# THE EFFECT OF PREMIXED GASES ON DETONATION IN AN INTERNAL COMBUSTION ENGINE

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THE EFFECT OF PREMIXED GASES ON DETONATION

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## LIST OF ABBREVIATIONS

1 RPM ............ Revolution per minute

2 W .............. Air density in pounds per cubic foot

3 $\rho$ ............. Air density in slugs per cubic foot

4 P .............. Pounds per square inch

5 Q .............. Pounds of air

6 $\alpha$ ............. Coefficient of discharge

7 BTDC ........... Before top dead center

8 m .............. Micrometer reading

9 PSI ............ Pounds per square inch

10 $^{o}F$ ............. Degrees fahrenheit

11 r .............. Ratio of pipe area and orifice area

12 h .............. Inches of alcohol

13 Hg ............. Mercury

14 AC ............. Alternating current

15 DC ............. Direct current

16 CFR ............ Coordinating fuel research

# THE EFFECT OF PREMIXED GASES ON DETONATION
# IN AN INTERNAL COMBUSTION ENGINE

## INTRODUCTION

Purpose:

The conventional intake manifold for most spark ignition engines does not produce an even distribution of the air fuel mixture to the combustion chamber in a multi cylinder engine. Also at low engine speeds it is believed that the air and fuel is not completely mixed. A "High Turbulence Intake Manifold" has been recently designed by Professor Robert L. Allen, the purpose of which is to give a better mixing of the air and fuel before entering the combustion chamber and also a more even distribution of the mixture to the cylinder. From this design arose the problem of what effect would a more thorough mixing of the air and gasoline, than has been done under conventional methods, have on detonation in an internal combustion engine. It is the purpose of this thesis to investigate the effect of premixed gases on detonation.

To accomplish this investigation a manifold was constructed with a blower section attached to mix the air and gasoline as completely as possible (see Figure 2). The manifold was installed on a CFR engine where detonation, compression ratio, and air fuel ratio could be controlled. The final object was to compare the compression ratio with different air fuel ratios, first with the new and then the conventional intake manifold. All the comparisons were made with a constant knockmeter reading, which indicated the same intensity of detonation.

## BACKGROUND

Detonation in modern high compression spark ignition engines is ever present and must be reckoned with. Detonation is the phenomenon which causes "pinging," "carbon knock," or "spark knock" familiar to all automobile drivers. It has been observed from laboratory research that this characteristic sound is usually accompanied by the following phenomena[1]:

(1) High-frequency pressure waves within the cylinder beginning near the end of the combustion process.

(2) An increase in the pressure-rise in the last part of the charge to burn resulting usually in a higher maximum pressure.

(3) A large increase in flame speed near the end of the flame travel.

Even during moderate knocking the pressure waves are so intense that they cause the cylinder wall to vibrate which can be distinguished by the characteristic "pinging" sound.

The present trend toward high speed engines with increased horsepower naturally leads to an increased cross-sectional area of the intake manifold with a larger tube diameter in the carburetor. This in turn

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[1]Taylor, Fayette C. and Taylor, Edward S., "Effects of Detonation" The Internal Combustion Engine. 1938, Scranton, Pennsylvania, International Textbook Company, Chapter 6, page 87

reduces the intake velocities at low engine speeds where detonation is most severe.

At high engine speeds the intake velocities are sufficient to cause turbulent flow of the incoming air-fuel mixture due to the physical structure of most manifolds. As the intake velocity is reduced the flow becomes less turbulent indicating that the air and fuel must be mixed chiefly by diffusion.

Previous work concerned with mixing of gases by diffusion and turbulence shows that it takes a much longer interval of time to mix gases by diffusion than it does by turbulence[1]. This would seem to indicate that with a relatively low turbulent flow in a comparative short intake manifold, the gases would not be completely mixed before entering the combustion chamber.

During the past few years a lot of work has been done concerning detonation, however there seems to be no clear cut explanation as to the effect the magnitude of mixing the air and fuel has on detonation.

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[1] Jost, Wilhelm, "Flames of Gases not Premixed" Explosion and Combustion Processes in Gases, Chapter VI, Mc-Graw Hill Book Company, Inc., New York, 1946.

## DESCRIPTION OF TEST EQUIPMENT

The arrangement of the equipment used in this test is shown in the photographs on pages 32 and 34.

ENGINE:

The engine used was a one cylinder variable compression engine and is part of a standard CFR testing unit built by Waukesha Motor Company, Wauskesha, Wisconsin. The compression ratio may be changed while engine is in operation by means of a movable cylinder head. To evaluate the compression ratio a micrometer is attached to the side of the cylinder which indicates the height of the cylinder head. This micrometer has been calibrated by the Tilt Method which is described on page 39 of the CFR Knock-Testing Manual. From this method the following equation was derived to correlate compression ratio with value obtained from micrometer.

$$\text{Compression Ratio} = \frac{5 \quad \text{micrometer reading}}{.5 \quad \text{micrometer reading}}$$

Specifications of the engine are as follows:

Compression ratio scale ........................ 4 to 10

Bore, inches ................................... 3.25

Stroke, inches ................................. 4.50

Displacement, cubic inches ..................... 37.3

Water cooled

COOLING SYSTEM:

The cooling system is an evaporative type with a water cooled condenser coil above the coolant level. Water from the city main is circulated through the condenser coil.

IGNITION SYSTEM:

The ignition system consists of a high tension coil arrangement with a neon tube to indicate the point of ignition. The neon tube is in line with the crank throw thus indicating the exact spark setting in degrees before or after top dead center by means of a spark timing indicating scale. The current for the ignition system is obtained from a small DC generator mounted on top of the power absorbing motor.

CARBURETOR:

The standard CFR adjustable level carburetor with three fuel supply tanks is used on this engine. The fuel level sight glass is used to determine the height of the gasoline in the float chamber. A set screw located below the float and float chamber assembly is used to change the height of the chamber, thus varying the fuel head which affects the flow of fuel into the manifold. A three way fuel selector knob is used to obtain fuel from any of the three tanks without stopping the engine. The amount of fuel placed in each fuel tank was carefully weighed on a set of balance scales.

INDUCTION SYSTEM:

An induction system was constructed to measure the amount of air taken into the engine. A 50 gallon surge tank was used to insure a steady flow of air through the orifice. A 7/16 inch orifice mounted between flanges was used to measure the flow of air (see Figure 8). Both pipes leading into and away from the orifice were 1-1/2 inches in diameter. A micromanometer filled with alcohol having a specific gravity of 0.8 was used to obtain the pressure drop across the orifice. The temperature of the air entering the surge tank was measured by a wet and dry bulb thermometer located near the intake pipe.

SYNCHRONOUS MOTOR:

A synchronous motor connected to the CFR engine by belts was used to start the engine, absorb the power, and also to control the engine speed.

KNOCKMETER:

The measurement of the knock intensity in the engine is made by means of a standard knockmeter of a bouncing pin type. The bouncing pin consists of a diaphragm, a steel rod insulated at the upper end, and two contacts in an electrical circuit. The current supplied to the unit is from the DC generator. The bouncing pin assembly is screwed into the cylinder head, the diaphragm being exposed to the combustion chamber. Detonation flexes the diaphragm sufficiently to cause the bouncing pin to close the contacts. This permits current to flow through the knockmeter heater circuit the duration of which shows up on the scale of the knockmeter. The knockmeter is a millivoltmeter type instrument actuated by a thermocouple placed within the heater element. The greater the knock intensity the greater time duration the contact points remain closed, resulting in a higher knockmeter indication. The standard procedure for setting the bouncing pin, as given on page 37 of the CFR knock-testing manual was followed.

INTAKE MANIFOLD AND BLOWER ASSEMBLY:

The blower assembly shown in Figure 2 was designed and built for this analysis. The conventional intake manifold is the vertical tube extending from the carburetor to the intake port of the cylinder head. The blower assembly consists of two horizontal tubes extending from the top and bottom of the intake manifold connected to a centrifugal blower. The mixture of air and gasoline enters the manifold at the top and is drawn through the top horizontal tube into the blower. From the centrifugal blower the mixture moves downward and is then discharged horizontally through the lower tube back into the manifold. The approximate ratio of the blower output to the amount of mixture taken into the engine per minute at 900 RPM is 5 to 1. The excess volume of mixture leaving the blower, being five times the engine demand, effects thorough recirculation. This gives the gasoline and air a better chance to mix before being drawn into the cylinder. This thorough mixing is the reason for using the blower assembly. It is believed by the author that by using the blower a more uniform mixture of the gasoline and air can be obtained than is obtained by letting the mixture pass normally straight through the intake manifold into the cylinder as in conventional practice. A rheostat controlled heater was installed in the manifold in order to keep the mixture temperature constant.

TEST PROCEDURE

Before the engine was started the crankcase oil was checked to make sure it was level with the top of the sight glass. The rocker arm section was also lubricated. The cooling system was filled with water and the valve which allows water from the city main to pass through the condenser case was opened slightly. To make sure that all parts of the engine moved freely, the flywheel was turned by hand several turns. Then the selection knob was turned to the desired fuel cylinder previously filled with gasoline. Next the compression setting was moved to 0.700 inches on the micrometer which was low enough to avoid apparent knocking. After all the preliminary checking was finished and the external switch turned on the engine was ready to start. To start the engine the start switch located on the switchboard was thrown and as the oil pressure reached 20 pounds per square inch the ignition switch was turned to the "on" position. The engine was allowed to warm up about two hours with the spark advance set at 20° B.T.D.C.

After the engine had reached the desired operating conditions a manual adjustment located on the side of the engine was moved to increase the compression ratio to 5 to 1. As this setting which was 0.625 inches on the micrometer the bouncing pin was adjusted to give a knockmeter reading of 54. Previous to setting the bouncing pin the carburetor was adjusted to give a minimum knock which was accomplished by adjusting the head pressure of gasoline. Therefore the reading of

54 on the knockmeter was the maximum knock that could be obtained at this setting. Several runs were made at the above setting and an average of all the runs was recorded as run number A-1. After having obtained sufficient data on this basic setting the blower was turned on and by means of the hand crank the compression ratio was varied to give a knockmeter reading of 54. Upon completion of a sufficient number of runs, under condition A-2, the blower was turned off and the engine set up under test procedure B-1 given on page 20. To obtain the setting for run B-1, the air fuel ratio was increased by lowering the head of gasoline until the knockmeter decreased 20 divisions. This decrease in knockmeter reading was established by increasing the compression ratio until the knockmeter again read 54. The engine was operated at this air fuel ratio with the blower first on and then off, always maintaining the knockmeter at 54 by either increasing or decreasing the compression ratio.

Run condition C was conducted the same as for B except the air fuel ratio was decreased by increasing the head of gasoline. The above data was collected for both 900 RPM and 600 RPM of the engine.

For each test the following conditions were held constant:

| | |
|---|---|
| Mixture temperature | $100^{\circ}F$ |
| Spark advance | $26^{\circ}$ |
| Cooling water temperature | $208^{\circ}F$ |
| Oil temperature | $120^{\circ}$-$150^{\circ}F$ |
| Oil pressure | 25-30 PSI |

## DISCUSSION

Theoretically a homogenous mixture of air and fuel should burn faster than one which is not homogenous. Therefore when the mixing blower, located in the intake manifold is turned on, the knock intensity should increase more at 600 RPM than at 900 RPM. However as shown by Figures 4, 5, 6, and 7 this was not the case. At the 600 RPM setting there was very little change in the knock intensity with the blower on or off, whereas at 900 RPM a small change could be detected. This might be attributed to several factors. First the engine used had only one cylinder and instead of a steady flow of mixture in the intake manifold and combustion chamber there was a pulsating flow. This was much more noticeable at the lower RPM. This pulsating effect could possibly have caused a more turbulent flow than was obtained at a higher engine speed thereby securing a better mixing of the air and fuel. The flow of air through the carburetor in a one cylinder engine will vary from approximately zero to some maximum velocity during each intake stroke. As the engine speed is increased the acceleration and deceleration of the air through the carburetor will also increase. However the flow of fuel into the air stream will not be increased as rapidly thus lagging behind somewhat. This would mean that as the change in air velocity was increased the first part of the air drawn into the carburetor on the intake stroke would not contain as much fuel as the last part. Consequently at high engine speeds the carburetor would tend to give a more incomplete distribution of the fuel.

It must be remembered that the reading on the knockmeter has no units therefore in order to obtain data which would have a meaning the knockmeter was kept constant by changing the compression ratio.

Although the test indicated that there is only a small increase in the knock intensity by securing a better mixing of air and fuel this might not be true in every case. The heater unit was not incorporated in the original manifold and the first few runs made were very inconsistent. It was observed that when the blower was on, the temperature of the mixture entering the combustion chamber would in some cases increase as much as 15°F. Therefore to keep all operating conditions constant a rheostat controlled heater was installed in the intake manifold. It is possible that the baffling effect caused by the heater unit in the manifold might give a much better mixing than is obtained with the ordinary intake manifold.

From Figure 4-7, the point of maximum knock intensity was with an air fuel ratio between 12 to 1 and 13 to 1. This region of air fuel ratios is unfortunately where the engine develops its maximum power. At 900 RPM (Figures 4 and 5) the knock intensity was increased with the blower on. Obviously an increase in the mixing of the air and fuel would be a disadvantage from a standpoint of detonation at this engine speed.

At the 600 RPM engine speed the only variation in knock intensity was with air fuel ratios below 12 to 1 (Ref. to Figures 6 and 7). At air fuel ratios below 12 to 1 there was a small increase in knock intensity due to a better mixing of the air and fuel. However none of these increases have much significance since they did not bring the knock intensity above the point of maximum knock which was around 12.5 to 1.

CONCLUSION

It has been shown for the prescribed engine that at certain settings for both 600 and 900 RPM there is an increase in detonation obtained by a better mixing of the air and fuel. However this increase in knock intensity is so small that the effect on compression ratio is of comparatively little importance. It is concluded therefore that the effect on detonation resulting from an increased mixing of the air and fuel by the blower located in the intake manifold is insignificant.

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# APPENDIX I

## AIR METERING SYSTEM

The air metering system shown in Figure 8 was used to determine the amount of air flowing into the engine.

A 0.532 inch orifice was installed between the flanges of a 1-1/2 inch steel pipe. The inside diameter of the pipe was 1.61 inches.

From Mr. E. Owers book on "The Measurement of Air Flow," the following equation was obtained.

$$Q = \alpha a g \sqrt{\frac{2 \rho r^2 (P_1 - P_2)}{r^2 - 1}} \qquad (1)$$

$\alpha$ is the coefficient of discharge

r is the ratio of the upstream and down stream areas $\left( \frac{\text{Pipe area}}{\text{Orifice area}} \right)$

$\rho$ is the density of the air in slugs per cubic foot.

$(P_1 - P_2)$ is the pressure drop across the orifice in pounds per square foot.

a is the area of the orifice in square feet.

Equation 1 can be rearranged to fit the existing conditions as follows:

$$(P_1 - P_2) = \frac{(h_1 - h_2)(0.79)(.33)}{12}$$

$$(P_1 - P_2) = \frac{h_1 - h_2}{35} \quad \text{pounds/square inch}$$

$$\rho = \frac{w}{(32.2)(12)^4} \quad \text{pounds sec}^2/\text{inch}^4$$

$$r = \frac{2.035 \text{ sq. in.}}{0.2214 \text{ sq. in.}} \quad 9.20$$

$h_1 - h_2$ = pressure drop across orifice in inches of alcohol

$a^1$ = a (144) square inches

w = air density in pounds per cubic foot

$$Q = \frac{\alpha a^1 g}{144} \sqrt{\frac{2wr^2(h_1 - h_2)}{35(r^2 - 1)(32.2)(12^4)}} \quad \text{lb/sec}$$

$$Q = \frac{\alpha (0.2214)(32.2)(12)}{144} \sqrt{\frac{w(h_1 - h_2)(84.6)}{(32)(83.6)(16.1)}} \quad \text{lb/sec}$$

$$Q = 0.594\,\alpha \sqrt{\frac{w(h_1 - h_2)}{557}} \quad \text{lb/sec}$$

$$Q = 1.51\,\alpha \sqrt{w(h_1 - h_2)} \quad \text{lb/min}$$

The only terms needed to calculate the pounds of air per minute across the orifice is the air density in pounds per cubic foot, the pressure difference across the orifice in inches of alcohol and the coefficient of discharge. The thin plate orifice used was circular and had a rounded edge on the upstream side. The coefficient of discharge for this type of orifice is 0.98 which was obtained from Kents Mechanical Engineer's Handbook.

# APPENDIX II

## Sample Calculation

## Run A-1 900 RPM

By the use of General Electric Psychrometric chart we find that: $w = 0.0733 \frac{\text{lbs}}{\text{cu ft}}$

Coefficient of discharge $\alpha = 0.98$

Pressure drop across orifice $h_1 - h_2 = 1.410$ inches of alcohol

$Q = 1.51 \alpha \sqrt{w(h_1 - h_2)}$ lbs/min

$Q = (1.51)(0.98)\sqrt{(0.733)(1.410)}$ lbs/min

$Q = 0.477$ lbs/min

pounds of fuel/min $= \frac{0.628 \text{ lbs}}{16.30 \text{ min}} = 0.386$ lbs/min

air fuel ratio $= \frac{0.477 \text{ lbs/min}}{.386 \text{ lbs/min}} = 12.36$ to 1

compression ratio $\frac{5 + m}{.5 + m}$

$m = 0.625$

compression ratio $= \frac{5.625}{1.125} = 5$ to 1

## KEY FOR DATA SHEET I - IV

1 Time in minutes

2 Wet bulb temperature °F

3 Dry bulb temperature °F

4 Micrometer setting in inches

5 Temperature of cooling water °F

6 Temperature of mixture °F

7 Micromanometer reading in inches of alcohol

8 RPM

9 Oil pressure PSI

10 Oil temperature

11 Knockmeter reading

12 D.C. voltage

13 Fuel level in carburetor in inches

14 Fan

15 Spark advance °BTDC

16 Barometric pressure in inches of mercury

17 Pounds of fuel

18 Manifold heater A.C. amps.

DATA SHEET I

RUN NUMBER

| Reading | A-1 | A-2 | B-1 | B-2 | C-1 |
|---|---|---|---|---|---|
| 1 | 16.30 | 16.10 | 19.33 | 18.82 | 12.77 |
| 2 | 68 | 60 | 60 | 60 | 60 |
| 3 | 78 | 74 | 75 | 75 | 78 |
| 4 | 0.625 | 0.630 | 0.587 | 0.591 | 0.590 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 100 | 100 | 100 | 100 | 100 |
| 7 | 1.410 | 1.463 | 1.448 | 1.497 | 1.465 |
| 8 | 900 | 900 | 900 | 900 | 900 |
| 9 | 35 | 35 | 35 | 35 | 35 |
| 10 | 124 | 122 | 123 | 124 | 122 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 110 |
| 13 | 1.2 | 1.2 | 1.8 | 1.8 | 0 |
| 14 | OFF | ON | OFF | ON | OFF |
| 15 | 26 | 26 | 26 | 26 | 26 |
| 16 | 28.85 | 28.9 | 28.9 | 28.9 | 29.1 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.70 | 0.60 | 0.70 | 0.40 | 0.46 |

DATA SHEET I (cont)

RUN NUMBER

| Reading | C-2 | D-1 | D-2 | E-1 | E-2 |
|---|---|---|---|---|---|
| 1 | 12.70 | 17.4 | 17.5 | 14 | 13.9 |
| 2 | 60 | 61 | 61 | 61 | 61 |
| 3 | 78 | 78 | 78 | 78 | 78 |
| 4 | 0.590 | 0.606 | 0.604 | 0.610 | 0.613 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 100 | 100 | 100 | 100 | 100 |
| 7 | 1.470 | 1.592 | 1.590 | 1.617 | 1.620 |
| 8 | 900 | 900 | 900 | 900 | 900 |
| 9 | 35 | 35 | 35 | 35 | 35 |
| 10 | 122 | 122 | 122 | 125 | 125 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 110 |
| 13 | 0 | 1.5 | 1.5 | 0.7 | 0.7 |
| 14 | ON | OFF | ON | OFF | ON |
| 15 | 26 | 26 | 26 | 26 | 26 |
| 16 | 29.1 | 28.8 | 28.8 | 29 | 29 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.70 | 0.40 | 0.40 | 0.70 | 0.50 |

DATA SHEET II

RUN NUMBER

| Reading | A'-1 | A'-2 | B'-1 | B'-2 | C'-1 |
|---|---|---|---|---|---|
| 1 | 15.1 | 15.2 | 18.95 | 18.95 | 17.4 |
| 2 | 61 | 62 | 62 | 62 | 60 |
| 3 | 77 | 78 | 78 | 78 | 80 |
| 4 | 0.500 | 504 | .450 | .450 | 0.475 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 100 | 100 | 100 | 100 | 100 |
| 7 | 1.592 | 1.624 | 1.625 | 1.625 | 1.595 |
| 8 | 900 | 900 | 900 | 900 | 900 |
| 9 | 35 | 35 | 35 | 35 | 35 |
| 10 | 120 | 120 | 120 | 120 | 125 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 110 |
| 13 | 1.2 | 1.2 | 1.9 | 1.9 | 1.65 |
| 14 | OFF | ON | OFF | ON | OFF |
| 15 | 26 | 26 | 26 | 26 | 26 |
| 16 | 28.93 | 28.93 | 28.93 | 28.93 | 28.8 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.60 | 0.40 | 0.50 | 0.50 | 0.70 |

DATA SHEET II (cont)

RUN NUMBER

| READING | C'-2 | D'-1 | D'-2 | E'-1 | E'-2 |
|---|---|---|---|---|---|
| 1 | 17.3 | 12.2 | 12.2 | 13.75 | 13.6 |
| 2 | 60 | 62 | 62 | 62 | 62 |
| 3 | 80 | 79 | 79 | 79 | 79 |
| 4 | 0.478 | .450 | .450 | 0.478 | 0.480 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 1000 | 100 | 100 | 100 | 100 |
| 7 | 1.605 | 1.625 | 1.628 | 1.605 | 1.610 |
| 8 | 900 | 900 | 900 | 900 | 900 |
| 9 | 35 | 35 | 35 | 35 | 35 |
| 10 | 125 | 125 | 125 | 124 | 124 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 110 |
| 13 | 1.65 | 0.30 | 0.30 | 0.60 | 0.60 |
| 14 | ON | OFF | ON | OFF | ON |
| 15 | 26 | 26 | 26 | 26 | 26 |
| 16 | 28.8 | 28.8 | 28.8 | 28.8 | 28.8 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.50 | 0.60 | 0.40 | 0.60 | 0.50 |

DATA SHEET III

RUN NUMBER

| Reading | A-1 | A-2 | B-1 | B-2 | C-1 |
|---|---|---|---|---|---|
| 1 | 20.5 | 20.5 | 27.0 | 27.0 | 25 |
| 2 | 60 | 62 | 62 | 62 | 62 |
| 3 | 74 | 76 | 76 | 76 | 76 |
| 4 | 0.625 | 0.625 | 0.500 | 0.500 | .560 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 100 | 100 | 100 | 100 | 100 |
| 7 | 1.307 | 1.307 | 1.301 | 1.301 | 1.289 |
| 8 | 600 | 600 | 600 | 600 | 600 |
| 9 | 32 | 32 | 32 | 32 | 32 |
| 10 | 120 | 120 | 120 | 120 | 120 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 110 |
| 13 | 1.2 | 1.2 | 1.7 | 1.7 | 1.6 |
| 14 | OFF | ON | OFF | ON | OFF |
| 15 | 13 | 13 | 13 | 13 | 13 |
| 16 | 28.7 | 28.7 | 28.7 | 28.7 | 28.7 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.70 | 0.60 | 0.50 | 0.30 | 0.50 |

DATA SHEET III (cont)

RUN NUMBER

| Reading | C-2 | D-1 | D-2 | E-1 | E-2 |
|---|---|---|---|---|---|
| 1 | 25 | 15.8 | 15.6 | 17.5 | 17.4 |
| 2 | 62 | 62 | 62 | 62 | 62 |
| 3 | 76 | 76 | 76 | 76 | 76 |
| 4 | .560 | .502 | .507 | .556 | .559 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 100 | 100 | 100 | 100 | 100 |
| 7 | 1.289 | 1.285 | 1.300 | 1.293 | 1.306 |
| 8 | 600 | 600 | 600 | 600 | 600 |
| 9 | 32 | 32 | 32 | 32 | 32 |
| 10 | 120 | 120 | 120 | 120 | 120 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 110 |
| 13 | 1.6 | 0.4 | 0.4 | 0.8 | 0.8 |
| 14 | ON | OFF | ON | OFF | ON |
| 15 | 13 | 13 | 13 | 13 | 13 |
| 16 | 28.7 | 28.6 | 28.6 | 28.6 | 28.6 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.20 | 0.50 | 0.20 | 0.50 | 0.20 |

DATA SHEET IV

RUN NUMBER

| Reading | A'-1 | A'-2 | B'-1 | B'-2 | C'-1 |
|---|---|---|---|---|---|
| 1 | 20.85 | 20.85 | 27 | 27 | 17.5 |
| 2 | 62 | 62 | 62 | 62 | 67 |
| 3 | 76 | 76 | 76 | 76 | 76 |
| 4 | 0.500 | 0.501 | 0.425 | 0.425 | 0.395 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 100 | 100 | 100 | 100 | 100 |
| 7 | 1.233 | 1.233 | 1.235 | 1.235 | 1.225 |
| 8 | 600 | 600 | 600 | 600 | 600 |
| 9 | 32 | 32 | 32 | 32 | 32 |
| 10 | 120 | 120 | 120 | 120 | 120 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 100 |
| 13 | 1.2 | 1.2 | 1.7 | 1.7 | 0.6 |
| 14 | OFF | ON | OFF | ON | OFF |
| 15 | 13 | 13 | 13 | 13 | 13 |
| 16 | 28.9 | 28.9 | 28.9 | 28.9 | 28.4 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.60 | 0.40 | 0.50 | 0.00 | 0.60 |

DATA SHEET IV (cont)

RUN NUMBER

| Reading | C'-2 | D'-1 | D'-2 | E'-1 | E'-2 |
|---|---|---|---|---|---|
| 1 | 17.2 | 19.1 | 19.0 | 24.8 | 24.8 |
| 2 | 67 | 67 | 67 | 67 | 67 |
| 3 | 76 | 76 | 76 | 76 | 76 |
| 4 | 0.400 | 0.445 | 0.447 | 0.462 | 0.462 |
| 5 | 208 | 208 | 208 | 208 | 208 |
| 6 | 100 | 100 | 100 | 100 | 100 |
| 7 | 1.229 | 1.220 | 1.237 | 1.215 | 1.215 |
| 8 | 600 | 600 | 600 | 600 | 600 |
| 9 | 32 | 32 | 32 | 32 | 32 |
| 10 | 120 | 120 | 120 | 120 | 120 |
| 11 | 54 | 54 | 54 | 54 | 54 |
| 12 | 110 | 110 | 110 | 110 | 110 |
| 13 | 0.60 | 0.90 | 0.90 | 1.5 | 1.5 |
| 14 | ON | OFF | ON | OFF | ON |
| 15 | 13 | 13 | 13 | 13 | 13 |
| 16 | 28.4 | 28.4 | 28.5 | 28.7 | 28.7 |
| 17 | 0.628 | 0.628 | 0.628 | 0.628 | 0.628 |
| 18 | 0.50 | 0.50 | 0.30 | 0.50 | 0.30 |

TABLE I

RESULTS FOR 900 RPM

LOW COMPRESSION

| Run No. | Compression Ratio | Air-fuel Ratio |
|---|---|---|
| A-1 | 5.00 to 1 | 12.36 to 1 |
| A-2 | 4.98 to 1 | 12.35 to 1 |
| B-1 | 5.13 to 1 | 14.78 to 1 |
| B-2 | 5.12 to 1 | 14.72 to 1 |
| C-1 | 5.13 to 1 | 9.88 to 1 |
| C-2 | 5.13 to 1 | 9.80 to 1 |
| D-1 | 5.07 to 1 | 14.00 to 1 |
| D-2 | 5.07 to 1 | 14.03 to 1 |
| E-1 | 5.04 to 1 | 11.37 to 1 |
| E-2 | 5.04 to 1 | 11.30 to 1 |

TABLE II

RESULTS FOR 900 RPM

HIGH COMPRESSION

| Run No. | Compression Ratio | Air-fuel Ratio |
|---|---|---|
| A'-1 | 5.50 to 1 | 12.25 to 1 |
| A'-2 | 5.48 to 1 | 12.30 to 1 |
| B'-1 | 5.73 to 1 | 15.43 to 1 |
| B'-2 | 5.73 to 1 | 15.43 to 1 |
| C'-1 | 5.61 to 1 | 13.90 to 1 |
| C'-2 | 5.60 to 1 | 13.95 to 1 |
| D'-1 | 5.73 to 1 | 10.01 to 1 |
| D'-2 | 5.73 to 1 | 10.01 to 1 |
| E'-1 | 5.60 to 1 | 11.06 to 1 |
| E'-2 | 5.59 to 1 | 11.03 to 1 |

TABLE III

RESULTS FOR 600 RPM

LOW COMPRESSION

| Run No. | Compression Ratio | Air-fuel Ratio |
|---|---|---|
| A-1 | 5.00 to 1 | 12.44 to 1 |
| A-2 | 5.00 to 1 | 12.44 to 1 |
| B-1 | 5.50 to 1 | 16.2 to 1 |
| B-2 | 5.50 to 1 | 16.26 to 1 |
| C-1 | 5.23 to 1 | 15.05 to 1 |
| C-2 | 5.23 to 1 | 15.05 to 1 |
| D-1 | 5.48 to 1 | 9.50 to 1 |
| D-2 | 5.46 to 1 | 9.46 to 1 |
| E-1 | 5.26 to 1 | 10.55 to 1 |
| E-2 | 5.24 to 1 | 10.50 to 1 |

TABLE IV

RESULTS FOR 600 RPM

HIGH COMPRESSION

| Run No. | Compression Ratio | Air-fuel Ratio |
|---|---|---|
| A'-1 | 5.50 to 1 | 12.36 to 1 |
| A'-2 | 5.50 to 1 | 12.40 to 1 |
| B'-1 | 5.87 to 1 | 15.95 to 1 |
| B'-2 | 5.87 to 1 | 15.95 to 1 |
| C'-1 | 6.02 to 1 | 10.01 to 1 |
| C'-2 | 6.00 to 1 | 10.01 to 1 |
| D'-1 | 5.76 to 1 | 11.23 to 1 |
| D'-2 | 5.75 to 1 | 11.20 to 1 |
| E'-1 | 5.68 to 1 | 14.48 to 1 |
| E'-2 | 5.68 to 1 | 14.48 to 1 |

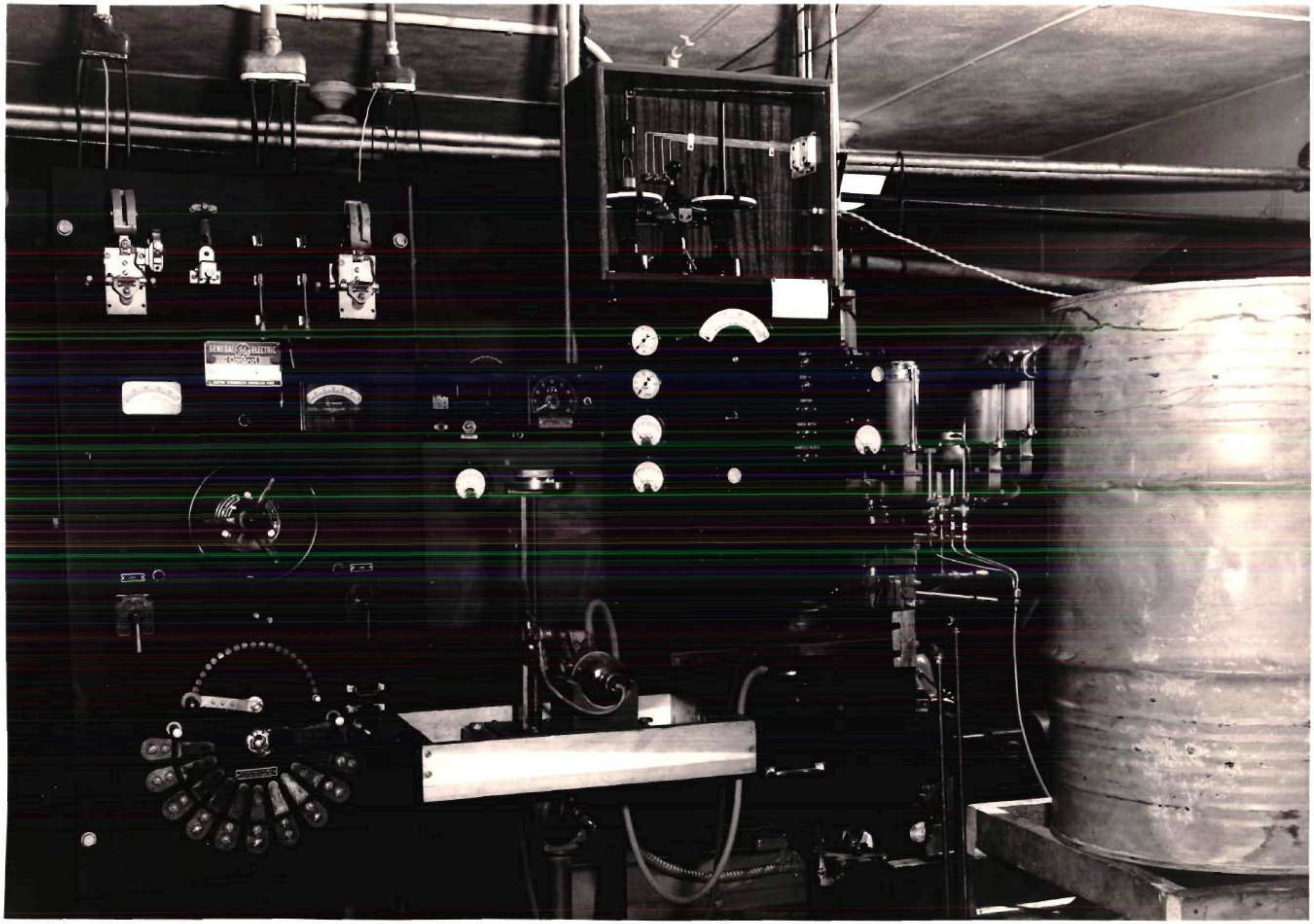



FIGURE 1

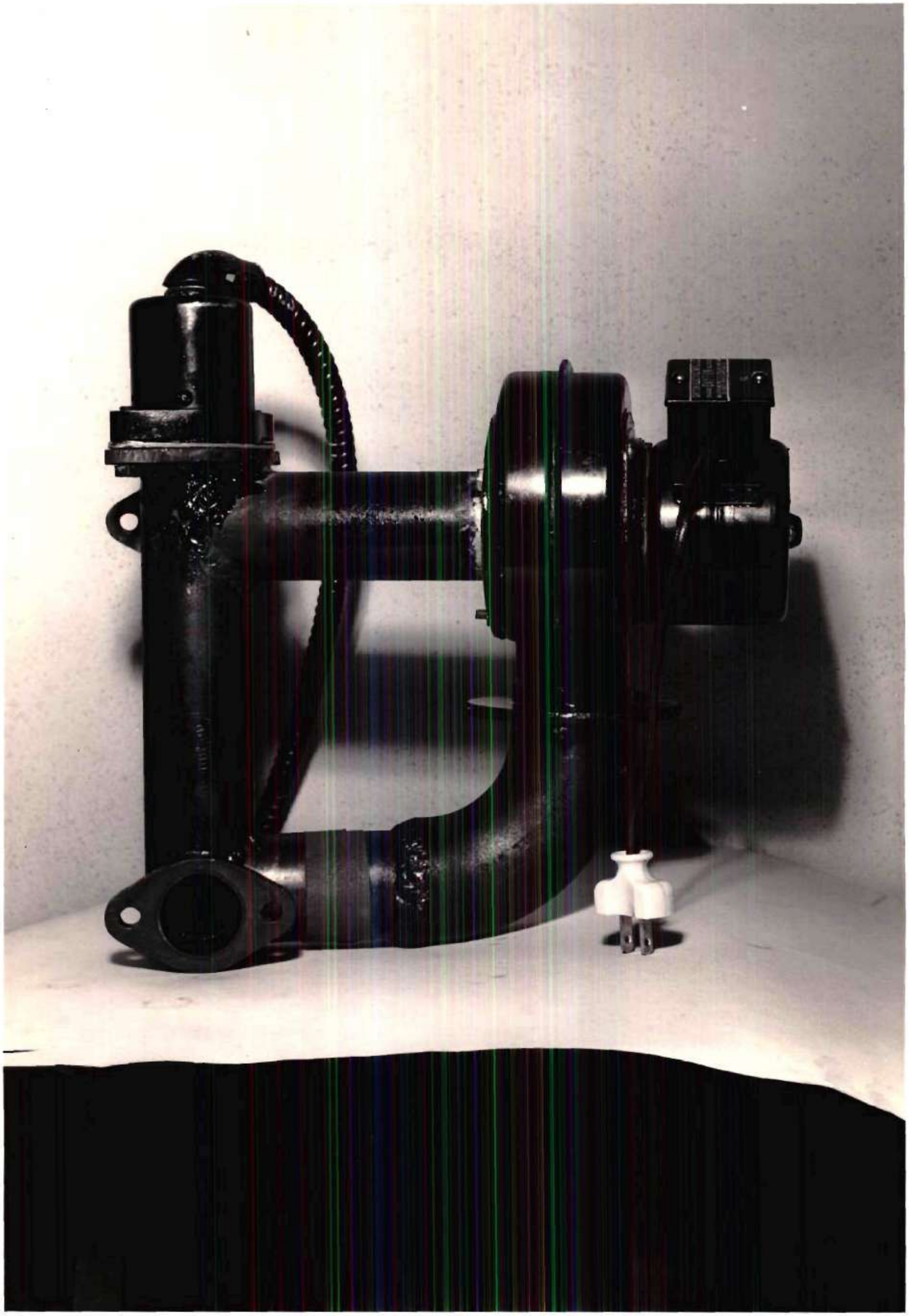


FIGURE 2

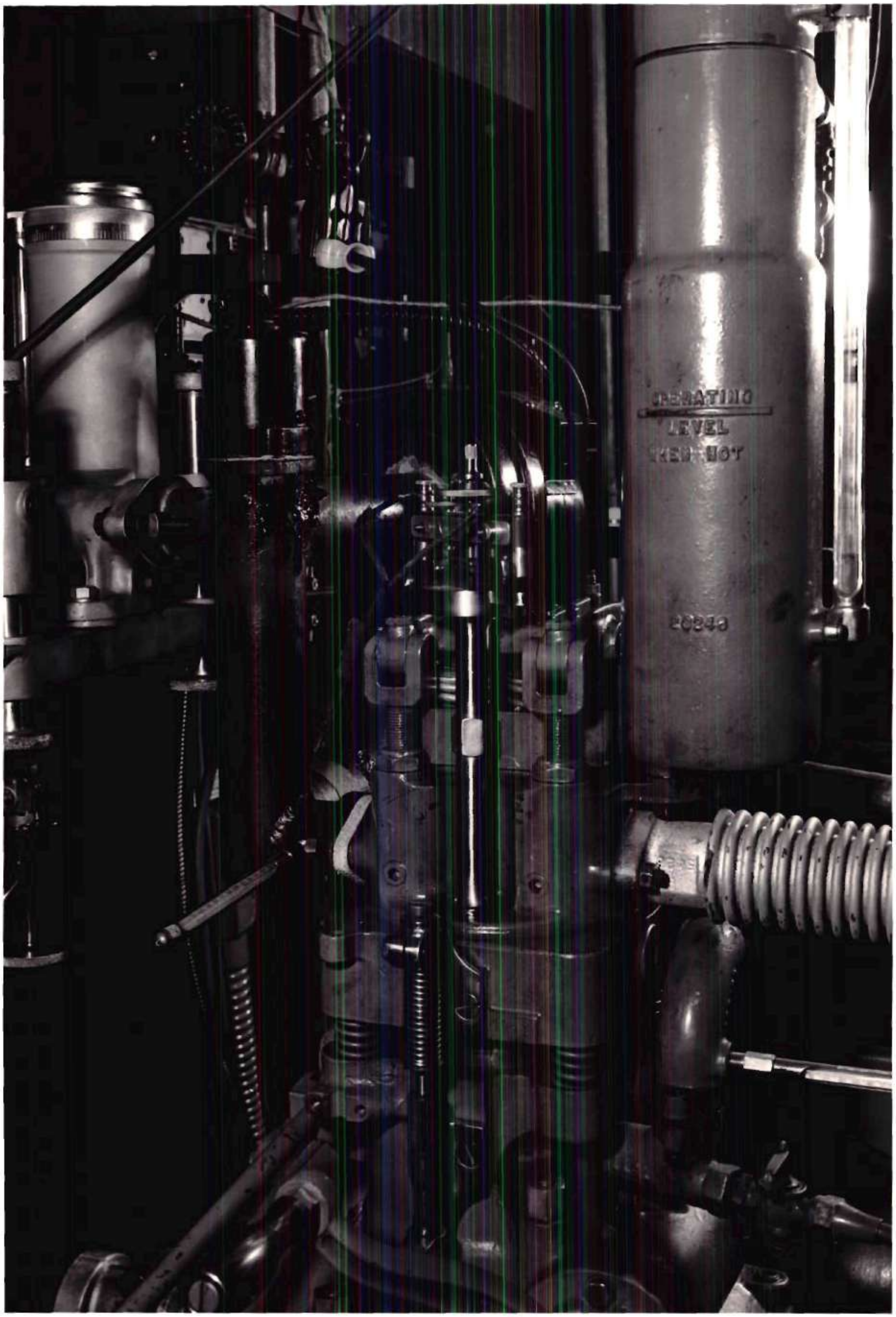
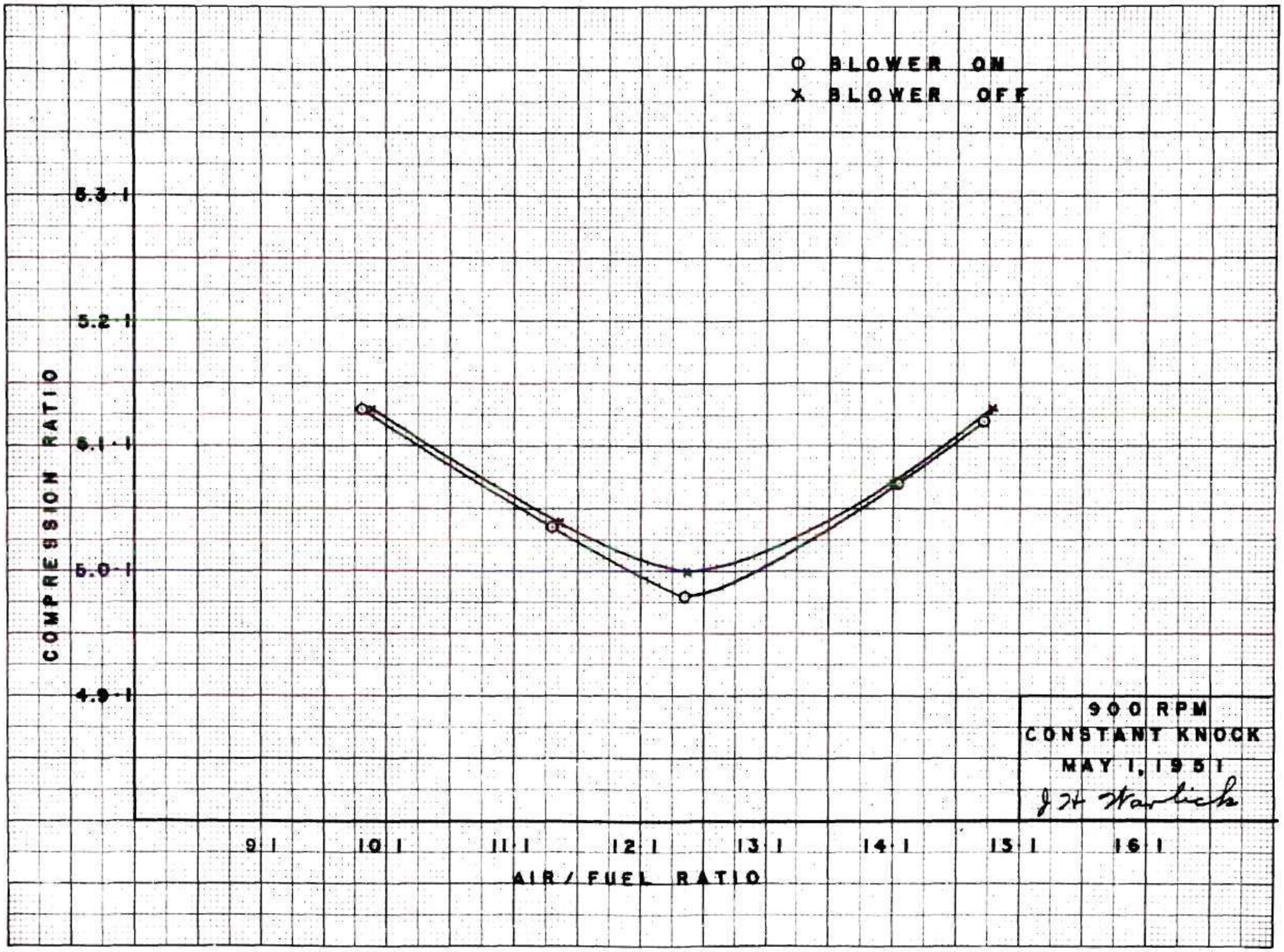
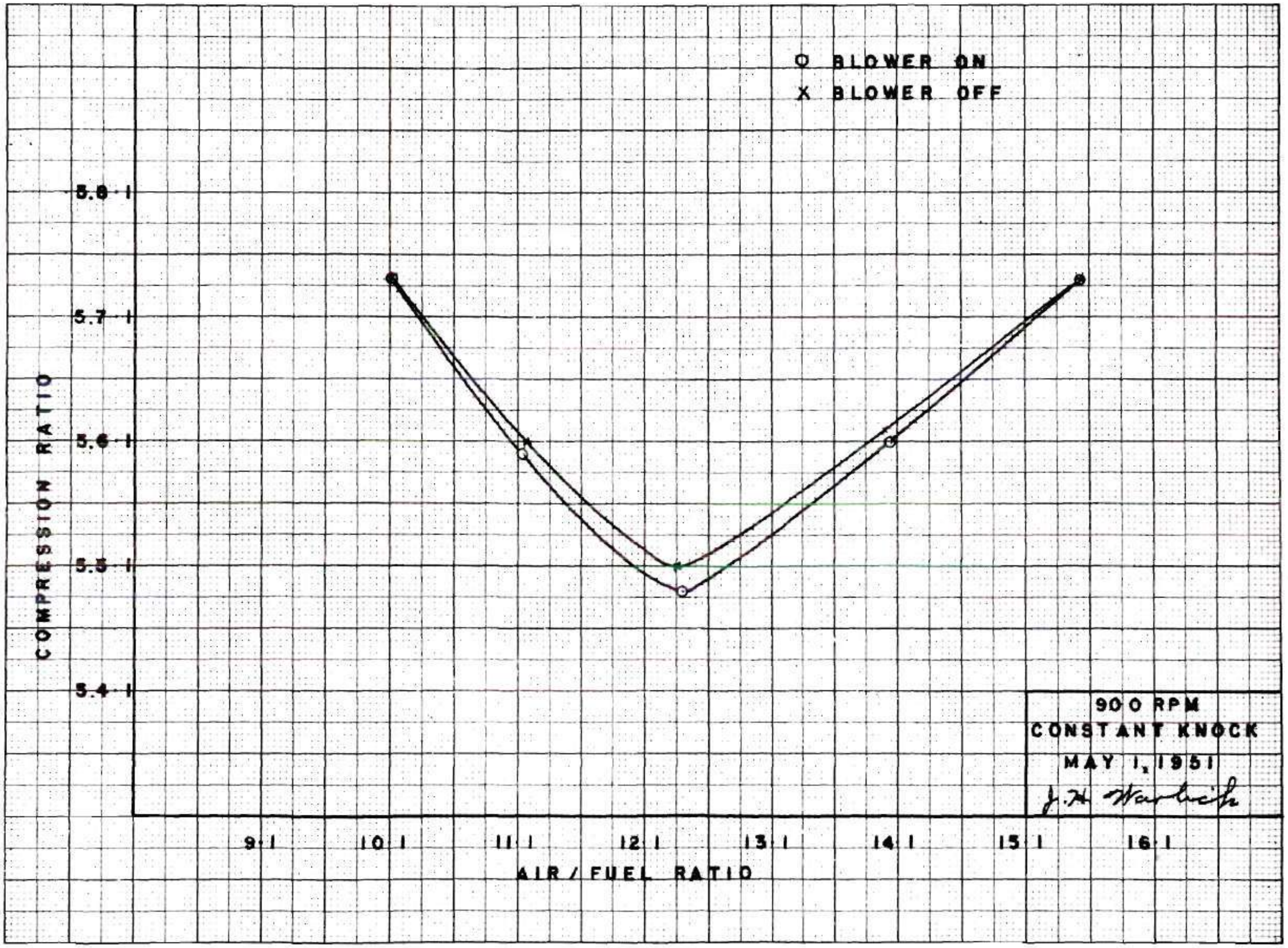


FIGURE 3



O BLOWER ON
X BLOWER OFF
5.3 : 1
5.2 : 1
5.1 : 1
5.0 : 1
4.9 : 1
COMPRESSION RATIO
9 : 1
10 : 1
11 : 1
12 : 1
13 : 1
14 : 1
15 : 1
16 : 1
AIR / FUEL RATIO
900 RPM
CONSTANT KNOCK
MAY 1, 1951


FIGURE 4



O BLOWER ON
X BLOWER OFF
5.8 : 1
5.7 : 1
5.6 : 1
5.5 : 1
5.4 : 1
COMPRESSION RATIO
9:1
10:1
11:1
12:1
13:1
14:1
15:1
16:1
AIR / FUEL RATIO
900 RPM
CONSTANT KNOCK
MAY 1, 1951


FIGURE 5

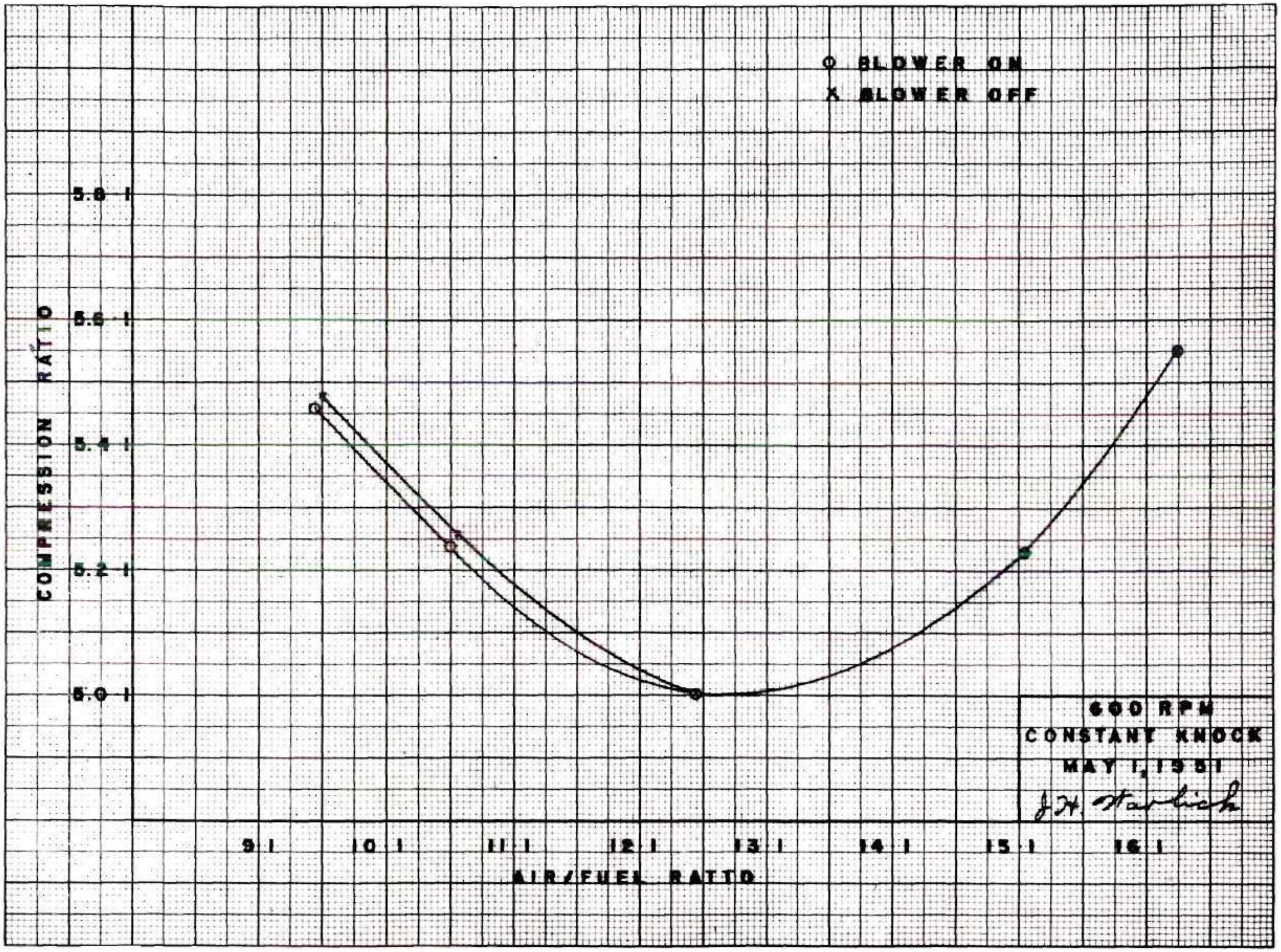
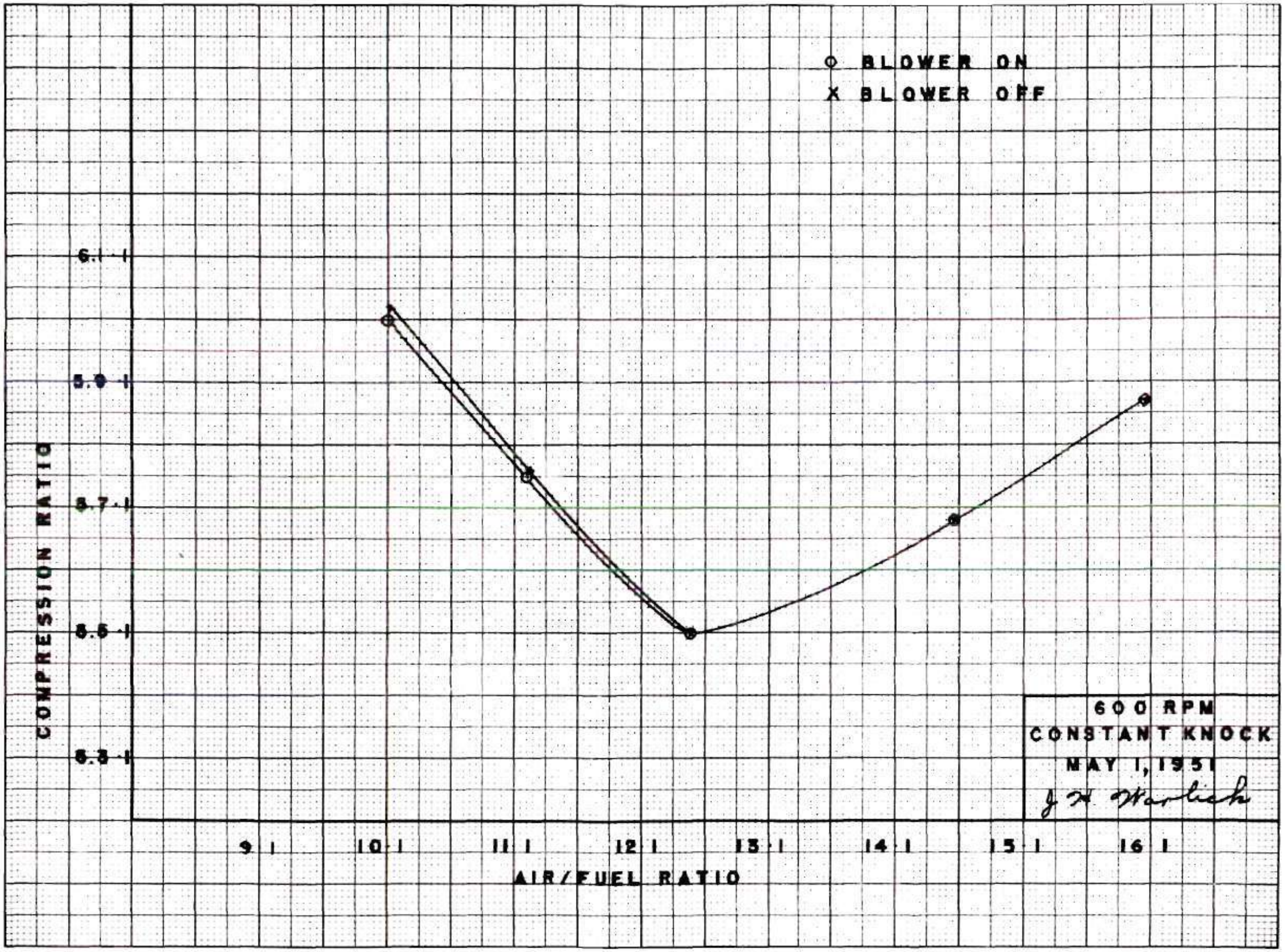

O BLOWER ON
X BLOWER OFF
5.8 : 1
5.6 : 1
5.4 : 1
5.2 : 1
5.0 : 1
COMPRESSION RATIO
9 : 1
10 : 1
11 : 1
12 : 1
13 : 1
14 : 1
15 : 1
16 : 1
AIR/FUEL RATIO
600 RPM
CONSTANT KNOCK
MAY 1, 1951

FIGURE 6



O BLOWER ON
X BLOWER OFF
6.1 · 1
COMPRESSION RATIO
9 · 1
10 · 1
11 · 1
12 · 1
13 · 1
14 · 1
15 · 1
16 · 1
AIR/FUEL RATIO
600 RPM
CONSTANT KNOCK
MAY 1, 1951
J. H. Warlich


FIGURE 7

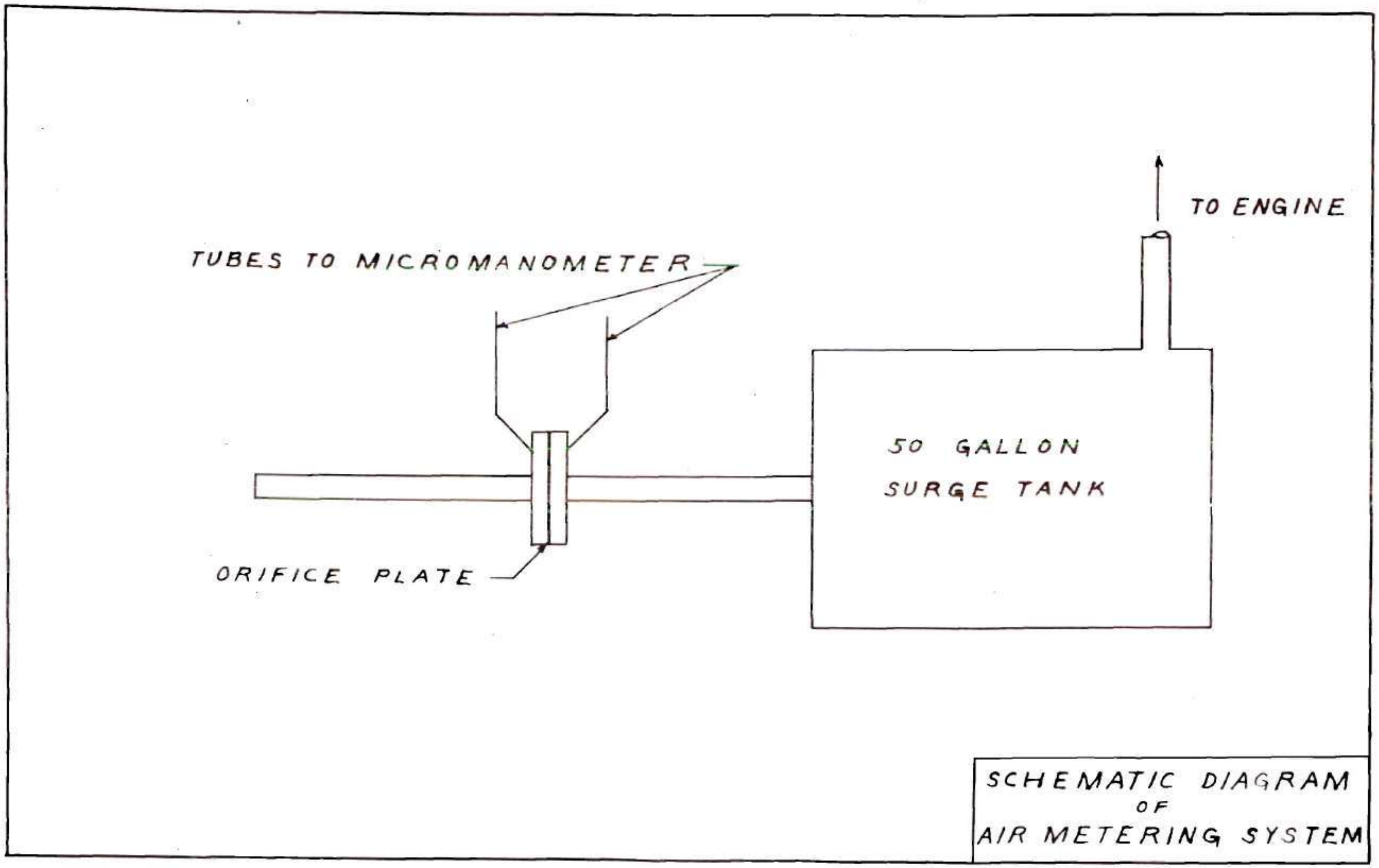

TO ENGINE
TUBES TO MICROMANOMETER
50 GALLON
SURGE TANK
ORIFICE PLATE
SCHEMATIC DIAGRAM
OF
AIR METERING SYSTEM

FIGURE 8