

A STUDY OF THE EFFECTS OF MALADJUSTMENTS  
ON THE PERFORMANCE OF AN I.C. ENGINE

A THESIS

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by  
Ernest Elsevier  
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approved*

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Date Approved by Chairman *Sept 1, 1950*

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## TABLE OF CONTENTS

	PAGE
Acknowledgments	iii
List of Tables	v
List of Figures	vi
List of Abbreviations	vii
Introduction	1
Purpose	1
Objectives	2
Equipment	4
Procedure	6
Discussion	9
Conclusion	9
Bibliography	20
Appendix I	21
Appendix II	22

## LIST OF TABLES

TABLE		PAGE
I	Performance Data of the Engine Spark Plug Gap .010 inches	11
II	Performance Data of the Engine Spark Plug Gap .020 inches	12
III	Performance Data of the Engine Spark Plug Gap .030 inches	13
IV	Performance Data of the Engine Spark Plug Gap .040 inches	14
V	Performance Data of the Engine Spark Plug Gap .050 inches	15
VI	Performance Data of the Engine Spark Plug Gap .060 inches	16
VII	Results of the Performance of the Engine B.H.P. and Thermal Efficiency For Table I and Table II	17
VIII	Results of the Performance of the Engine B.H.P. and Thermal Efficiency For Table III and Table IV	18
IX	Results of the Performance of the Engine B.H.P. and Thermal Efficiency For Table V and Table VI	19

## LIST OF FIGURES

FIGURE		PAGE
1	Photograph of the Fisher Gas Analyzer	23
2	Photograph of the Control Panel, Taylor Dynamometer, Fairbanks Scales, and the Direct Reading Potentiometer	24
3	Photograph of the thermocouple leads, variable carburetor, and spark advance control	25
4	Graph of sparking voltage required to jump a given spark plug gap	26
5	Graph of the thermal efficiency for a given spark advance at 5 in. Hg vacuum	27
6	Graph of the thermal efficiency for a given spark advance at 10 in. Hg vacuum	28
7	Graph of the thermal efficiency for a given spark advance at 15 in. Hg vacuum	29
8	Graph of the thermal efficiency for a given spark plug gap at 5 in. Hg vacuum	30
9	Graph of the thermal efficiency for a given spark plug gap at 10 in. Hg vacuum	31
10	Graph of the thermal efficiency for a given spark plug gap at 15 in. Hg vacuum	32

## LIST OF ABBREVIATIONS

1.	$\text{CO}_2$	Carbon Dioxide
2.	$\text{O}_2$	Oxygen
3.	$\text{CO}$	Carbon Monoxide
4.	$\text{KOH}$	Potassium Hydroxide
5.	$\text{HCL}$	Hydrochloric Acid
6.	$\text{CuCl}_2$	Cuprous Chloride
7.	$\text{Hg}$	Mercury
8.	R.P.M.	Revolutions Per Minute
9.	B.H.P.	Brake Horse Power
10.	c.c.	Cubic Centimeter
11.	lbs.	Pounds
12.	in.	Inches
13.	min.	Minutes

A STUDY OF THE EFFECTS OF MALADJUSTMENT  
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INTRODUCTION

Purpose

Current internal combustion engines are characterized by their higher operating speeds and wider speed range, higher compression ratios, higher specific outputs, and greater economy.

From the spark plug point of view this resolves itself into operation over wider ranges of speed, pressures, and temperatures, and in leaner or less easily ignitable mixtures.

Furthermore, the addition of detonation inhibitors to the fuel, notably tetraethyl lead, has greatly influenced spark plug behavior.<sup>1</sup>

Two of the more easily met requirements of the spark plug are: the conduction of high tension current into the combustion chamber, and the furnishing of a suitable pair of electrodes between which the voltage

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<sup>1</sup> Bychinsky, W.A., "Factors Affecting Functioning of Spark Plugs", S.A.E. Quarterly Transactions, Vol. 2, No. 2, 1948, page 180-189.

can spark. These requirements are considered simple and easily met.

There are many things that a spark plug must not do. It must not cause an extra heavy load on the ignition system. The gap should not change or wear, the required sparking voltage should not vary, and it must not be located in the engine where the initial ignition is undesired. It must not run at too high a temperature, thereby causing preignition.

The electrical needs of the engine are not, by any means, constant in value. We are required to furnish a voltage sufficient to jump the gap of the plug. The amount of voltage required, is a function of gap size.<sup>2</sup>

In presenting the following thesis, the author will show that if a spark is obtained across the gap of a spark plug of .020 inch, the mixture will be ignited satisfactorily and even if the spark plug gap is opened to .060 inch, it will have little or no influence on the burning after the mixture has been ignited.

### Objectives

The objectives selected for this thesis were as follows:

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<sup>1</sup> Bychinsky, W.A., "Factors Affecting Functioning of Spark Plugs", page 180-189.

1. To redesign the distributor whereby the spark advance would have a positive control.

2. To install a carburetor whereby the air-fuel ratio could be controlled.

3. To study the effects on the performance as spark plug gaps were opened and the distributor spark advanced.

## EQUIPMENT

The engine used for this thesis was a four cylinder Continental Red Seal Engine, whose bore was  $2\frac{1}{2}$  in. and whose stroke was 3 in. The compression ratio was 6.2-1, and the S.A.E. rated horsepower was 10.0.<sup>3</sup>

The engine was connected to a Taylor Dynamometer with an automotive type universal joint.<sup>4</sup>

The dynamometer constant was 6000. The dynamometer was connected to a Fairbanks scale so the load applied to the dynamometer could be measured.<sup>5</sup>

The fuel for the engine was weighed on a Toledo scale. The scale could be read to one hundredth of a pound.

A control panel was installed which contained an intake manifold manometer, an exhaust manometer, a tachometer, a direct reading manifold pressure gage, and engine oil pressure gage, a throttle, a switch, a starter button, and a temperature selector switch.<sup>6</sup>

An aircraft type tachometer generator was installed

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<sup>3</sup> Figure 3, Page 25.

<sup>4</sup> Figure 2, Page 24.

<sup>5</sup> Figure 2, Page 24.

<sup>6</sup> Figure 2, Page 24.

on the shaft end of the Taylor Dynamometer.'

The distributor which came installed on the engine was taken apart and the fly weights were locked in the closed position, a plate marked in degrees was then installed and an indicator was so set whereby the advancing or retarding of the distributor, in degrees, could be accurately controlled. This engine was not equipped with vacuum advance.

Thermocouples were installed in the water jacket and in the exhaust system, whereby the operating temperatures could be checked with a direct reading potentiometer.

Figure 2, Page 2<sup>1\*</sup>.

8 Figure 2, Page 2*h*.

<sup>1</sup> Figure 3, Page 2?<sup>?</sup>.

## PROCEDURE

The degree of distributor advance desired was set on the engine and the spark plug gap was opened to its desired size. The engine tachometer was checked and calibrated with a strobotac.

The engine was given ample time to reach its required operating temperatures, the required R.P.M. and manifold pressure were then set to their desired values. Before any data were taken, from the dynamometer, to determine the horsepower, the air-fuel ratio was first determined by analyzing the exhaust gas.

The exhaust gas was analyzed in a Fisher Gas Analyzer, Unitized, Technical Universal Model, of the Orsat type.<sup>10</sup> The procedure consists of first confining a measured (100 c.c.) quantity of the exhaust gas in a graduated tube called the burett and then passing the gas into vessels called pipettes containing different chemical solutions wherein the various components are successively absorbed. After the exhaust gas is bubbled through each pipette it is returned to the burette and the volume measured. The decrease in volume is determined and the percentage of the particular component present in the exhaust gas calculated.

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<sup>10</sup> Figure 1, Page 23.

The Orsat analysis of the exhaust gases absorbs three distinct gases in the following order,  $\text{CO}_2$ ,  $\text{O}_2$ , and  $\text{CO}$ . The  $\text{CO}_2$  was absorbed in the first pipette containing a twenty-five percent solution of potassium hydroxide. The  $\text{O}_2$  was absorbed in a solution of pyrogallic acid made by dissolving fifteen grams of resublimated pyrogallic acid in 150 c.c. of twenty-five percent solution of the potassium hydroxide. The  $\text{CO}$ , if present in the gas, was determined by absorption in acid cuprous chloride made by saturating  $\text{HCL}$  with  $\text{CuCl}_2$ , and reduced with copper wire.

A sampling bulb unit was used for the transference of the exhaust sample to the precision gas analysis assembly. The sampling bulbs were attached to each exhaust port on the engine.

A supply of fresh chemicals was available at all times and the aspirator was in continuous operation during the duration of the run, insuring accurate results. Chemicals were replaced according to instructions given by the manufacturer. Care was taken to see that the water used in the burette was saturated with a salt solution to prevent absorption of the gas in the water.

If, Volume of sample	= A
Volume after ( $\text{CO}_2$ ) absorption	= B
Contraction (A-B)	= C

then  $\% \text{CO}_2 = (C \times 100) \div A$

and, Volume after  $\text{O}_2$  absorption = D

Contraction (B-D) = E

then,  $\% \text{O}_2 = (E \times 100) \div A$

and, Volume after CO absorption = F

Contraction (D-F) = G

then,  $\% \text{CO} = (G \times 100) \div A$

and,  $\% \text{N}_2 = A - (\% \text{CO}_2 + \% \text{O}_2 + \% \text{CO})$

The air-fuel ratio was kept constant for all the runs.

After the carburetor was readjusted and the air-fuel ratio checked again, the fuel consumption was then recorded for a ten minute run and the load on the dynamometer scale was recorded.

Calculations were then made for the B.H.P. and the thermal efficiency.

## DISCUSSION

The fuel consumption was the same for the same manifold vacuum but the load and the efficiencies varied.

The efficiencies were plotted against the spark plug gap opening and the degree of spark advance.

Where the thermal efficiencies were plotted against the spark plug gap, it was shown that for 5 in. Hg vacuum, the optimum spark advance was 10 degrees advanced, and for 10 in. Hg vacuum, the optimum spark advance was 20 degrees advanced, and for 15 in. Hg vacuum, the optimum spark advance was 20 degrees, although the 30 degrees advanced was only .03 percent less for 15 Hg in. vacuum.<sup>11</sup>

Where the thermal efficiencies were plotted against the spark advance, it was shown that for 5 in Hg vacuum, that the maximum efficiencies were reached at a little less than 10 degrees spark advance for all the spark plug gap openings, and for 10 in. Hg vacuum, the maximum efficiencies occurred at 18 degrees spark advance, and for 15 in Hg vacuum the maximum efficiencies occurred at 20 degrees spark advance.

Conclusion

It has been shown that if a good spark is obtained across a gap of .020 or greater, the mixture will be

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<sup>11</sup> Figure 10, Page 32.

ignited satisfactorily and the gap size will have little or no effect on the efficiency.<sup>12</sup>

From the preceding statement it may seem that we should set all spark plugs at the highest settings, but to do so would increase the sparking voltage requirement. The higher sparking voltage would decrease the amount of fouling that could be tolerated without engine miss.

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<sup>12</sup> Figure 7, Page 29.

TABLE I

## Performance Data of the Engine

Run No.	Dynamo-meter Load, lbs.	Spark Plug Gap, in.	Spark Advance degrees	Intake Vacuum Hg, in.	Air-Fuel Ratio	R.P.M.	Fuel Cons. 10 min. lbs.
1	32.50	.010	10	5	14.9	1500	0.97
2	32.00	.010	20	5	14.9	1500	0.98
3	29.50	.010	30	5	14.9	1500	0.97
4	26.50	.010	40	5	14.9	1500	0.97
5	20.80	.010	10	10	14.9	1500	0.76
6	21.00	.010	20	10	14.9	1500	0.77
7	20.30	.010	30	10	14.9	1500	0.77
8	18.20	.010	40	10	14.9	1500	0.76
9	8.80	.010	10	15	14.9	1500	0.55
10	9.00	.010	20	15	14.9	1500	0.55
11	8.50	.010	30	15	14.9	1500	0.56
12	5.00	.010	40	15	14.9	1500	0.55

TABLE II

## Performance Data of the Engine

Run No.	Dynamo- meter Load, lbs.	Spark Plug Gap, in.	Spark Advance degrees	Intake Vacuum Hg, in.	Air- Fuel Ratio	R.P.M.	Fuel Cons. 10 min. lbs.
13	34.20	.020	10	5	14.9	1500	0.99
14	32.80	.020	20	5	14.9	1500	0.93
15	29.90	.020	30	5	14.9	1500	0.98
16	26.10	.020	40	5	14.9	1500	0.98
17	20.70	.020	10	10	14.9	1500	0.76
18	20.90	.020	20	10	14.9	1500	0.76
19	20.20	.020	30	10	14.9	1500	0.76
20	18.00	.020	40	10	14.9	1500	0.76
21	9.30	.020	10	15	14.9	1500	0.54
22	10.00	.020	20	15	14.9	1500	0.54
23	10.00	.020	30	15	14.9	1500	0.54
24	8.40	.020	40	15	14.9	1500	0.54

TABLE III

## Performance Data of the Engine

Run No.	Dynamo-meter Load, lbs.	Spark Plug Gap, in.	Spark Advance degrees	Intake Vacuum Hg, in.	Air-Fuel Ratio	R.P.M.	Fuel Cons. 10 min. lbs.
25	34.20	.030	10	5	14.9	1500	0.98
26	33.10	.030	20	5	14.9	1500	0.98
27	30.40	.030	30	5	14.9	1500	0.98
28	26.70	.030	40	5	14.9	1500	0.97
29	20.90	.030	10	10	14.9	1500	0.77
30	20.50	.030	20	10	14.9	1500	0.76
31	20.40	.030	30	10	14.9	1500	0.77
32	17.60	.030	40	10	14.9	1500	0.76
33	9.36	.030	10	15	14.9	1500	0.55
34	10.00	.030	20	15	14.9	1500	0.54
35	10.00	.030	30	15	14.9	1500	0.55
36	9.00	.030	40	15	14.9	1500	0.56

TABLE IV

## Performance Data of the Engine

Run No.	Dynamo-meter Load, lbs.	Spark Plug Gap, in.	Spark Advance degrees	Intake Vacuum Hg, in.	Air-Fuel Ratio	R.P.M.	Fuel Cons. 10 min. lbs.
37	34.00	.040	10	5	14.9	1500	0.97
38	33.00	.040	20	5	14.9	1500	0.97
39	30.00	.040	30	5	14.9	1500	0.97
40	27.10	.040	40	5	14.9	1500	0.97
41	20.90	.040	10	10	14.9	1500	0.76
42	21.40	.040	20	10	14.9	1500	0.76
43	20.60	.040	30	10	14.9	1500	0.76
44	18.00	.040	40	10	14.9	1500	0.75
45	9.80	.040	10	15	14.9	1500	0.53
46	10.20	.040	20	15	14.9	1500	0.52
47	10.00	.040	30	15	14.9	1500	0.53
48	8.50	.040	40	15	14.9	1500	0.52

TABLE V

## Performance Data of the Engine

Run No.	Dynamo-meter Load, lbs.	Spark Plug Gap, in.	Spark Advance degrees	Intake Vacuum Hg, in.	Air-Fuel Ratio	R.P.M.	Fuel Cons. 10 min. lbs.
49	33.70	.050	10	5	14.9	1500	0.97
50	32.50	.050	20	5	14.9	1500	0.97
51	30.00	.050	30	5	14.9	1500	0.97
52	27.30	.050	40	5	14.9	1500	0.97
53	21.50	.050	10	10	14.9	1500	0.76
54	22.00	.050	20	10	14.9	1500	0.77
55	20.70	.050	30	10	14.9	1500	0.76
56	17.60	.050	40	10	14.9	1500	0.77
57	9.20	.050	10	15	14.9	1500	0.53
58	10.10	.050	20	15	14.9	1500	0.54
59	9.80	.050	30	15	14.9	1500	0.54
60	8.70	.050	40	15	14.9	1500	0.55

TABLE VI

## Performance Data of the Engine

Run No.	Dynamo-meter Load, lbs.	Spark Plug Gap, in.	Spark Advance degrees	Intake Vacuum Hg, in.	Air-Fuel Ratio	R.P.M.	Fuel Cons. 10 min. lbs.
61	33.70	.060	10	5	14.9	1500	0.97
62	32.20	.060	20	5	14.9	1500	0.98
63	30.00	.060	30	5	14.9	1500	0.97
64	27.20	.060	40	5	14.9	1500	0.97
65	21.50	.060	10	10	14.9	1500	0.76
66	22.00	.060	20	10	14.9	1500	0.77
67	20.80	.060	30	10	14.9	1500	0.75
68	18.40	.060	40	10	14.9	1500	0.76
69	8.80	.060	10	15	14.9	1500	0.53
70	10.00	.060	20	15	14.9	1500	0.52
71	9.80	.060	30	15	14.9	1500	0.54
72	9.60	.060	40	15	14.9	1500	0.53

TABLE VII

Results of the Performance of the Engine

For Table I Spark Gap .010 in.			For Table II Spark Gap .020 in.		
Run No.	B.H.P.	Thermal Efficiency %	Run No.	B.H.P.	Thermal Efficiency %
1	8.13	17.80	13	8.55	18.72
2	8.0	17.52	14	8.2	17.95
3	7.4	16.21	15	7.5	16.43
4	6.5	14.24	16	6.5	14.24
5	5.2	14.3	17	5.2	14.30
6	5.25	14.54	18	5.28	14.52
7	5.1	14.03	19	5.1	14.03
8	4.55	12.51	20	4.5	12.38
9	2.2	8.48	21	2.3	8.87
10	2.25	8.67	22	2.50	9.65
11	2.1	8.10	23	2.5	9.65
12	1.25	4.42	24	2.1	8.10

TABLE VIII

Results of the Performance of the Engine

For Table III Spark Gap .030 in.			For Table IV Spark Gap .040 in.		
Run No.	B.H.P.	Thermal Efficiency %	Run No.	B.H.P.	Thermal Efficiency %
25	8.55	18.72	37	8.5	18.62
26	8.28	18.13	38	8.25	18.06
27	7.6	16.64	39	7.5	16.43
28	6.68	14.63	40	6.78	14.85
29	5.23	14.40	41	5.3	14.60
30	5.13	14.65	42	5.42	14.90
31	5.1	14.05	43	5.15	14.17
32	4.40	12.30	44	4.5	12.38
33	2.34	9.02	45	2.37	9.14
34	2.50	9.64	46	2.55	9.83
35	2.50	9.64	47	2.5	9.64
36	2.25	8.67	48	2.13	8.20

TABLE IX

## Results of the Performance of the Engine

For Table V Spark Gap .050 in.			For Table VI Spark Gap .060 in.		
Run No.	B.H.P.	Thermal Efficiency %	Run No.	B.H.P.	Thermal Efficiency %
49	8.43	18.46	61	8.43	18.46
50	8.13	17.80	62	8.05	17.60
51	7.5	16.43	63	7.5	16.40
52	6.75	14.78	64	6.83	14.85
53	5.38	14.80	65	5.39	14.80
54	5.5	15.13	66	5.5	15.13
55	5.18	14.25	67	5.2	14.30
56	4.33	11.90	68	4.58	12.50
57	2.3	8.85	69	2.2	8.48
58	2.53	9.75	70	2.5	9.64
59	2.45	9.45	71	2.45	9.45
60	2.18	8.4	72	2.40	9.25

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## APPENDIX I

## General Test Material

- A: Continental Red Seal Engine  
Manufacturer - Continental Motors Corp.  
Type - Y-69
- B: Direct Reading Galvanometer  
Manufacturer - Leeds & Nothrup Co.  
No. 506743
- C: Generator - Tachometer  
Manufacturer - General Electric Co.  
Type - AN 5531-1
- D: Taylor Dynamometer  
Manufacturer - Taylor Manufacturing Co.  
Type HI-EFF
- E: Fairbanks Scale  
Manufacturer - Fairbanks Morse & Co.  
Type - HI-EFF

## APPENDIX II

## Sample Calculations

Load on Dynamometer Scale = 20.80 lbs.

Engine R.P.M. = 1500

Heating value of fuel = 20000 Btu per lb.

B.H.P. = 2545 Btu per hour

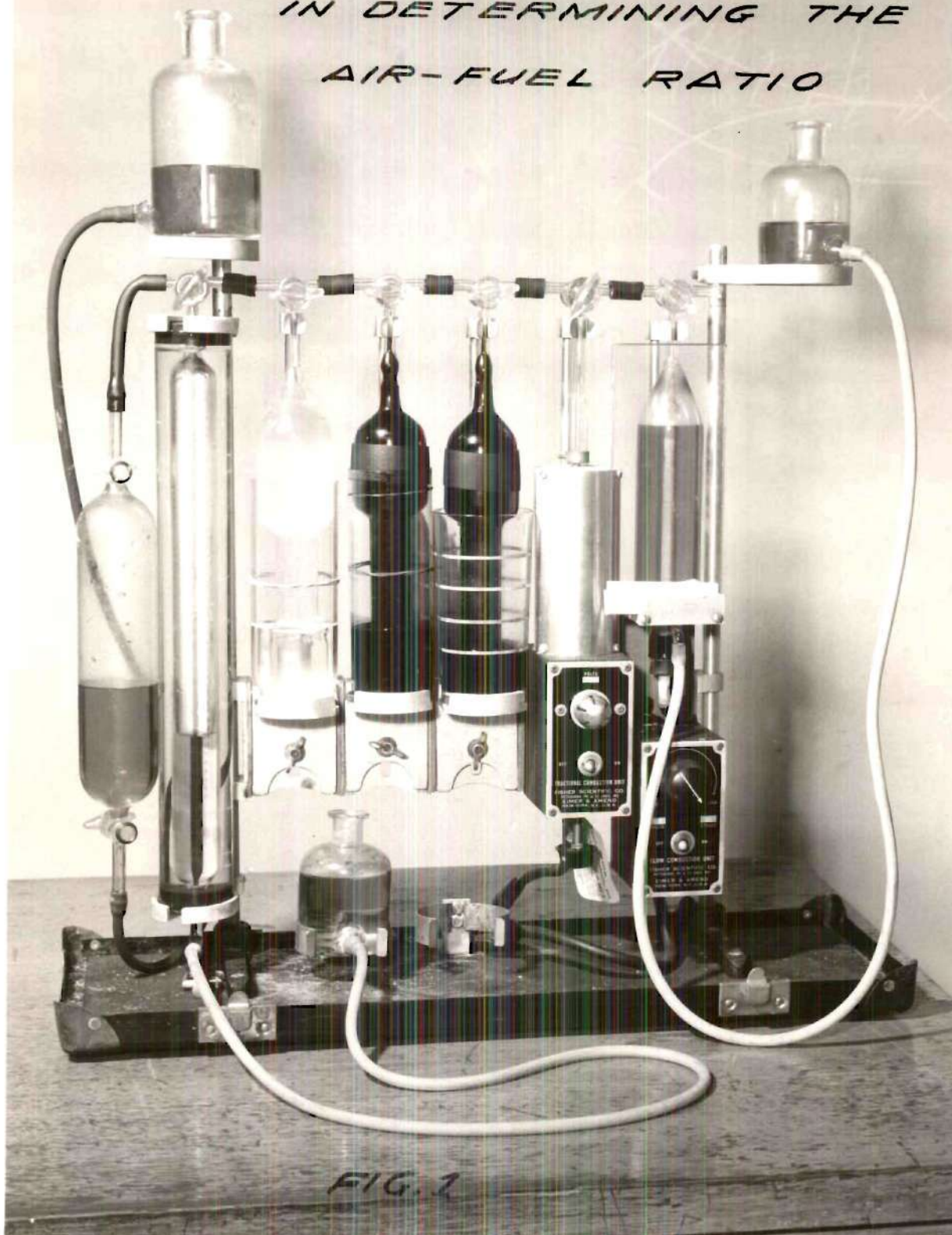
B.H.P. =  $\frac{\text{load on dynamometer scale} \times \text{R.P.M.}}{6000}$

$$= \frac{8.80 \times 1500}{6000} = 2.20$$

Thermal Efficiency =  $\frac{2545 \times \text{B.H.P.}}{20000 \times \text{Fuel consumed per hr.}}$

$$= \frac{2545 \times 2.20}{20000 \times .55 \times 6} = 8.48\%$$

FISHER GAS ANALYZER USED  
IN DETERMINING THE  
AIR-FUEL RATIO



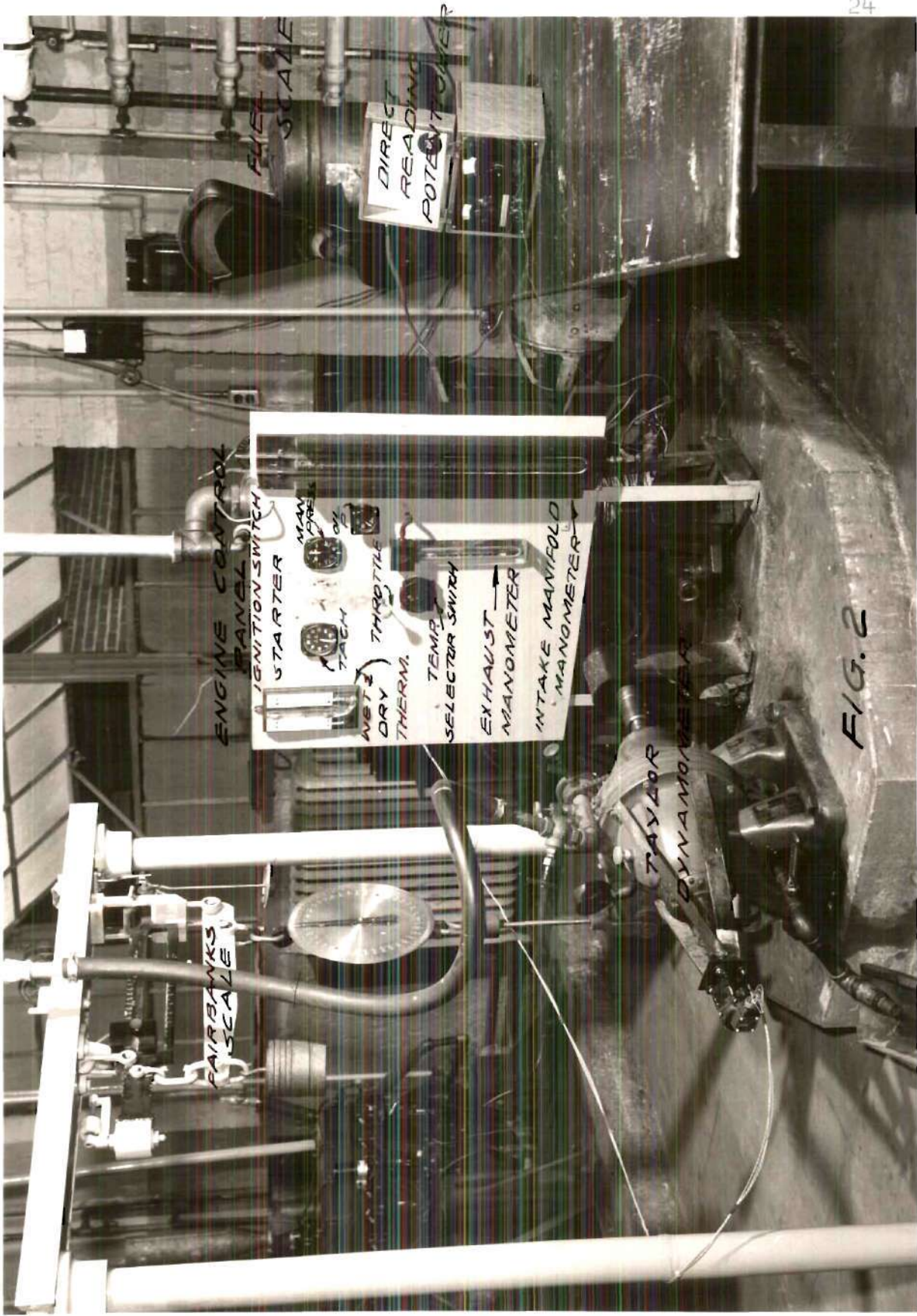
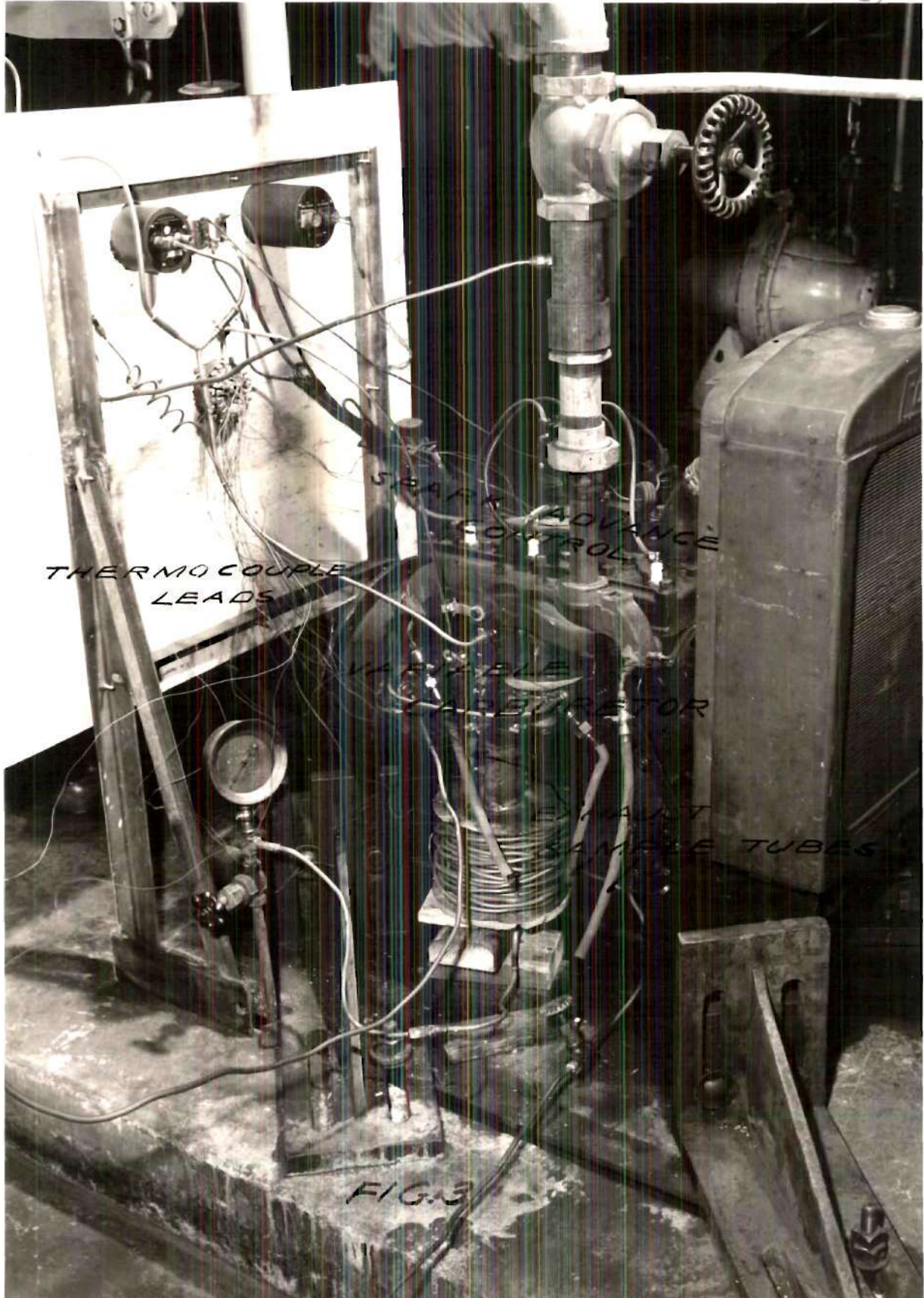


FIG. 2



THERMO COUPLE  
LEADS

SPARK ADVANCE  
CONTROL

VALVE LEAD  
VALVE RETOR

MAIN  
SAMPLE TUBES

FIG. 3

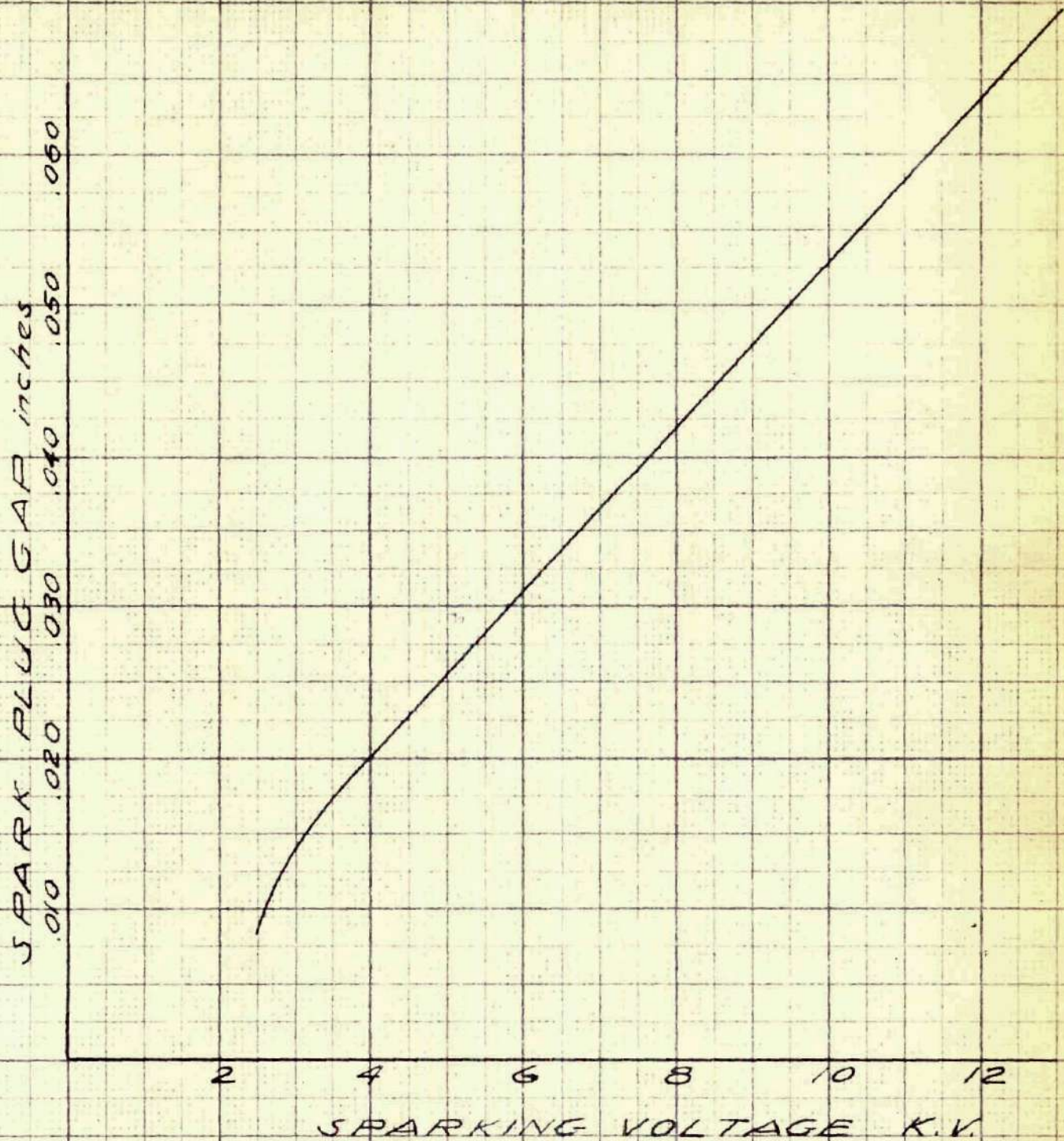


FIGURE 4

GRAPH SHOWING THE VOLTAGE REQUIRED TO JUMP A GIVEN SPARK GAP - COPIED FROM J.A.E. TRANSACTIONS 48 "FACTORS AFFECTING THE FUNCTIONING OF SPARK PLUGS" BY W.A. BYCHINSKY

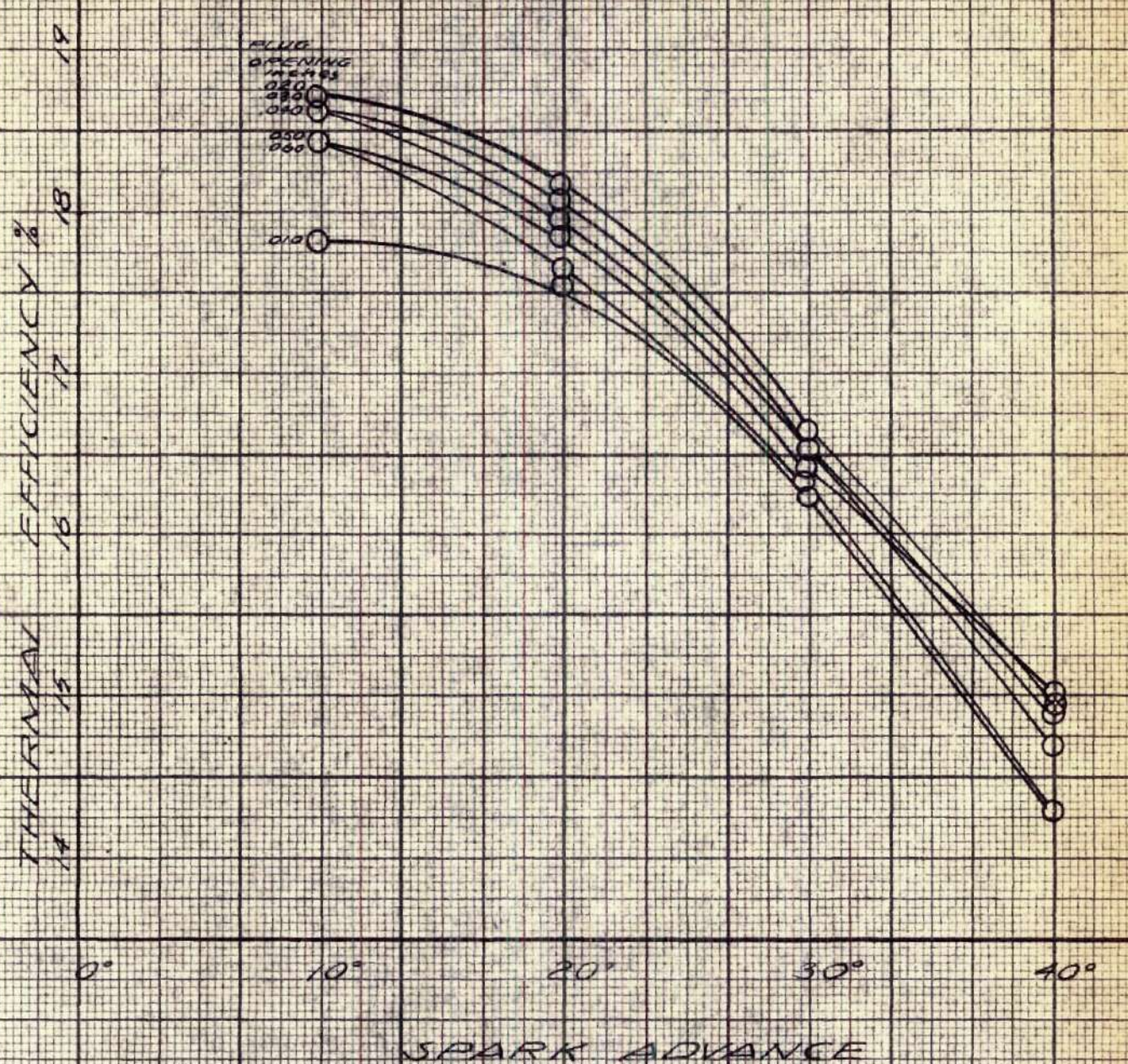


FIGURE 5

5" Hg VACUUM  
14.9:1 P/F RATIO  
1500 R.P.M.

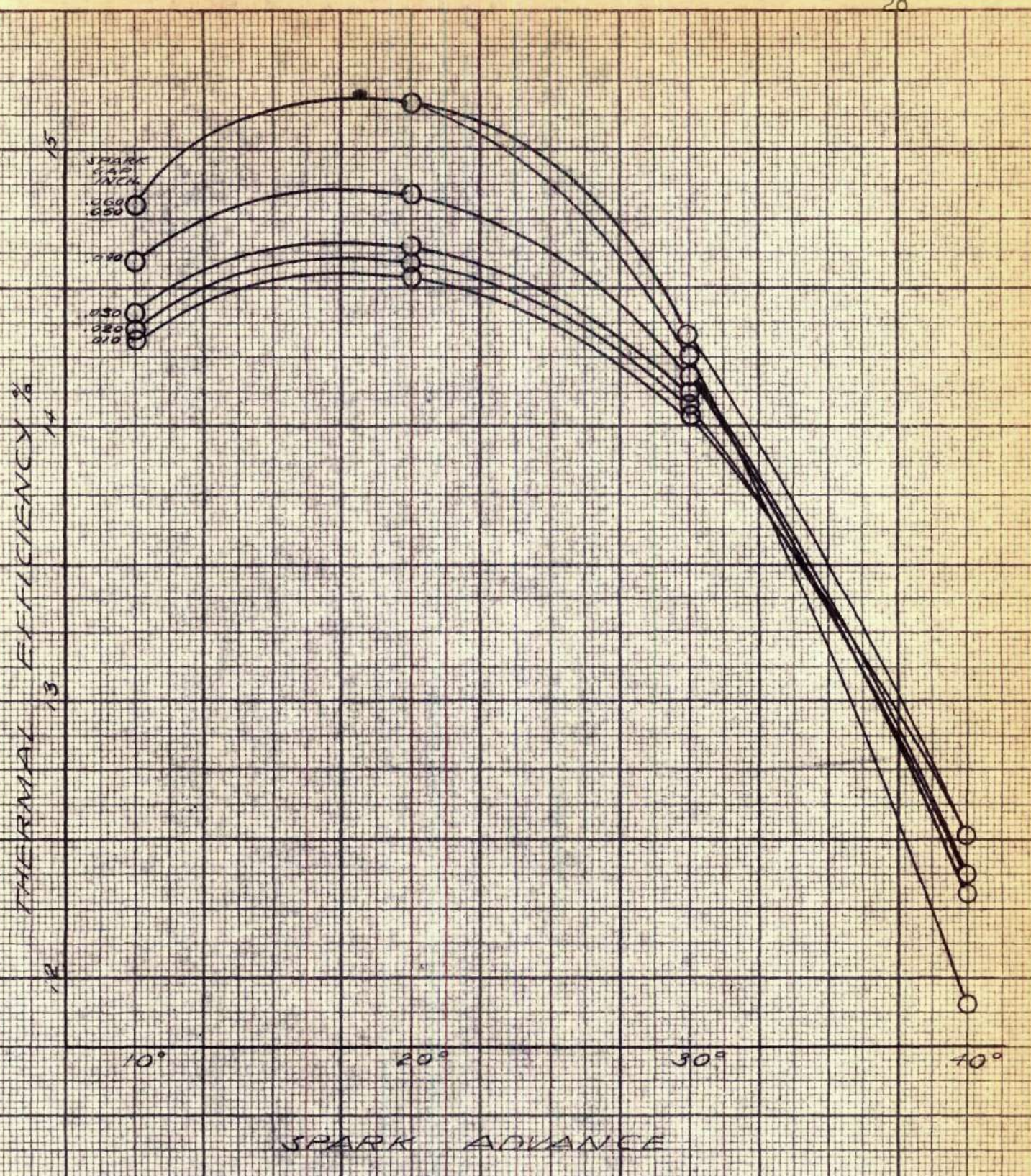


FIGURE 6

10" Hg VACUUM  
 14:1 R/F RATIO  
 1500 R.P.M.

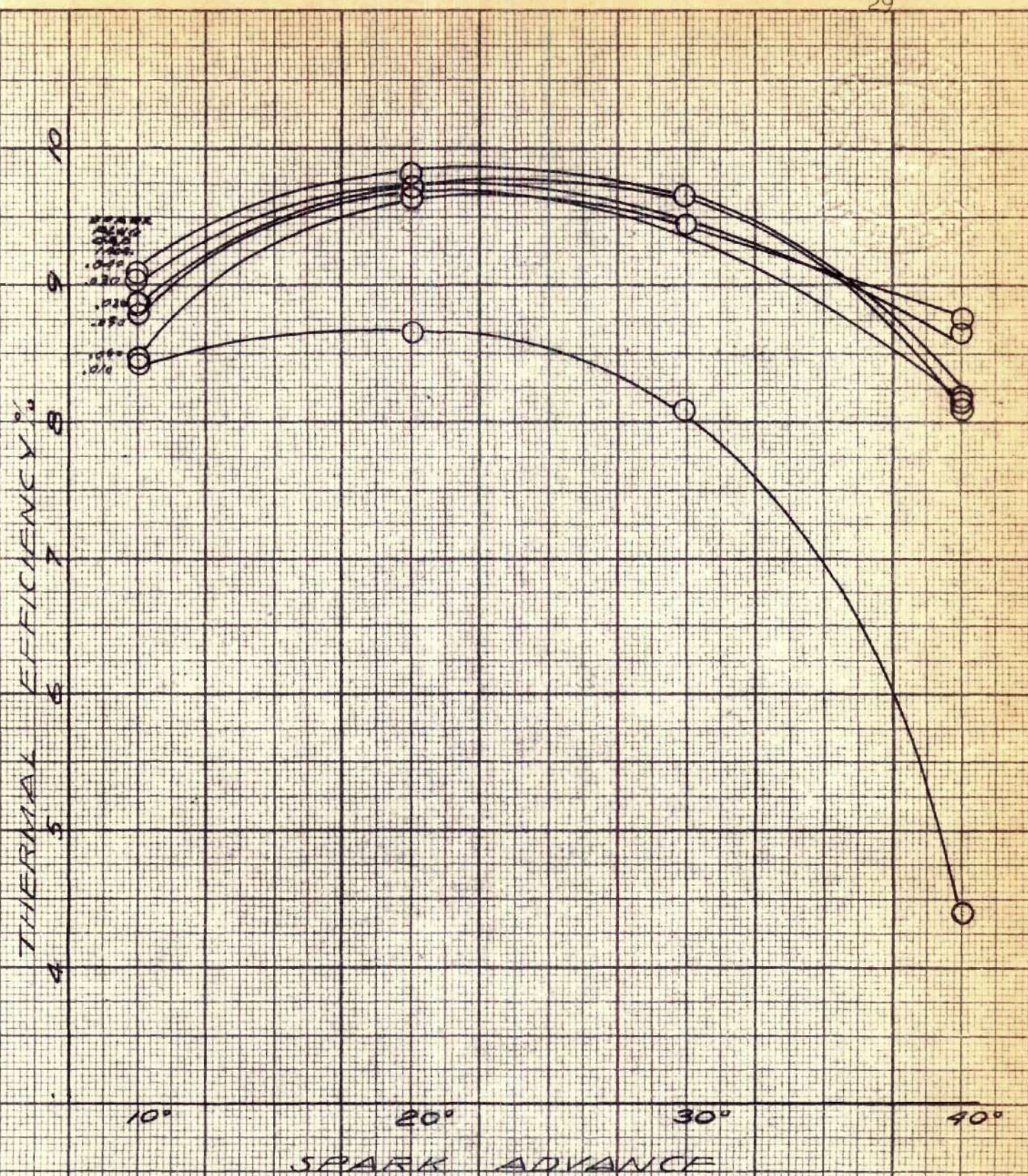


FIGURE 7

15" Hg VACUUM  
14.9:1 P/F RATIO  
1500 R.P.M.

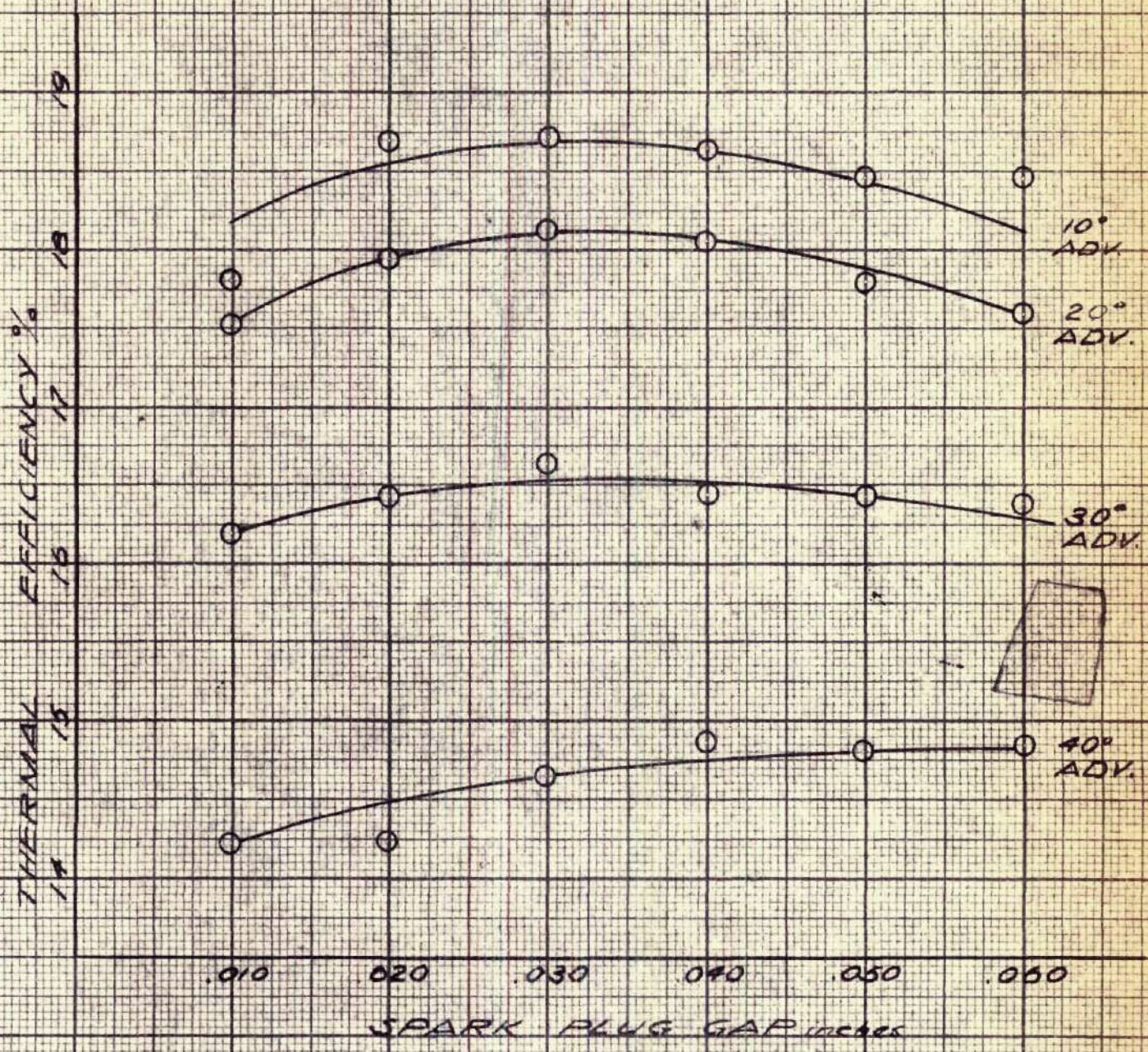


FIGURE B

5" Hg VACUUM  
14.9:1 A/F RATIO  
1500 R.P.M.

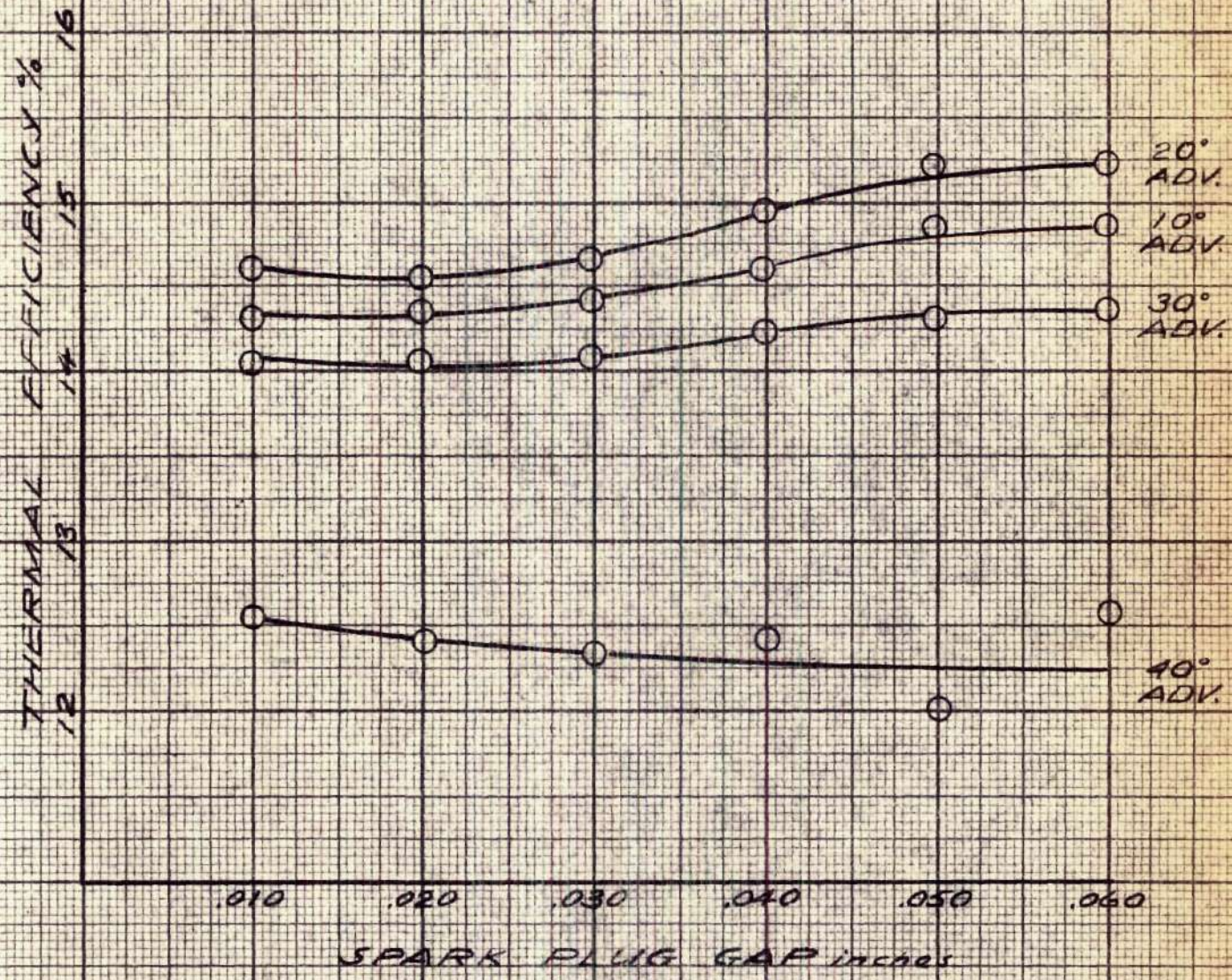


FIGURE 9

10" VACUUM  
14.9:1 A/F RATIO  
1500 R.P.M.

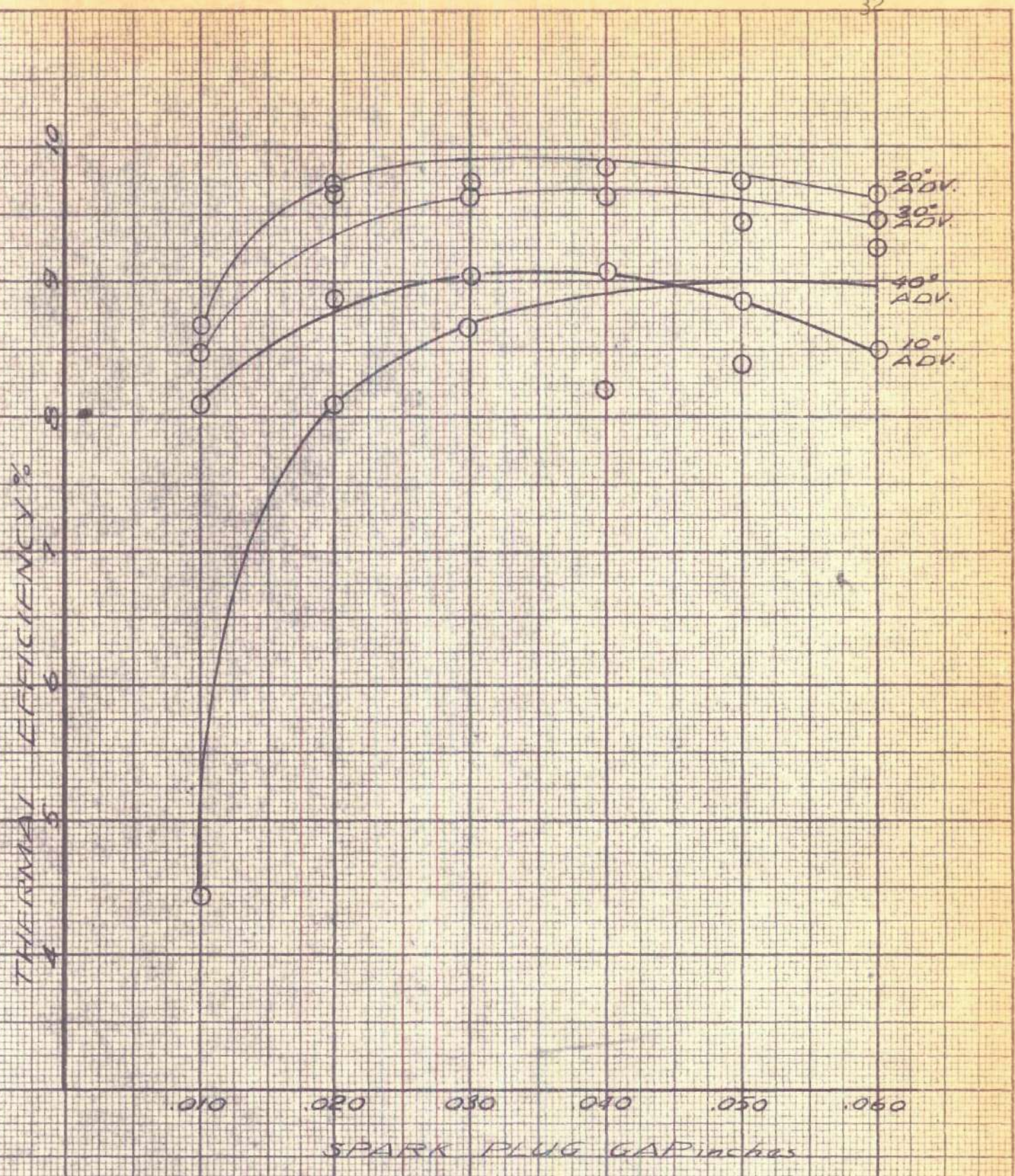


FIGURE 10

15" Hg VACUUM  
14.9:1 P/F RATIO  
1500 R.P.M.