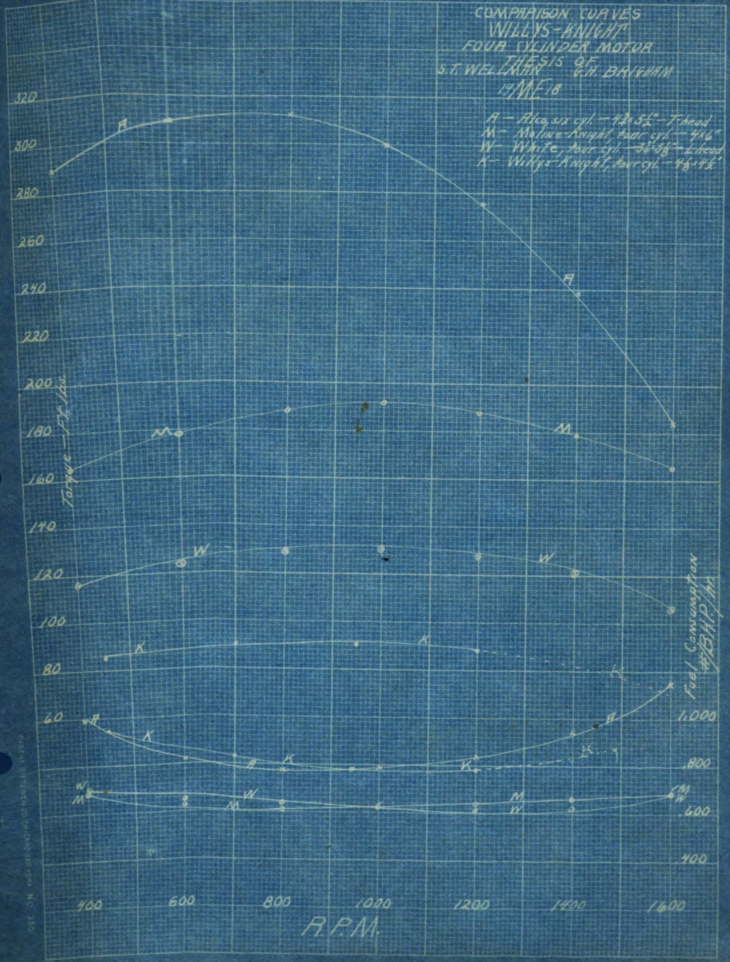
O --- Cylinder intake port.

P --- Piston pin.






COMPARISON CURVES
WILLYS-KNIGHT
FOUR CYLINDER MOTOR
THESIS OF
S.T. WELLMAN G.H. BRIGHAM
19 ME 18
A – Alco, six cyl. – 4¼ × 5½" – T head
M – Moline-Knight, four cyl. – 4×6"
W – White, four cyl. – 3¾ × 5⅛" – L head
K – Willys-Knight, four cyl. – 4⅛ × 4½"
Horsepower
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
400
600
800
1000
1200
1400
1600
R.P.M.
A
M
K
W


COMPARISON CURVES
WILLYS-KNIGHT
FOUR CYLINDER MOTOR
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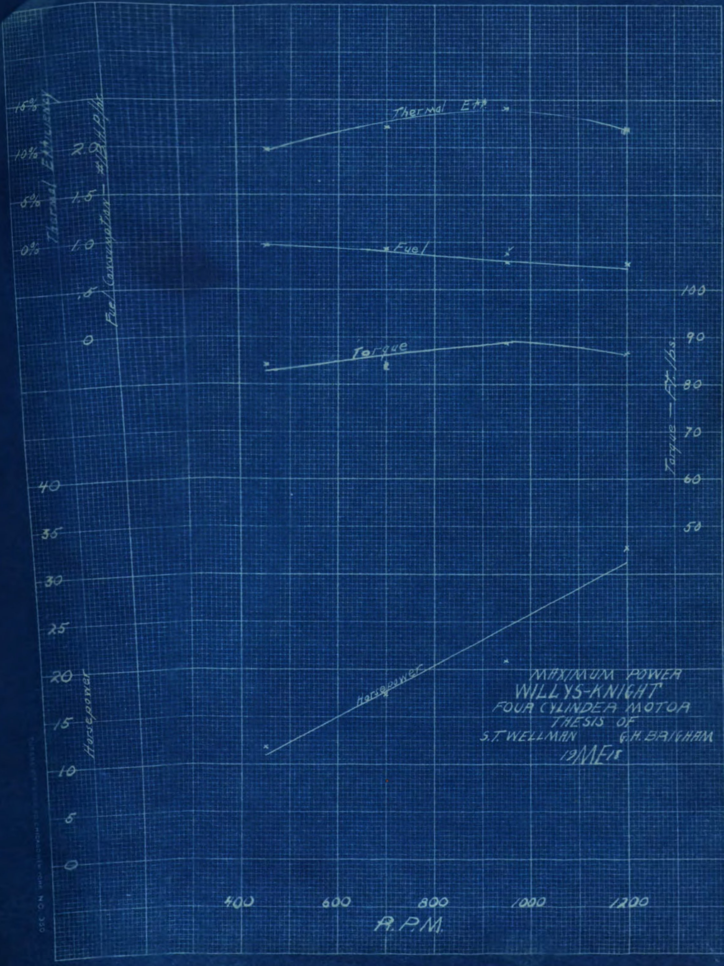
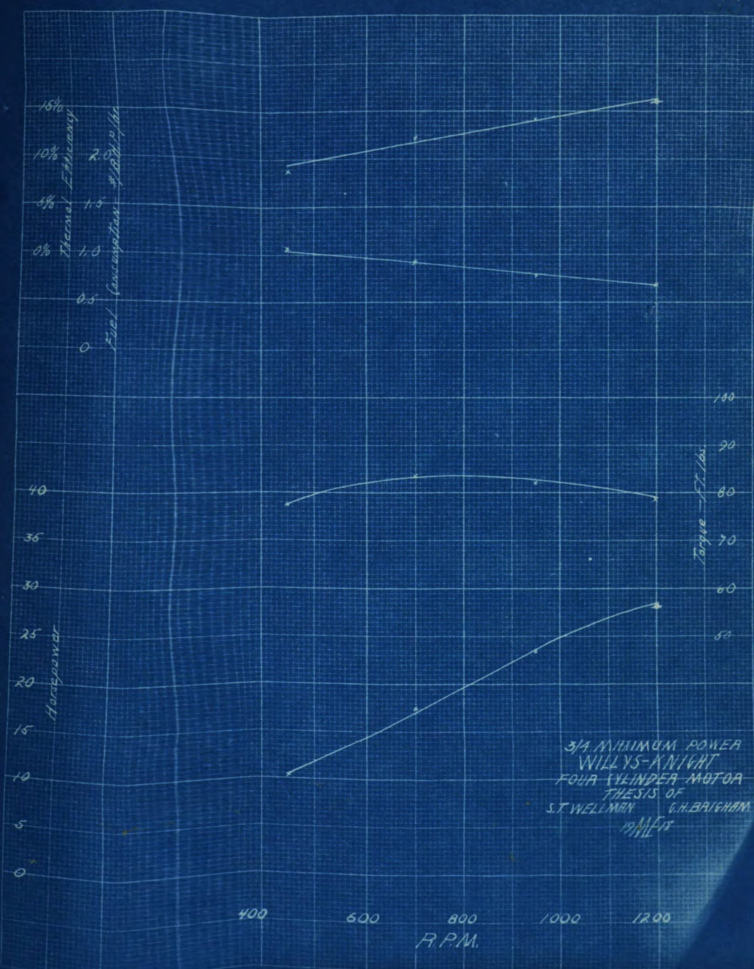
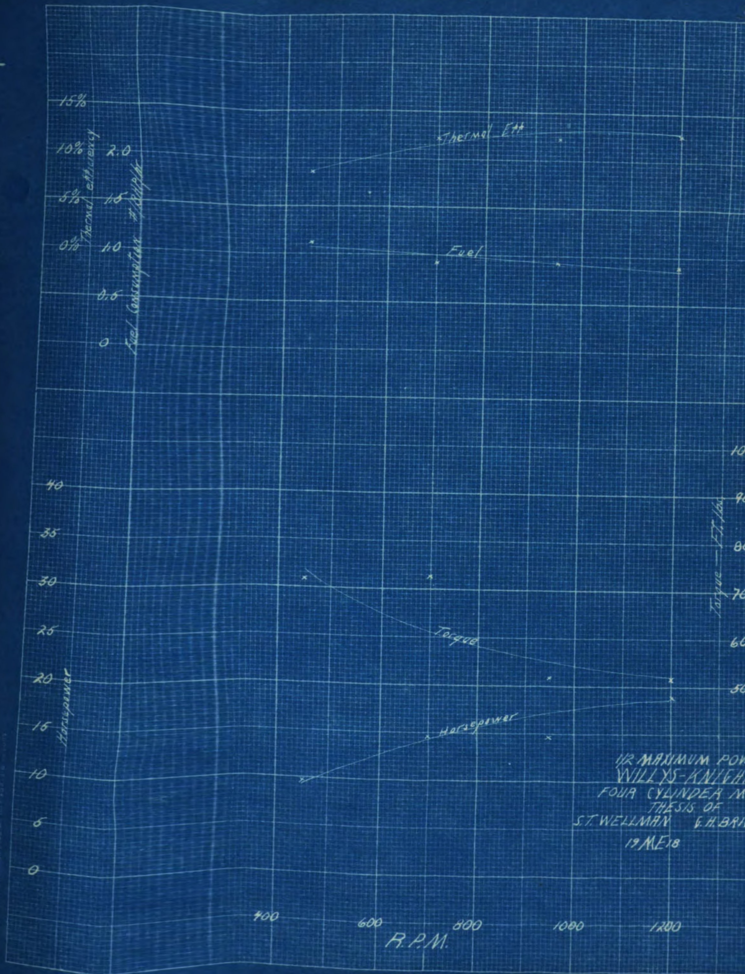
W – White, four cyl. – 3¾x5⅛" – L-head
K – Willys-Knight, four cyl. – 4⅛x4½"
Torque – Ft. lbs.
Fuel Consumption #/BHP./hr.
R.P.M.
320
300
280
260
240
220
200
180
160
140
120
100
80
60
1.000
.800
.600
.400
400
600
800
1000
1200
1400
1600

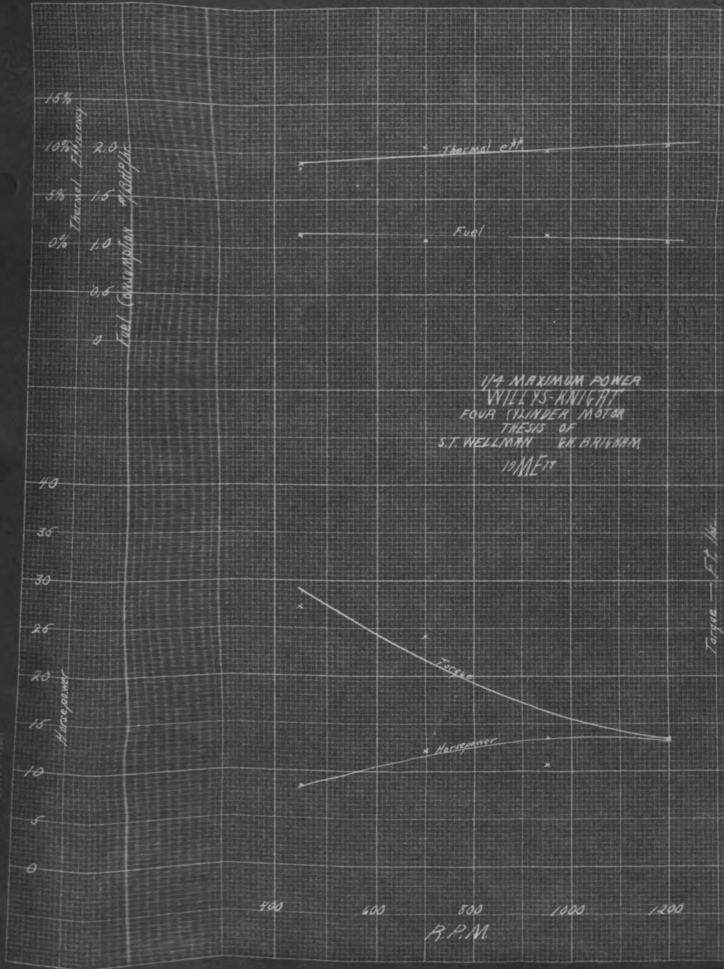

MAXIMUM POWER
WILLYS-KNIGHT
FOUR CYLINDER MOTOR
THESIS OF
S.T. WELLMAN G.H. BRIGHAM
19 ME 18
Thermal Eff.
Fuel
Torque
Horsepower
Thermal Efficiency
15%
10%
5%
0%
Fuel Consumption — #/B.H.P./hr.
2.0
1.5
1.0
.5
0
Torque — Ft. lbs.
100
90
80
70
60
50
Horsepower
40
35
30
25
20
15
10
5
0
400
600
800
1000
1200
R.P.M.



15%
10%
5%
0%
Thermal Efficiency
2.0
1.5
1.0
0.5
0
Fuel Consumption
40
35
30
25
20
15
10
5
0
Horsepower
100
90
80
70
60
50
Torque - FT. lbs.
400
600
800
1000
1200
R.P.M.
3/4 MAXIMUM POWER
WILLYS-KNIGHT
FOUR CYLINDER MOTOR
THESIS OF
S.T. WELLMAN
G.H. BRIGHAM
19 ME 17



15%
10%
5%
0%
Thermal efficiency
2.0
1.0
0
Fuel Consumption #/BHP hr
Thermal Eff
Fuel
40
35
30
25
20
15
10
0
Horsepower
Torque
Torque — Ft. lbs.
400
600
800
1000
1200
R.P.M.
THESIS OF
S.T. WELLMAN
19 M.E. 18


1/4 MAXIMUM POWER
WILLYS-KNIGHT
FOUR CYLINDER MOTOR
THESIS OF
S.T. WELLMAN G.H. BRIGHAM
19 ME 17
Thermal eff
Fuel
Torque
Horsepower
15%
10%
5%
0%
Thermal Efficiency
2.0
1.5
1.0
0.6
0
Fuel Consumption #/BHP/hr
40
35
30
25
20
15
10
5
0
Horsepower
Torque — Ft. lbs.
400
600
800
1000
1200
R.P.M.