A SINGLE-CYLINDER INTERNAL COMBUSTION ENGINE TEST UNIT FOR THE ENGINEERING LABORATORY

By

Loren Douglas Strege

March 31, 1962

A Thesis submitted to the Faculty of the
NORTH DAKOTA STATE UNIVERSITY
in partial fulfillment of the requirements
for the degree; Master of Science.

The undersigned, appointed by the Dean of the Graduate School, have examined a thesis entitled "A Single-Cylinder Internal Combustion Engine Test Unit for the Engineering Laboratory", presented by Loren Douglas Strege, a candidate for the degree, Master of Science, and hereby certify that in their opinion it is worthy of acceptance.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the following individuals and organizations for interest shown, and for assistance given in the work associated with this thesis:

Professor A. W. Anderson, who suggested the project and supplied helpful criticism and guidance during the design, construction, installation, and testing of the equipment, and during the writing of the thesis.

Mr. Hjalmer Miller, Mr. Arvid Olson, and Professor Edward G. Hosted, on the Mechanical Engineering staff, who always willingly helped whenever needed.

Professors L. L. Melanson and E. M. Anderson, of the Electrical Engineering Department. for their assistance and advice.

The North Dakota State University for providing the necessary funds and assistance during the construction and testing stages.

The Mechanical, Electrical, and Civil Engineering Departments of the North Dakota State University for the use of their equipment and facilities.

Also to several other persons and organizations known only to the author, for their helpful suggestions and encouragement.

L.D.S.

TABLE OF CONTENTS

TABLE OF CONTENTS

(continued)

SYMBOLS AND ABBREVIATIONS

ac	Alternating current
AF	Air to fuel-weight ratio
Approx	Approximately
ASTM	American Society for Testing Materials
ATDC	After top dead center
Ave	Average
Bhp	Brake horsepower
BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
BTDC	Before top dead center
bul	Bulletin
CFR	Coordinating Fuel Research
CO	Carbon monoxide
CO_2	Carbon dioxide
corr	Corrected value
dc	Direct Current
F	Fahrenheit
ft	Feet
GMC	General Motors Corporation
Hg	Mercury
hr	Hour
in	Inches
Inc	Incorporated
lb	Pound

SYMBOLS AND ABBREVIATIONS
(continued)

lbs	Pounds
ml	Milliliters
NC	National Coarse
n d	No date
No	Number
O_2	Oxygen
obs	Observed value
p	Page
pp	Pages
press	Pressure
psi	Pounds per square inch
Rev	Revolutions
rpm	Revolutions per minute
SAE	Society of Automotive Engineers
sec	Second, seconds
SFC	Specific fuel consumption
TDC	Top dead center
Temp	Temperature
o	Degrees
$	Dollars
=	Equals
"	Inches
%	Per cent

LIST OF FIGURES

LIST OF FIGURES

(continued)

SECTION I

INTRODUCTION

The study of the reciprocating internal combustion engine is of prime importance to the student engineer. In our present civilization, the number of units and the total rated power of internal combustion engines in use is far greater than that of all other prime movers combined.[1] Many basic engineering problems are present in the study of the operation of internal combustion engines. A number of mechanical and electrical devices have been developed to aid the engineer in his studies of engine performance.

The purpose of this project is to provide the Mechanical Engineering Department of the North Dakota State University with an addition to its laboratory facilities which will enable the student to do additional experimental work in the internal combustion engine field. Many of the fundamentals and parameters over which the engine designer has some control, and the theories underlying the operation of internal combustion engines, can be taught through actual laboratory instruction. Research testing may also be undertaken to study some phase of power production that is not thoroughly understood, or to test the validity of theories that are advanced.

This project includes developing some of the needed facilities, including incorporating a method for the dynamic measurement of

---

[1] C. F. Taylor, <u>The Internal Combustion Engine in Theory and Practice</u>, p.3.

engine cylinder pressure, on a Standard Knock Testing Unit. This Standard Knock Testing Unit is known as the "ASTM-CFR Engine" and is referred to in this report as the CFR engine, or simply engine.

The single-cylinder, CFR engine is suited to experimental testing and laboratory instruction as many variables can be completely controlled in its operation. The compression ratio is continuously variable; the ignition spark timing can be readily changed; the air-fuel mixture ratio can be varied; and operating temperatures may be governed by the engine operator. By means of a dynamometer, the load and rotative speed may also be regulated. The engine is also adaptable for pressure measurement studies since the knock meter pressure pickup hole may be utilized for instrumentation, thus eliminating the problem of providing an auxiliary hole in the combustion chamber head. An advantage is also obtained in a single-cylinder engine over a multi-cylinder engine, in that operation studies are simplified and may be concentrated on the one cylinder.

The test unit comprises a CFR engine coupled to a direct current, electric dynamometer. An ac-dc motor-generator supplies the required direct current voltage. A pressure sensitive pickup, an amplifier-calibrator, a low noise pickup cable, and a conventional oscilloscope are utilized for the dynamic measurement of engine cylinder pressure. Necessary devices for obtaining speed, fuel consumption, engine vacuum, combustion analysis and synchronizing the oscilloscope with the rotation of the engine, are also exploited.

The apparatus is not a unique idea since similiar test units and principles employed, have been used and practiced by commercial engine manufacturers, fuel companies, and other educational institutions for many years.

The author has attempted to develop a test unit which can be understood and operated without a great amount of effort. Data can be taken quite simply, and principles and theory can be demonstrated to aid the student in understanding many of the fundamentals of the internal combustion engine.

The equipment has been tested by the writer with good results, both from the standpoint of operation of the equipment and the quality of the results. This report includes the development and description of the equipment along with a number of tests and results to aid the reader in the use and understanding of the test unit.

SECTION II

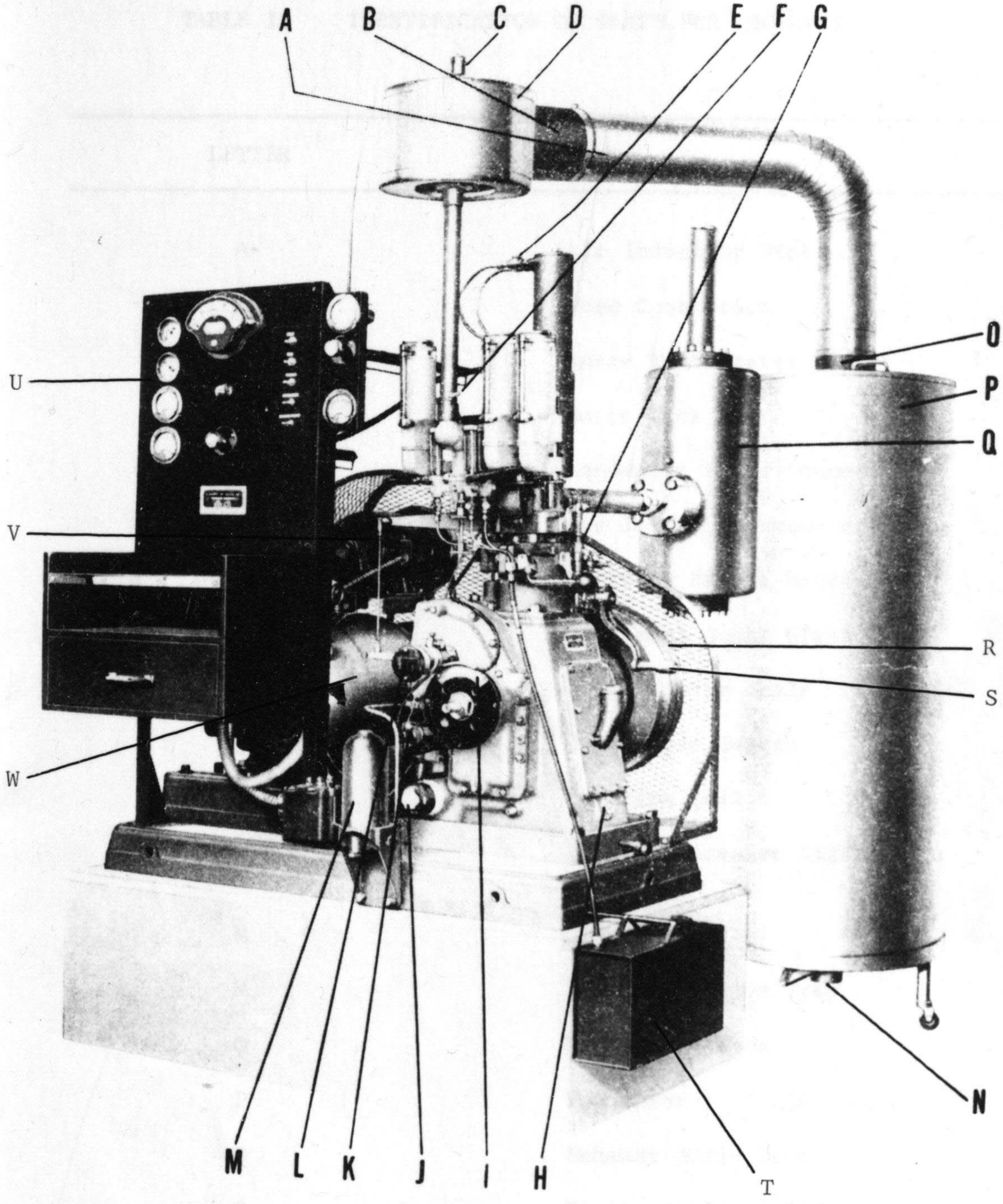
EQUIPMENT DESCRIPTION, DESIGN, FABRICATION, AND INSTALLATION

Knock Testing Unit. The knock testing unit used in this project consists essentially of a single-cylinder engine, synchronous motor, direct current generator and accessory equipment and instruments, mounted on a stationary base. Figure 1, page 5 , illustrates the knock testing unit as it looked at the start of this project. It is manufactured by the Waukesha Motor Company, Waukesha, Wisconsin, to the specificational requirements of the American Society for Testing Materials and the Coordinating Fuel Research Committee, for the purpose of evaluating the combustion characteristics of motor fuels.

The Mechanical Engineering Department has used this unit solely to teach the method of determining the knock characteristic of fuels for use in spark ignition engines in terms of A.S.T.M. Motor Octane Numbers.

The engine has overhead valves and the capability of continuously variable compression ratio. The variable compression ratio is obtained by making the head and cylinder in one piece. This cylinder can be raised or lowered by a hand crank, thus varying compression volume, and therefore compression ratio since the stroke of the piston is constant.

The spark advance is automatically adjusted to compensate for changes in compression ratio by a control link between the cylinder



NOTE: Letters refer to parts listed in Table 1.

Figure 1. Standard Knock Testing Unit

TABLE I. IDENTIFICATION OF PARTS FOR FIGURE I

LETTER	NAME
A	Air Induction Pipe
B	Hose Connection
C	Surge Tank Heater Plug
D	Surge Tank
E	Condenser Water Connections
F	Air Intake Thermometer
G	Cylinder Height Micrometer
H	Oil Level Sight Glass
I	Spark Timing Scale
J	Oil Heater Switch
K	Ignition Coil
L	Ignition Breaker Distributor Housing
M	Oil Filter
N	Ice Tower Drain Trap
O	Hose Connection
P	Ice Tower
Q	Exhaust Surge Tank
R	Timing Scale on Flywheel
S	Crank for Adjusting Compression Ratio
T	Scrap Fuel Can

TABLE I. IDENTIFICATION OF PARTS FOR FIGURE I
(continued)

LETTER	NAME
U	Control Panel
V	Direct Current Generator
W	Synchronous Motor

NOTE: Letters refer to parts on Figure 1 head and the distributor housing. A neon-tube ignition spark indicator, actuated by the crankshaft, indicates the degree of advance or retardation on a spark timing scale.

Tests for the rating of fuels are performed under certain prescribed speeds, temperatures, and other operation conditions. The speed is held constant by the synchronous motor which is also used for starting the engine and absorbing the power developed by it. The generator limits the engine speed to a submultiple of the line frequency as well as supply the current required for the bouncing pin circuit and the engine ignition system.

The carburetor for the engine has three, individually, adjustable-level fuel containers and float bowls. Changing the level of the float bowls will change the fuel level, thus varying the air-fuel ratio.

Intake air temperature is maintained and controlled by an electric intake air heater located in the intake air surge tank. An air inlet thermometer with a range of 0 to 220° F is located near the base of the inlet air tube to monitor this temperature. Humidity may be controlled by an ice tower which is arranged to pass the inlet air through an ice bed, thus chilling it and delivering saturated air at approximately 32° F with a moisture content of 26 to 28 grains per pound of dry air.

Fuel mixture temperatures are controlled by a carbon-pile rheostat connected to an electric element in the intake manifold. A mercury thermometer is also mounted in the manifold to monitor temperatures through a range of 100 to 400° F.

Crankcase oil temperatures are maintained by means of an electric heater mounted on the base of the crankcase, and a combination oil cooler and filter mounted near the front of the distributor coil. The oil cooler utilizes city water for cooling. An oil temperature gage with a range of 90 to 160° F is located on the control panel of the CFR engine.

The Exigency For A Dynamometer. The measurement of engine torque, or work output per unit of time, is prerequisite for the laboratory evaluation of the performance of an engine. Many devices have been produced for this purpose. The most preferred and versatile machine is the cradle-mounted electric dynamometer.[1] It may be used either as a motor to start and drive the engine at various speeds or as a generator to absorb the power output of the engine.

Inquiry into the purchase of a d-c cradled dynamometer for application to the CFR engine was made by Professor A. W. Anderson, prior to acceptance of this project by the author. Results of that inquiry revealed the purchase price to be from $6732 to $12,645. Since justification of these prices for this equipment was not feasible, it was suggested to the author, during his introduction to the project, that he develop a dynamometer by cradle mounting a 10 horsepower, d-c motor. A search for a suitable d-c motor for this adoption was made. Fortunately, the department had a dynamometer unit constructed for a single-cylinder

[1] E. F. Obert, Internal Combustion Engines, pp. 31-33.

Nordberg diesel engine, which due to extreme vibration of the engine, was not being used. Experimental testing of the dynamometer, along with an investigation of a dynamometer used with a CFR engine at another educational institution, and correspondence with the engine manufacturer, revealed that the dynamometer could suitably be used with the CRF engine employed in this project.

My advisor approved the use of the dynamometer with the suggestion that it be made portable for use with either the Nordberg diesel engine or the CFR engine.

The dynamometer unit consists essentially of a 10 horsepower, compound wound, direct current motor, supported in ball-bearing trunnions so that it is permitted to swing freely about the axis of its shaft. The rotation of the motor frame is restricted by a Chatillon dial scale with a capacity of 100 pounds. A "cradle lock" is provided so that any and all rotational movement of the stator or field frame is prevented when using the dynamometer as a motor. A series of metal grids are used to transmute the generated d-c current into heat when the dynamometer is used as a generator. A four-terminal starting box, a rheostat and the necessary switches complete the unit.

The general problem was then to adapt the available dynamometer to the CFR engine. Specifically, this consisted of designing and fabricating an adapter drive coupling and dynamometer unit foundation, and altering the engine exhaust system to provide required room for the dynamometer unit.

Dynamometer Coupling. The engine portion of the drive coupling was the only constituent required to complete the drive mechanism since the available dynamometer was already equiped with a coupling. Figure 2, page 12, is a drawing of the engine adaptor coupling for the CFR engine. The flange and hub portions were welded together before machining to the dimensions shown, to avoid warp. Design computations were believed unnecessary since the engine portion of the coupling was made to conform to the dynamometer portion of the coupling and the torque transmitted is small relative to the coupling design. Two leather center rings provide for minor misalignment, and minute vibration and shock characteristics of the drive.

Exhaust System. The engine exhaust surge tank and discharge pipe were moved $38\frac{1}{4}$ inches back from the engine to allow room for the dynamometer unit. Three 7/16 x 2 inch bolts were leaded into the floor to secure the base of the surge tank. A $1\frac{1}{4}$ inch pipe, with flanges on the ends, was used to make the connection from the flexible exhaust pipe to the surge tank. From the surge tank, the discharge pipe extends vertically to the roof for exhaust to the atmosphere. Necessary braces were added to rigedly support the exhaust system, and water drain line connections were made to conform to the requirements of the CFR engine.

A means was also provided for obtaining a sample of the exhaust gases for an exhaust gas analysis. This consists of a 3/8 inch stop-cock and necessary piping tapped into the $1\frac{1}{4}$ inch discharge pipe.

Dynamometer Foundation. The next problem was constructing the

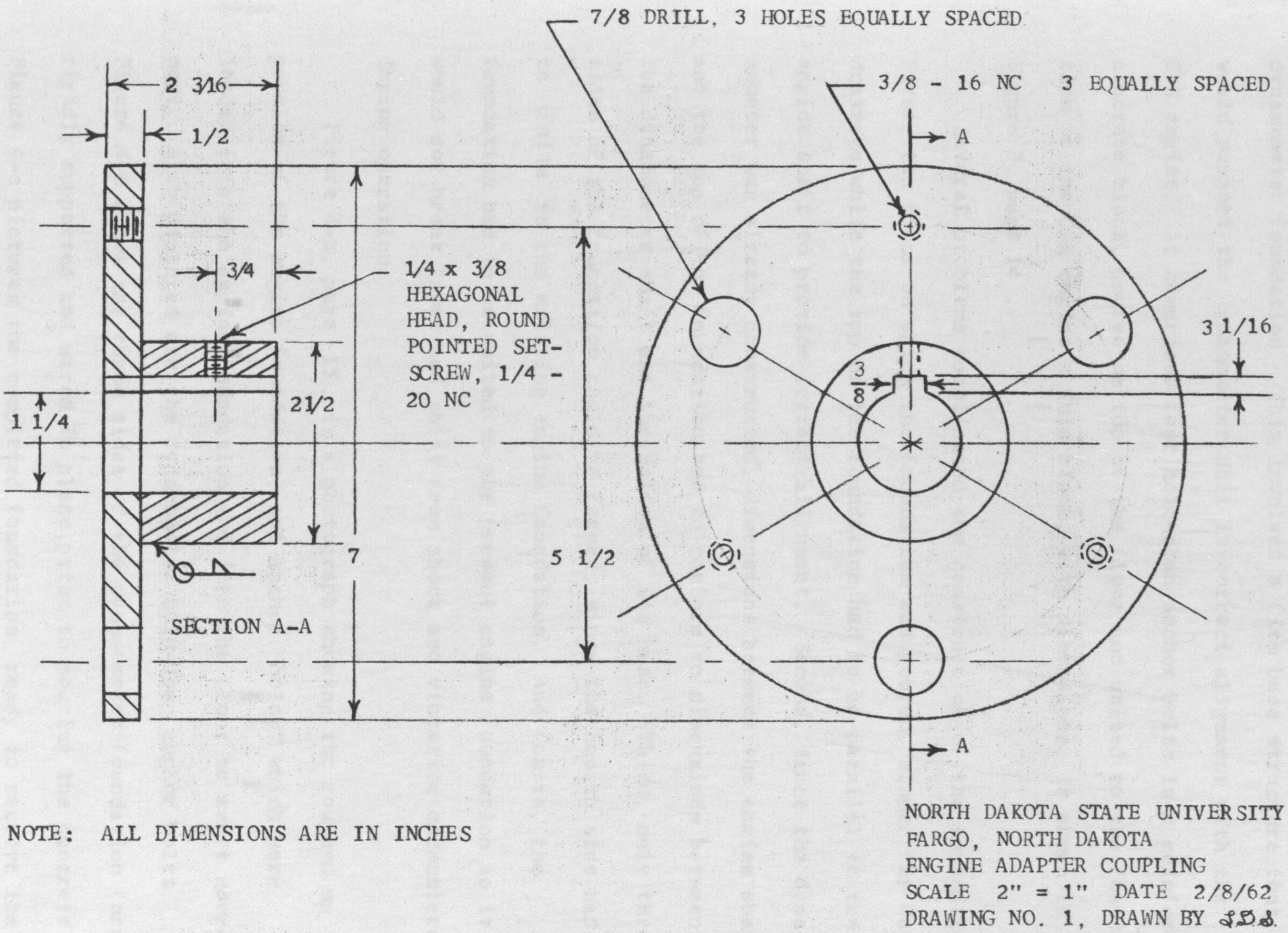


Figure 2. Engine Adaptor Coupling Drawing

dynamometer foundation. This involved a firm base structure that would support the dynamometer unit in correct alignment with the CFR engine. It comprises four hold-down anchor bolts in a reinforced concrete block, poured on top of the floor and united to the foundation of the CFR engine. This block, with dimensions, is shown in Figure 3, page 14 .

Several problems complicated the construction of the foundation. First, the floor on which the foundation was poured, sloped for water drainage while the top of the foundation had to be parallel to the engine shaft to provide correct alignment. Second, since the dynamometer was already constructed, dimensions between the engine shaft and the top of the foundation had to conform to dimensions between the dynamometer shaft and the bottom of its base. Third, only three sides of the foundation could be formed, since the fourth side had to unite to the existing engine foundation. And fourth, the foundation had to be united to the present engine foundation so it would not break loose and shift from shock and vibration encountered during operation.

Figure 4-a, page 15 , is a photograph showing the roughed up portion of the engine foundation, and anchor "holds" which were leaded into the engine foundation and into the floor to avert movement. Also pictured are the dynamometer hold-down anchor bolts. Figure 4-b shows the three sides of the dynamometer foundation form, rigidly supported and wired in place prior to pouring the concrete. Figure 4-c pictures the completed foundation, ready to receive the

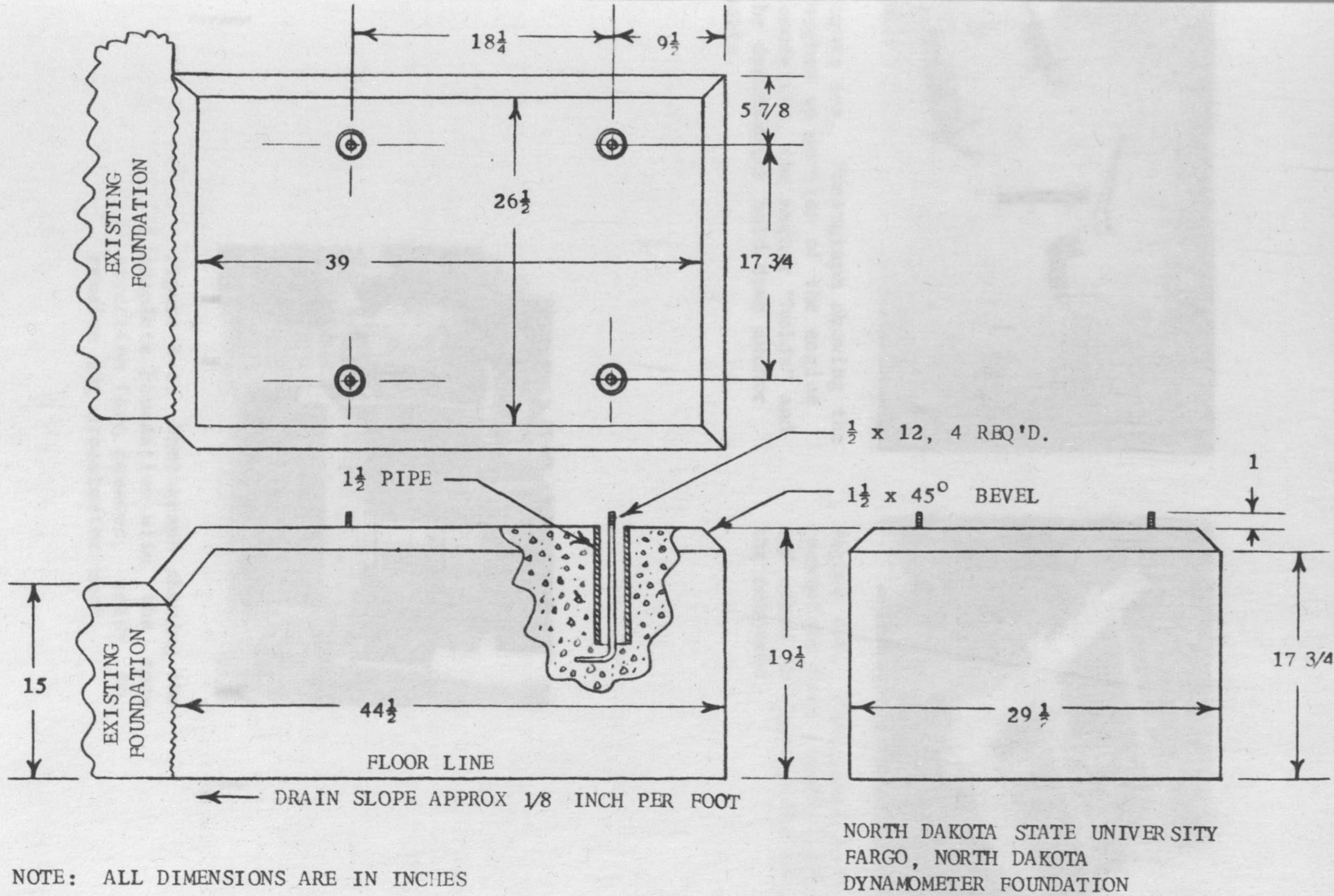


Figure 3. Sketch of Dynamometer Foundation

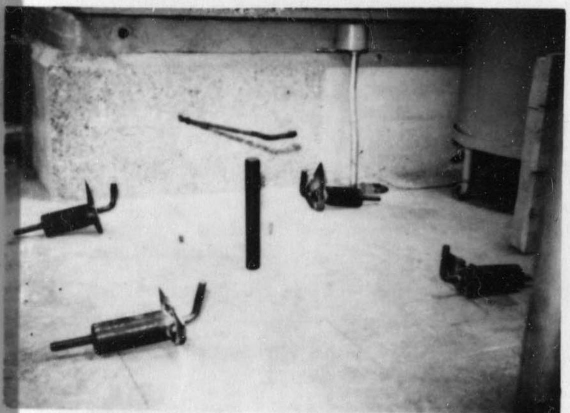


Figure 4-a. Photograph showing the roughed up portion of the engine foundation, the anchor "holds" and the dynamometer hold-down anchor bolts.

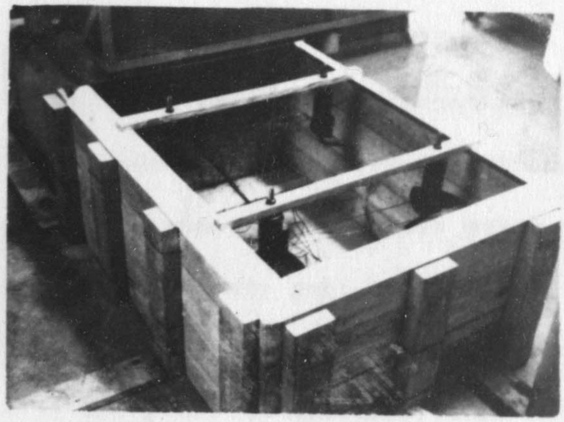


Figure 4-b. Photograph showing the foundation form rigidly supported and wired in place prior to pouring the concrete.

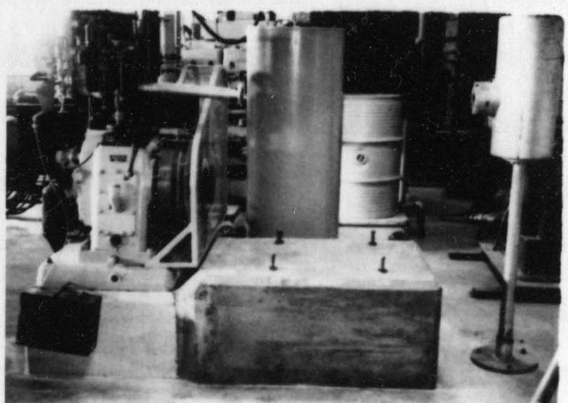


Figure 4-c. Photograph showing the complete foundation with the construction form removed, ready to receive the dynamometer unit.

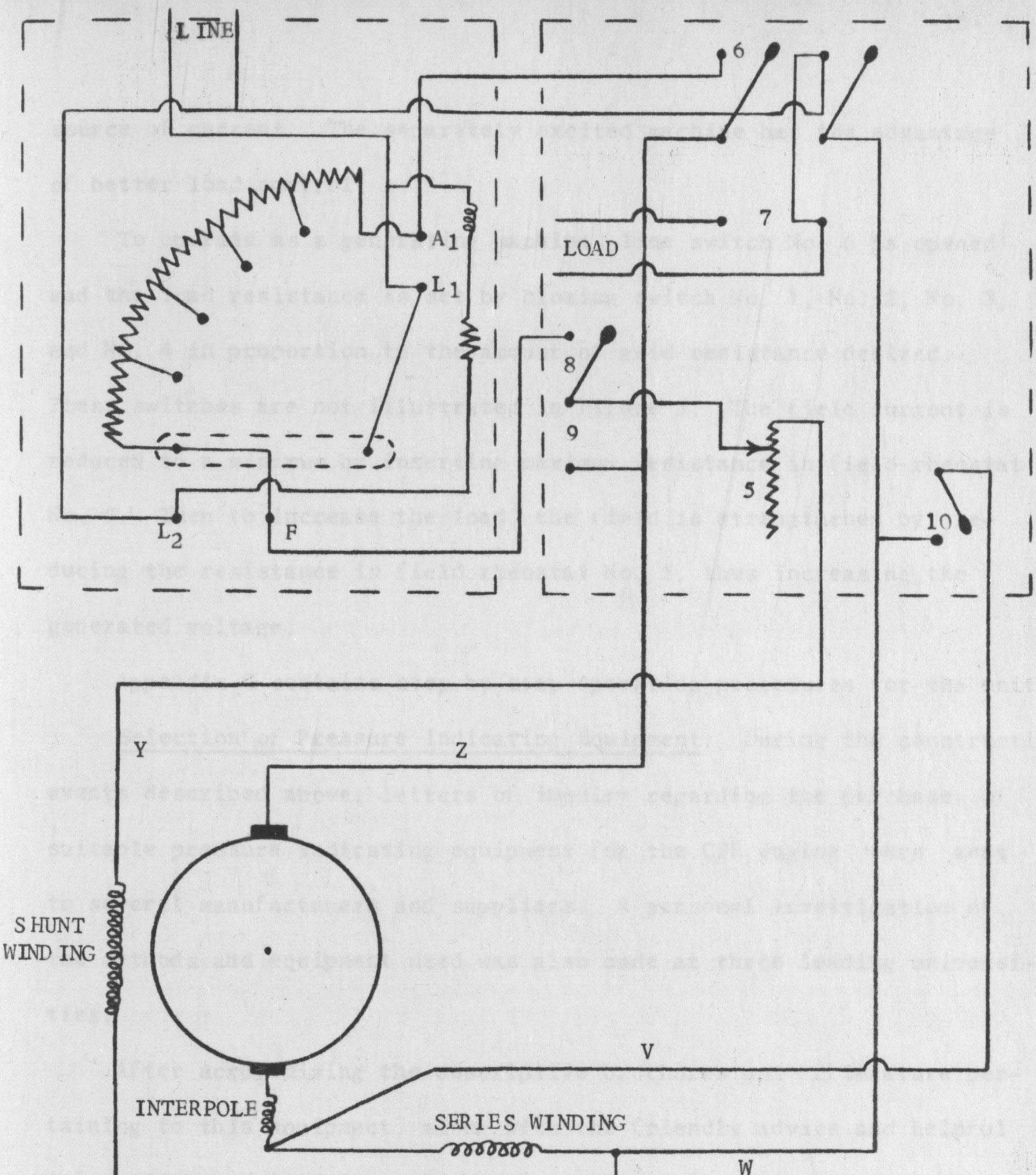
Figure 4. Photographs of Dynamometer Foundation

dynamometer unit.

Installation of Dynamometer. The dynamometer unit was aligned and coupled to the CFR engine. Drive belts between the synchronous motor and the engine were disconnected to permit dynamometer operation. Direct current wiring connections were made from the laboratory motor-generator unit to a three pole, double throw, safety switch used to direct the current to either the CFR unit or the Ford-GMC dynamometer test unit. Electrical conduit, laid in the floor of the laboratory at the time the building was constructed, was used to receive the electrical wires from the safety switch to the CFR unit.

Figure 5, page 17 , is a wiring diagram for the CFR engine dynamometer. When the dynamometer is used as a motor, rheostat No. 5 is placed at minimum resistance to provide maximum strength in the field coils. This will give the maximum starting torque. Line switch No. 6 is closed and the starting resistance is set at full resistance to limit the current to the armature. By reducing the starting resistance, the motoring speed can be increased. When the starting resistance is all cut out, the armature is directly across the line and the motor will come up to rated speed. Higher speeds may be obtained by increasing the resistance at rheostat No. 5, to reduce the field strength. Care should be taken, however, so that the motor will not reach a dangerous speed.

When the dynamometer is used as a generator, it may be self excited or excited by the motor-generator. This simply means that the field power is provided by the machine itself or by a separate



NORTH DAKOTA STATE UNIVERSITY
FARGO, NORTH DAKOTA
CFR ENGINE DYNAMOMETER
DATE 2/9/62
DRAWING NO. 3 DRAWN BY L.D.S.

Figure 5. Wiring Diagram for Dynamometer

source of current. The separately excited machine has the advantage of better load control.

To operate as a generating machine, line switch No. 6 is opened and the load resistance is set by closing switch No. 1, No. 2, No. 3, and No. 4 in proportion to the amount of grid resistance desired. These switches are not illustrated in Figure 5. The field current is reduced to a minimum by inserting maximum resistance in field rheostat No. 5. Then to increase the load, the field is strengthened by reducing the resistance in field rheostat No. 5, thus increasing the generated voltage.

Appendix C contains step by step operating procedures for the unit.

Selection of Pressure Indicating Equipment. During the construction events described above, letters of inquiry regarding the purchase of suitable pressure indicating equipment for the CFR engine were sent to several manufacturers and suppliers. A personal investigation of the methods and equipment used was also made at three leading universities.

After scrutinizing the descriptive brochures and literature pertaining to this equipment, along with the friendly advice and helpful information received from the above mentioned investigation, Kistler Instrument Corporation of North Tonawanda, New York, was selected to supply the necessary equipment. This equipment consists of the following:

(a) Kistler Model SLM 401 Pressure Responsive Quartz Crystal Pickup.

(b) Kistler Model 427 Water Cooled Adaptor.

(c) Kistler Model 471 Low Noise Pickup Cable.

(d) Kistler Model 651-B Piezo Calibrator.

The pickup is the heart of the pressure indicator. The Kistler pickup contains two semi-cylindrical natural quartz crystals mounted in a rigid column arrangement. High accuracy and excellent repeatability is obtained from crystalline quartz because it remains practically unaffected by temperature and is immune to aging effects. The transducer is also rugged and reliable because of the mechanical stability and strength of natural quartz.

When pressure or force is applied to the sensitive end of the pickup, the crystal transducer generates an electrostatic charge proportional to the input, which forms a voltage on a high-insulating capacitor. The piezo calibrator contains an electrometer tube circuit which measures this charge without providing a path for the charge to leak off and provides an output voltage signal compatible for display on a conventional oscilloscope. The piezo calibrator also has a range selector switch that controls a capacitor attenuator to provide full output voltage for different magnitudes of input applied to the pickup. The range selector switch can be set in any of the following ranges corresponding to the desired full scale value:

(1) 0 - 1.25 psi.

(2) 0 - 12.5 psi.

(3) 0 - 125 psi.

(4) 0 - 1250 psi.

(5) 0 - 3000 psi.

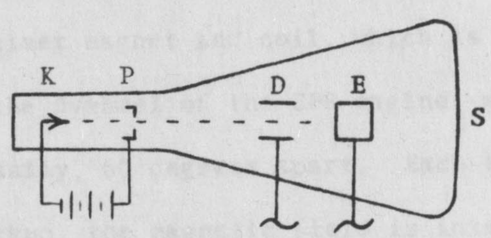
This equipment also provides for measuring the rate of change of pressure, force, or acceleration by selecting a high rate or low rate position on the range switch. The high rate provides a pressure rate of 12,500 psi/sec/dial division, while the low rate equals 1,250 psi/sec/dial division. This faculty, however, was not used in the work associated with this thesis. A complete operation booklet and operation guide have been supplied by Kistler Instrument Corporation to facilitate correct operation of the pressure indicating equipment.

<u>Installation of Pressure Pickup and Water Cooled Adaptor</u>. It has been stated that the quartz crystal pickup remains practically unaffected by temperature. However, at temperatures above 400^{o} F the internal resistance of the pickup decreases rapidly. The manufacturer recommends that the temperature of the quartz pickup should not exceed 150^{o} F. to obtain good static response. To protect the pickup from prejudicial temperatures and to facilitate mounting the pickup in the knock meter bouncing pin hole, a water-cooled adaptor was used. Figure 6, page 24 , is a photograph showing the water-cooled adaptor and the quartz crystal pickup installed in the knock meter bouncing pin hole of the CFR engine. The water supply and outlet lines of the water-cooled adaptor may also be seen. Also shown is a portion of the special low-noise, high insulating value, coaxial cable, connected from the pickup to the input of the piezo-calibrator. This special cable is necessary to minimize noise, ignition, and other electrical interference.

Engine Vacuum Aperture. A line equipped with a 3/8 inch stopcock was tapped into the intake manifold to provide a means for measuring the intake vacuum of the engine. This may also be seen in the photograph of Figure 6. The vacuum gage of the Sun Motor Tester pictured in Figure 10, page 28 , may be used to indicate this value.

Cathode-ray Oscilloscope. The cathode-ray oscilloscope used is a Du Mont Model 304-H. This device is used for measuring the instantaneous variations of cylinder pressure by indicating the electrostatic charge generated by the pressure pickup. It eliminates the inertia effect of moving parts found in mechanical engine indicators commonly used with engines of low rotative speed, by utilizing beams of electrons instead of mechanical linkages.

The principal part of the oscilloscope is the cathode-ray tube shown schematically below:



This indicating tube is a glass bulb which is evacuated of air. Within the tube is a cathode, K, which emits a stream of free electrons when the tube is in operation. These electrons are attracted by the anode, P, and while some actually reach the anode, others pass through the hole in the anode into the enlarged portion of the tube. The anode not only attracts the electrons, but serves to condense the electron stream and focus it on screen, S, at the end of the tube. The screen is coated with phosphorescent or fluorescent material which produces a spot of light upon the impact of the electrons. This light is used as the indicator to register engine phenomena.

To portray pressure-time variations, the spot of light is deflected by a vertical set of deflection plates, D, and a horizontal set of deflection plates, E. The deflecting plates are used to impart a force on the electrons as they pass by. When a voltage is applied to the deflecting plates, the beam of electrons is deflected in direct proportion to time or angular position on one, and in direct proportion to cylinder pressure for the other. The time required for an electron to pass through a set of deflecting plates is of the order of 10^{-9} second. Therefore, very rapid changes in pressure can be studied.

Magnetic Pickup. A magnetic pickup is utilized to plot the pressure studies against time or angular position. The pickup consists of a telephone receiver magnet and coil, which is mounted approximately $\frac{1}{2}$ inch away from the flywheel of the CFR engine, where six bolts are attached, individually, 60 degrees apart. Each time a bolt head passes the magnetic pickup, the magnetic field is interrupted. This generates an electrical a-c voltage pulse. A conventional pentode voltage amplifier increases this electrical pulse to the level needed to modulate the oscilloscope beam. The electrical pulse is introduced into the "z" input of the oscilloscope to superimpose a bright "pip" on the pressure trace, indicating 60 degrees of crank shaft rotation. This signal is also used to synchronize the sweep of the oscilloscope with the crankshaft rotation by connecting to the external sync terminal on the oscilloscope. Figure 7, page 24 , is a photograph showing the magnetic pickup installed on the CFR engine. The conventional pentode voltage amplifier is located in the electrical chassis which can be seen in Figure 10, page 28 . This amplifier is the only portion of the electrical chassis used in the work associated with this thesis.

Spark Advance Control. It was stated that the spark advance on the CFR engine is automatically controlled for changes in compression ratio. For tests related to firing timing, the need existed for an independent method of controlling the spark advance. This was done by fabricating a turn-buckle with a right-and-left screw link to vary the length of the control rod, thus changing the spark timing. The turn-buckle permits the rod length to vary, regulating the spark advance over a range of spark timing from 40 degrees before TDC to 40 degrees after TDC. Figure 8, page 26 , is a photograph showing the turn-buckle determinant. Lock nuts on each end of the turn-buckle spark advance control rod, occlude and avert turn-buckle action for accurate automatic control of spark advance during compression ratio changes.

Ignition Test Lead. An ignition test lead was fabricated to note the spark response on the oscilloscope screen. When the lead is connected it superimposes two vertical spikes of very narrow width on the pressuregraph picture, indicating when the points open and close, when the spark starts, the dwell angle, and the cam angle. The lead consists of a coaxial cable, 72 inches long. On the engine end of the cable are two leads provided with spring clips. The black lead is clipped around

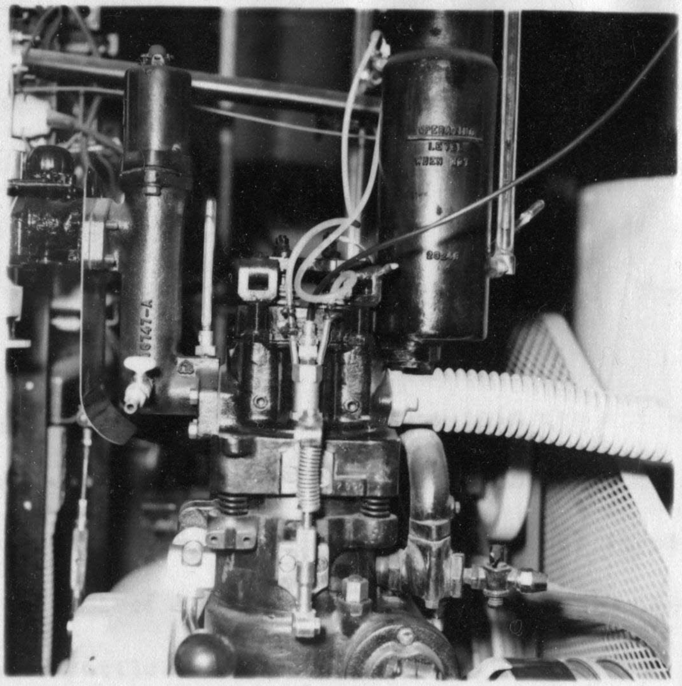


Figure 6. Photograph showing the water cooled adaptor and the quartz crystal pickup installed in the knock meter bouncing pin hole of the CFR engine.

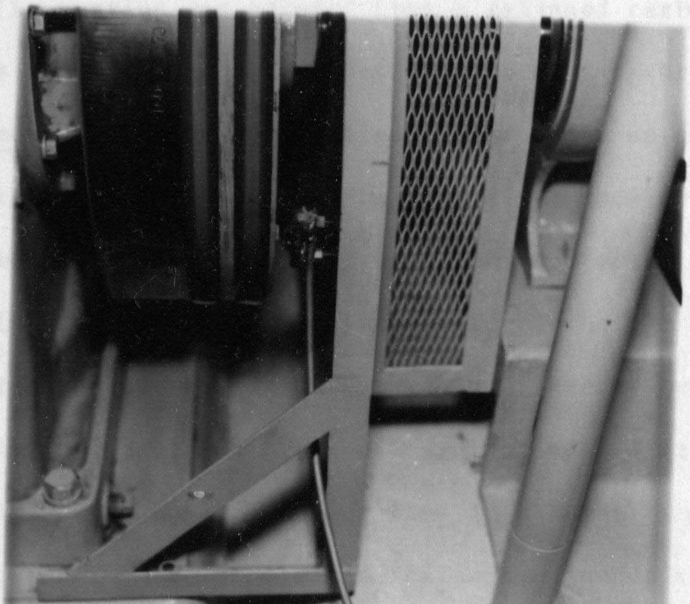


Figure 7. Photograph showing the magnetic pickup installed on the CFR engine.

the spark plug wire, while the yellow lead is clipped to a ground connection provided on the CFR engine for that purpose. The black and yellow leads on the oscilloscope end of the cable are connected to the vertical input and ground terminals, respectively. The ignition test lead may be observed in Figure 10.

Throttle Control. Also required in this project was some means of regulating the speed of the CFR engine, independently of the load. This was accomplished by constructing a butterfly throttle valve to regulate the amount of fuel-air mixture admitted to the combustion chamber. The throttle valve was installed between the carburetor and the intake manifold heater.

Figure 9, page 26 , is a photograph of the throttle control valve. The butterfly portion was adopted from a salvaged carburetor. A wing lock nut is used to lock the throttle valve in any throttle setting.

Tachometer. During the testing of the unit, an accurate means of obtaining the rotative speed of the engine was required. Several tachometers were tried and compared, and many different ones could be successfully used. However, the one employed for the tests included in this report is an electric tachometer, manufactured by The Standard Electric Time Company. It has three indicating dials: one showing speed in rpm., one showing elapsed time in minutes, and the third a revolution counter. The rpm dial indicates continuously and is used in tests to set the throttle at any desired speed. The other two dials are controlled by a pushbutton, which starts both and stops both after a definite time period, thus indicating the actual number of revolutions

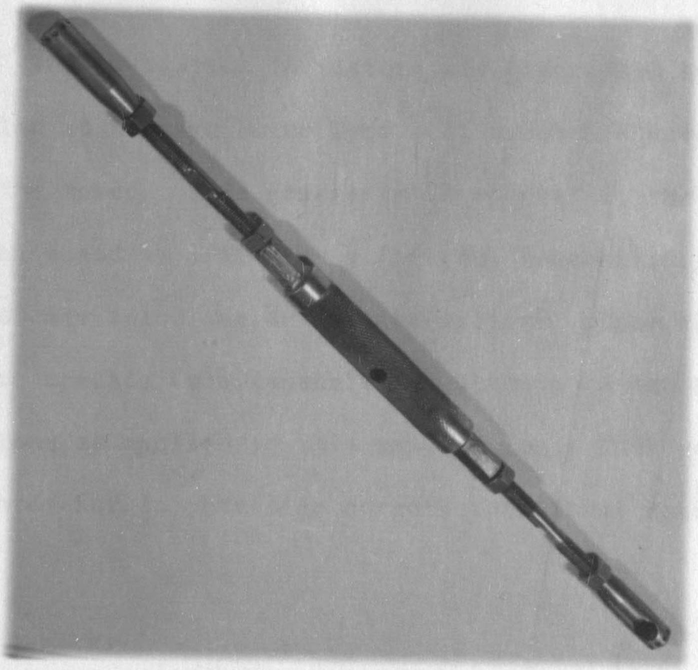


Figure 8. Photograph of Spark Advance Control Turn-buckle.

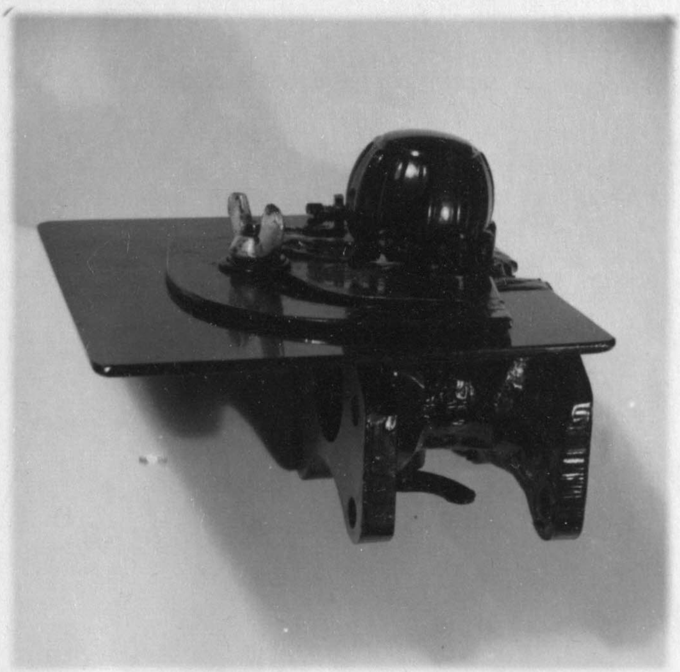
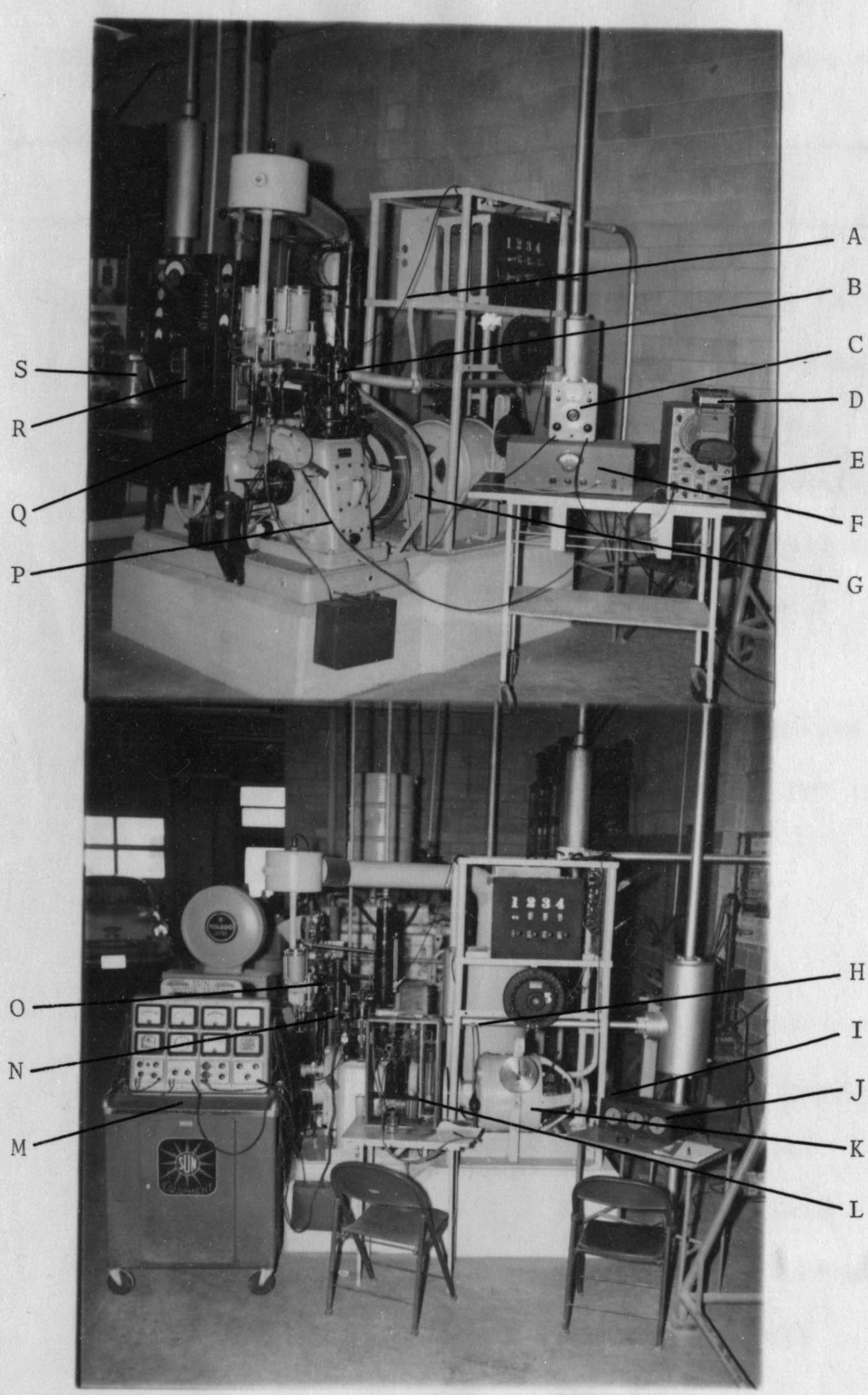


Figure 9. Photograph of Throttle Control Valve.

in that time. The revolution indicators are controlled by a small generator called an Autosyn Motor Type - I, which produces a current varying with the speed. This generator is mounted at the end of the dynamometer shaft and is driven by a flexible connection. The revolution dials indicate twice the actual revolutions, since the tachometer was designed to operate from camshaft revolutions rather then crankshaft revolutions as applied in this application. This correction must be accounted for in obtaining correct rotational speed.



NOTE: Letters refer to equipment and parts listed in Table 2.

Figure 10. Test Setup and Equipment

TABLE 2. IDENTIFICATION OF EQUIPMENT AND PARTS FOR FIGURE 10

LETTER	NAME
A	Low Noise Pickup Cable
B	Quartz Crystal Pickup
C	Piezo Calibrator
D	Polaroid Land Camera
E	Cathode-ray Oscilloscope
F	Electrical Chassis
G	Magnetic Pickup
H	Exhaust-gas Sampling Stopcock
I	Autosyn Motor Type - I
J	Tachometer
K	Dynamometer
L	Orsat Apparatus
M	Sun Motor Tester
N	Engine Vacuum Stopcock
O	Throttle Control
P	Ignition Test Lead
Q	Spark Advance Control
R	Graduate Cylinder
S	Fuel Can

NOTE: Letters refer to equipment and parts on Figure 10.

SECTION III

TESTS AND SUGGESTED EXPERIMENTS

On the following pages are a number of tests that have been performed to determine and illustrate some of the possibilities of the test unit with which this paper is concerned. These tests are only a suggestion of the experiments that may be developed on this equipment to teach students through actual laboratory testing, the verification of some of the fundamentals of the reciprocating, spark-ignition, internal combustion engine. The tests are covered concisely, yet adequately enough to enable a cognizant operator to understand and reproduce the tests. Only the scope of the test is covered since it is felt that the form of the experiment should be left up to the instructor in charge. This intent is presented by a brief discussion on the purpose of the tests and the results obtained. The actual relevant performance characteristics for nearly all of the tests are shown in graphic form. Test data sheets are also included for information not in the discussion or in the curves but relating to the operation and conduct of the test.

Humidity was not controlled in these tests since this factor was considered of slight importance. However, barometric pressure and ambient temperature were considered by applying the applicable correction factor. Formulas and definitions of terms used for calculated results are included in Appendix A.

Fuel consumption was obtained by recording the time required for the engine to use a measured volume of fuel by means of a graduated cylinder. This measured volume was then converted to weight.

Each test was initiated by allowing the engine to reach operating temperatures and the electrical equipment to thoroughly warm up. In the majority of tests, standard operating conditions, as specified for the motor method of rating fuels, were maintained. In each test, unless otherwise specified, a regular grade fuel was used.

FULL-LOAD, VARIABLE-SPEED TEST

The full-load, variable-speed test is a standard Society of Automotive Engineers experiment to determine the performance characteristics of an engine. It is performed primarily on engines designed to operate under variable speed conditions, such as automotive and marine engines.

The objective of this test is to ascertain significant operating traits of the engine, functioning at maximum power and different speeds. This test was performed by operating the engine at full throttle and adjusting the dynamometer load so as to maintain the desired speed for each run. The spark timing was then adjusted to give maximum power at each speed. The test depicted on pages 67 to 70 was used to expedite spark timing adjustment. For each run, the fuel consumption, average speed, brake load, temperatures and other data necessary to calculate the required results as well as reproduce the test were recorded. The test figures and derived results are shown on the data sheet, page 33 .

Figure 11, page 34 , shows the performance curves obtained from this test. These performance curves do not picture all information pertinent to engine performance, but only give the important factors measured in routine tests. The curves are typical in form for spark ignition engines, however, since the CFR engine is not specifically designed to operate under variable speed conditions, only a small speed range can be illustrated.

The curves show that the optimum operating conditions occur near 900 rpm, which is the specified operating speed of the engine. This illustrates

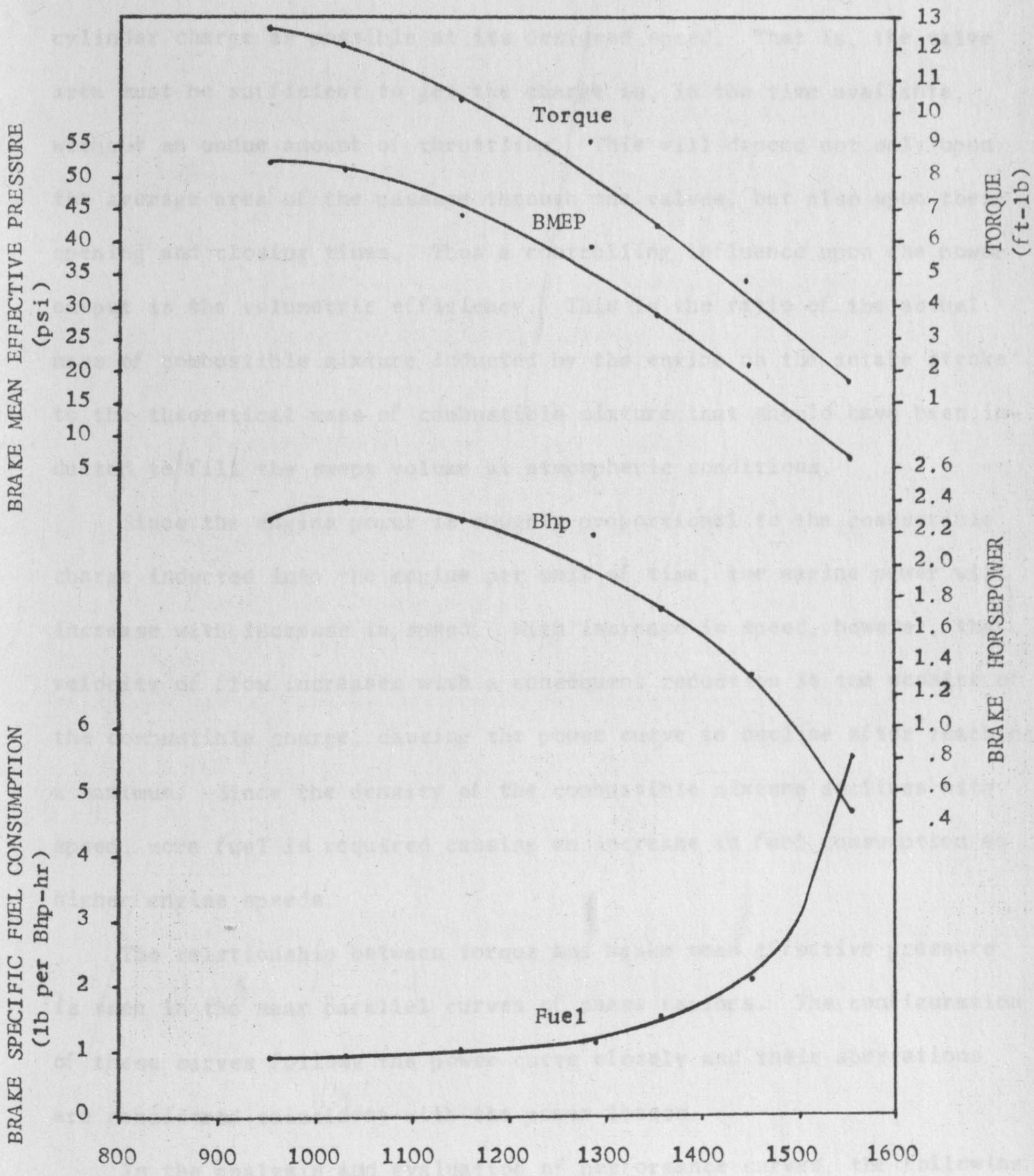
DATA SHEET

FULL-LOAD, VARIABLE-SPEED TEST

Barometer	29.13 in. Hg.	Date	December 30, 1961
Dry Bulb	73 °F.	Oil Temp.	135 °F.
Tare	0.5 pounds	Coolant Temp.	210 °F.
Fuel Level	1.3 (Bowel 1) in.	Intake Air Temp.	100 ± 25 °F.
Fuel Consumption	200 ml/run equals 0.30 lb/run	Mixture Temp.	300 ± 2 °F.
		Compression Ratio	6.0:1
Throttle position	wide open	Micrometer Reading	0.400

1. Run No.	1	2	3	4	5	6	7
2. Time, minutes	10.400	9.900	9.107	8.673	8.083	7.879	7.409
3. Total Rev. obs.	19,908	20,394	20,910	22,346	22,039	22,877	23,037
4. Rev., corr.	9,954	10,197	10,455	11,173	11,019	11,438	11,518
5. Ave. rpm.	955	1030	1150	1289	1363	1450	1555
6. Brake load obs., lbs.	10.75	10.50	9.00	8.00	6.00	4.50	2.00
7. Brake load corr., lbs.	10.25	10.00	8.50	7.50	5.50	4.00	1.50
8. Bhp obs.	1.86	1.96	1.86	1.83	1.42	1.10	0.43
9. Correction Factor	1.24	1.24	1.24	1.24	1.24	1.24	1.24
10. Bhp corr.	2.31	2.43	2.31	2.27	1.76	1.36	0.53
11. Torque corr. lb-ft.	12.72	12.40	10.55	9.30	6.82	4.96	1.86
12. BMEP, psi	43.2	42.3	36.2	32.2	24.1	18.1	6.0
13. BMEP corr., psi.	53.6	52.5	44.9	39.9	29.9	22.4	7.4
14. SFC, lb/hr.	1.73	1.82	1.98	2.07	2.23	2.29	2.43
15. BSFC, lb/Bhp-hr.	0.93	0.93	1.06	1.13	1.57	2.08	5.65
16. Spark Timing °BTDC	16	16	15	15	17	20	22
17. Oil press., psi.	31	32	33	34	34	34	35

Figure 11. Performance Curves for Full-load, Variable-speed Test



that the performance characteristics are imposed by mechanical considerations inherent to the design of the engine. For example, the engine's breathing arrangements are designed to enable it to get as nearly a full cylinder charge as possible at its designed speed. That is, the valve area must be sufficient to get the charge in, in the time available, without an undue amount of throttling. This will depend not only upon the average area of the passage through the valves, but also upon their opening and closing times. Thus a controlling influence upon the power output is the volumetric efficiency. This is the ratio of the actual mass of combustible mixture inducted by the engine on the intake stroke to the theoretical mass of combustible mixture that should have been inducted to fill the swept volume at atmospheric conditions.

Since the engine power is roughly proportional to the combustible charge inducted into the engine per unit of time, the engine power will increase with increase in speed. With increase in speed, however, the velocity of flow increases with a consequent reduction in the density of the combustible charge, causing the power curve to decline after reaching a maximum. Since the density of the combustible mixture declines with speed, more fuel is required causing an increase in fuel consumption at higher engine speeds.

The relationship between torque and brake mean effective pressure is seen in the near parallel curves of these factors. The configuration of these curves follows the power curve closely and their aberrations are considered coincident with the power losses.

In the analysis and evaluation of performance curves, the following points are of particular interest: (Values are obtained from the curves, some by means of extrapolation for the reason already mentioned.)

(a) Maximum or peak horsepower and the speed at which this brake horsepower occurs. (Approximately 2.4 Bhp at 1030 rpm).

(b) Value of maximum torque and the speed at which it occurs. (Approximately 13 lbs.-ft. at 900 rpm).

(c) Ratio of speed at maximum torque to speed at maximum brake horsepower. Approximately 900/1030 equals 0.87).

(d) Maximum brake mean effective pressure and ratio of brake mean effective pressure at peak brake horsepower to maximum brake mean effective pressure. (Approximately 54 psi ; 52/54 equals 0.96).

(e) Minimum brake specific fuel consumption and speed at which it occurs. (Approximately 0.9 lb/Bhp-hr at 900 rpm).

CONSTANT SPEED TEST

The constant speed test is a routine performance test run chiefly on land power plant engines or engines designed to operate at constant rotative speed. The purpose of the test is to determine the specific fuel consumption for different load demands on the engine.

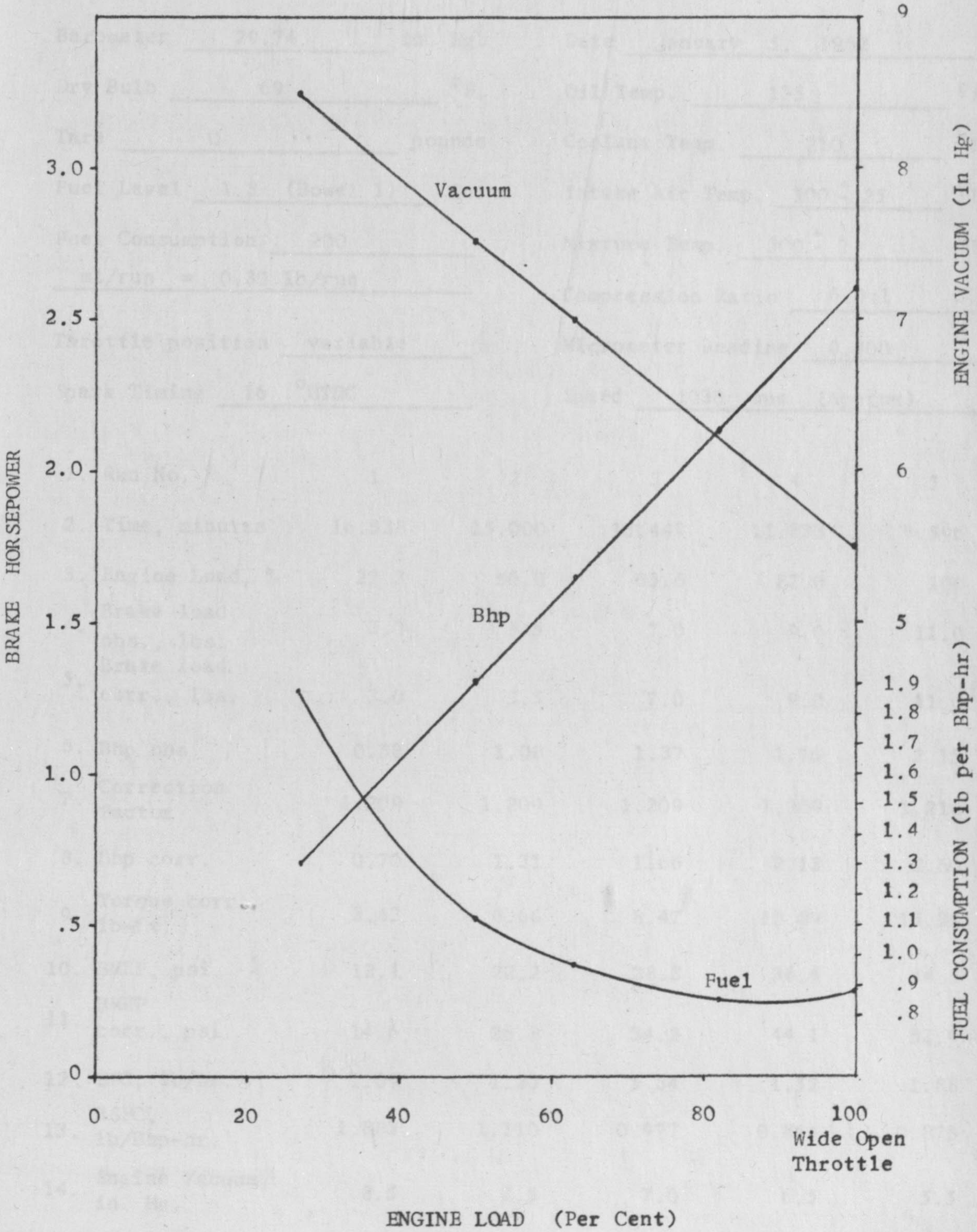
This test was performed by varying the throttle from no load to full load for the different test runs, while maintaining a constant speed. The spark advance was held constant and the mixture ratio varied only as normally caused by varied air flow through the carburetor and as explained below.

The performance curves obtained, are illustrated in Figure 12, page 38. They are typical for this type of test and show that the specific fuel consumption has a minimum value at some power output. The specific fuel consumption is a comparative parameter that shows how efficiently the engine is converting fuel into work. The results of this test would indicate that optimum performance is obtained for the CFR engine near 90 per cent load, obtained by drawing a horizontal tangent to the fuel curve. It may be assumed that at this point the engine has complete combustion of the air-fuel mixture.

At wide open throttle, the engine is running at maximum power and requires a rich mixture strength increasing the fuel consumption per horsepower. At part throttle, the pressures are reduced throughout the cycle increasing the proportion of exhaust gas present during the compression. This exhaust gas which mingles with the fresh charge may easily be doubled under throttled conditions and this dilution

Figure 12. Performance Curves for

Constant Speed Test



DATA SHEET

CONSTANT SPEED TEST

Barometer 29.74 in. Hg.

Date January 5, 1962

Dry Bulb 69 °F.

Oil Temp. 135 °F.

Tare 0 pounds

Coolant Temp. 210 °F.

Fuel Level 1.3 (Bowel 1) in.

Intake Air Temp. 100 ± 25 °F.

Fuel Consumption 200 ml/run = 0.30 lb/run

Mixture Temp. 300 ± 2 °F.

Compression Ratio 6.0:1

Throttle position variable

Micrometer Reading 0.400

Spark Timing 16 °BTDC

Speed 1030 rpm (Approx)

1. Run No.	1	2	3	4	5
2. Time, minutes	16.538	15.000	13.449	11.833	9.596
3. Engine Load, %	27.3	50.0	63.6	82.0	100
4. Brake load obs., lbs.	3.0	5.5	7.0	9.0	11.0
5. Brake load corr., lbs.	3.0	5.5	7.0	9.0	11.0
6. Bhp obs	0.58	1.08	1.37	1.76	2.15
7. Correction Factor	1.209	1.209	1.209	1.209	1.210
8. Bhp corr.	0.70	1.31	1.66	2.13	2.60
9. Torque corr., lb-ft.	3.63	6.66	8.47	10.89	13.30
10. BMEP, psi.	12.1	22.2	28.3	36.4	44.5
11. BMEP corr., psi	14.6	26.8	34.2	44.1	53.9
12. SFC, lb/hr.	1.09	1.20	1.34	1.52	1.88
13. BSFC, lb/Bhp-hr.	1.883	1.110	0.977	0.864	0.875
14. Engine Vacuum, in. Hg.	8.5	7.5	7.0	6.5	5.5

severely effects the fuel consumption per horsepower. Many engines incorporate a means of ignition advance to counteract this effect of increased dilution and slow burning. This regulation is usually automatically accomplished by engine vacuum. The engine vacuum curve pictures the relationship with load and the linarity at which it occurs for control in advancing the ignition.

STUDY OF PRESSURE-TIME DIAGRAMS

The knowledge of the amount of pressure developed within the combustion chamber at any given time is useful in studying the performance of the engine. The pressures encountered during the engine cycle are directly related to events governing the operation, such as, fuel mixtures, changes in ignition, engine load, rotative speed, compression ratio, fuels, and the mechanical condition of the engine.

This experiment illustrates the pressure patterns obtained for various predetermined operating conditions. Except where otherwise stated, all diagrams are obtained at full open throttle, with the speed maintained at approximately 1000 rpm by motorizing the dynamometer. The compression ratio was set at 6.0 to 1 with ignition occurring 17 degrees before TDC. The carburetor was set at a fuel level of 1.3 inches and the air, mixture, and coolent temperatures were maintained at 100, 300, and 210 degrees F respectively.

Varied Air-Fuel Ratio. Figure 13, page 43 , shows the effects of a rich and a lean air-fuel mixture as compared to a normal mixture. Figure 13-a was the resulting trace of pressure versus crankshaft degrees (time) for a rich mixture, obtained by setting the carburetor fuel level at .2 inches. This produced a air-fuel ratio near 10.25 : 1 resulting in a maximum pressure of 388 psi. The fuzzy, heavy part of the trace results from that portion of the diagram produced while the camera shutter was open.

Figure 13-b shows the results of a lean mixture. The carburetor was set at a fuel level of 2.8 inches producing an air-fuel ratio of

about 19.6 : 1. At this setting, several misfirings occurred due to lack of combustible mixture in the combustion chamber. The lower light trace indicates compression pressure only, obtained when no ignition resulted, while the upper light trace indicates the pressure obtained from ignition of the enriched combustible charge in the cylinder after the misfire. It can be seen that this resulted in rough engine operation while the peak pressure on the diagram proper was only 312 psi indicating power loss relative to the rich mixture diagram.

Figure 13-c shows the results obtained for the normal diagram. The trace indicates that the pressure begins to rise at approximately 120 degrees before TDC and continues to rise at an increasing rate until TDC, where it rises at a greater rate to a maximum pressure of 413 psi around 20 degrees after TDC. From this point it decreases rapidly until 120 degrees after TDC, where it levels off slightly, indicating the opening of the exhaust valve, and then drops to a minimum around 240 degrees after TDC.

Varied Ignition Spark Timing. Figures 14, 15, and 16, pages 45, 46, and 48, respectively, illustrate the effects of varied ignition spark timing. Figure 14-a was obtained with ignition occurring 30 degrees after TDC. The trace indicates that the pressure increased due to compression to TDC. This compression pressure is around 137 psi. Then the combustion pressure occurred reaching a maximum of only 100 psi about 90 degrees after TDC. This pressure is considerably below the compression pressure since the piston is nearly at the bottom of its power stroke. Pressure occurring at this time will not produce an

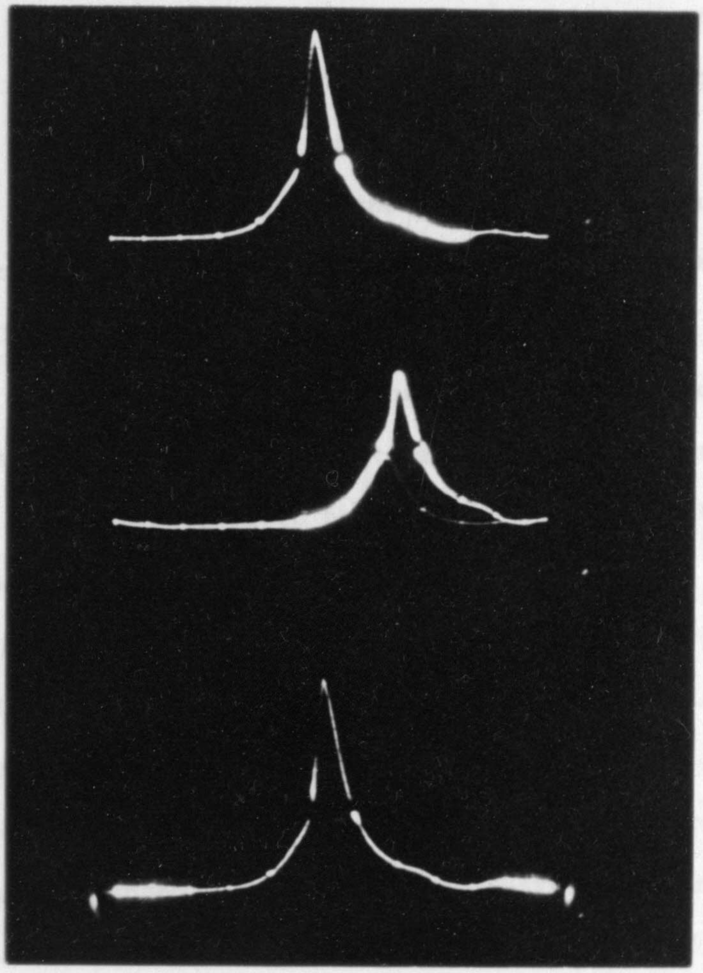
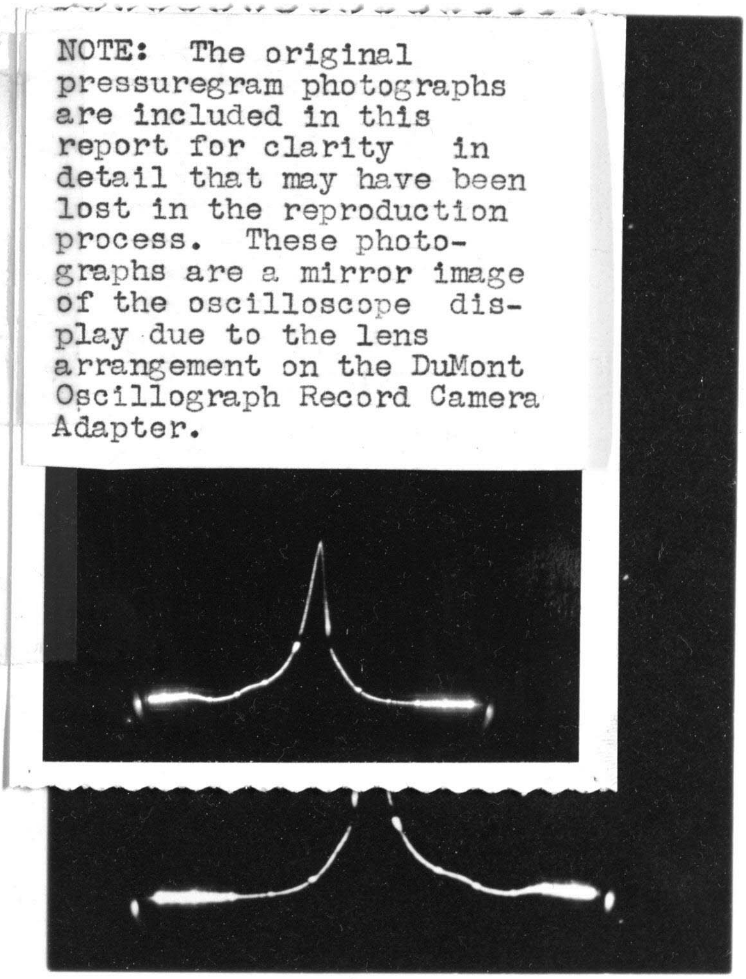


Figure 13. Pressuregram. Varied Air-Fuel Ratio (a) Rich mixture. (b) Lean mixture. (c) Normal diagram (normal mixture and spark).

NOTE: The original pressuregram photographs are included in this report for clarity in detail that may have been lost in the reproduction process. These photographs are a mirror image of the oscilloscope display due to the lens arrangement on the DuMont Oscillograph Record Camera Adapter.

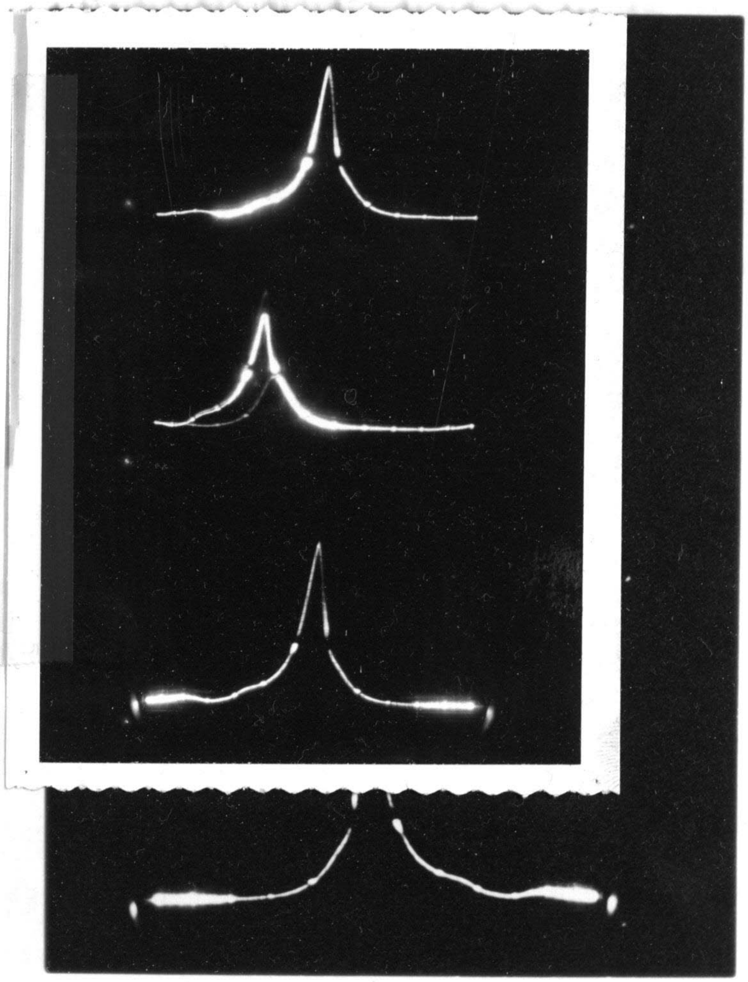


(a)

(b)

(c)

Figure 13. Pressuregram. Varied Air-Fuel Ratio (a) Rich mixture. (b) Lean mixture. (c) Normal diagram (normal mixture and spark).



(a)

(b)

(c)

Figure 13. Pressuregram. Varied Air-Fuel Ratio (a) Rich mixture. (b) Lean mixture. (c) Normal diagram (normal mixture and spark).

appreciable power output from the engine.

Figure 14-b pictures the pressure trace with ignition set to occur 20 degrees after TDC. A maximum combustion pressure of 144 psi was attained approximately 70 degrees after TDC.

Figure 14-c was obtained with the spark resulting 10 degrees after TDC. The combustion pressure peaked at 187 psi about 50 crankshaft degrees after TDC.

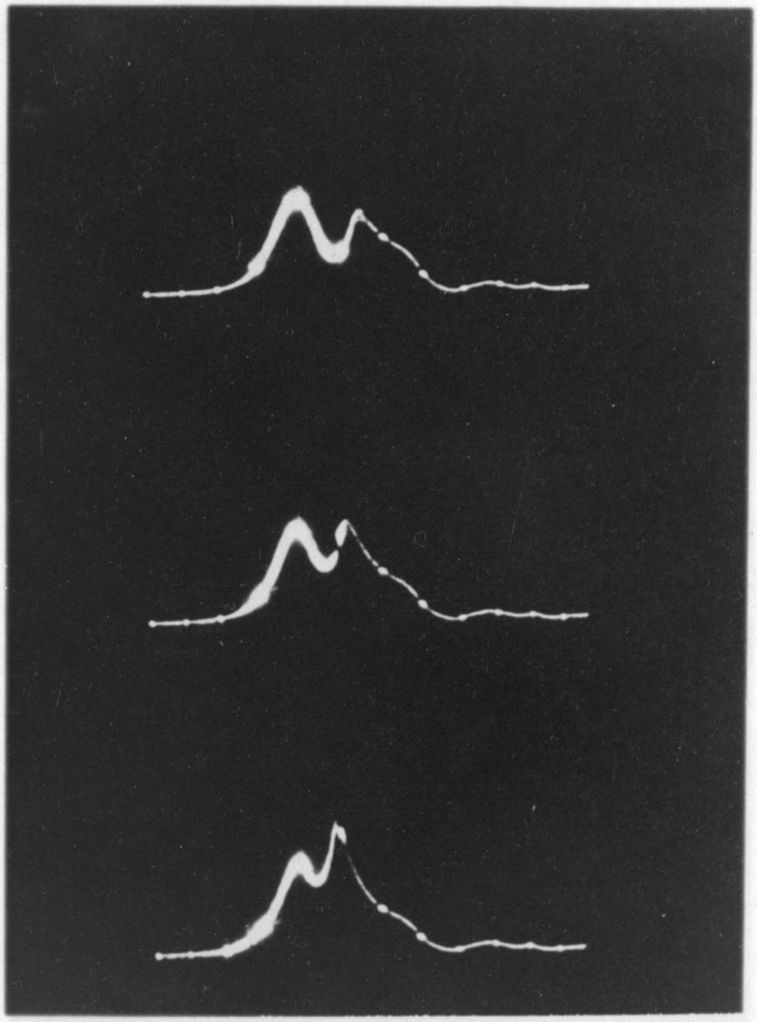
Figure 15-a was obtained with the ignition occurring 30 degrees before TDC. At this setting, audible detonation was present and the rate of pressure rise can be seen to be quite rapid. The peak pressure of 463 psi was not photographed in this trace.

Figure 15-b is the result obtained with the ignition firing at 20 degrees before TDC. A slightly lower rate of pressure rise is evident, producing a maximum pressure of 425 psi.

With the ignition set at 10 degrees before TDC, the trace of Figure 15-c was photographed. The delay of combustion pressure is evident from this trace since the pressure tends to level off near TDC. A maximum pressure of 356 psi was attained.

Figure 16-a was obtained with a very lean mixture (the same as Figure 13-b) and the spark advanced to 30 degrees before TDC resulting in a maximum pressure of 425 psi. Audible detonation was present and can be seen in this diagram.

Figure 16-b reveals the diagram obtained from a very rich mixture (the same as Figure 13-a) and the spark advanced to 30 degrees before TDC. Audible detonation was present and more profound then that of

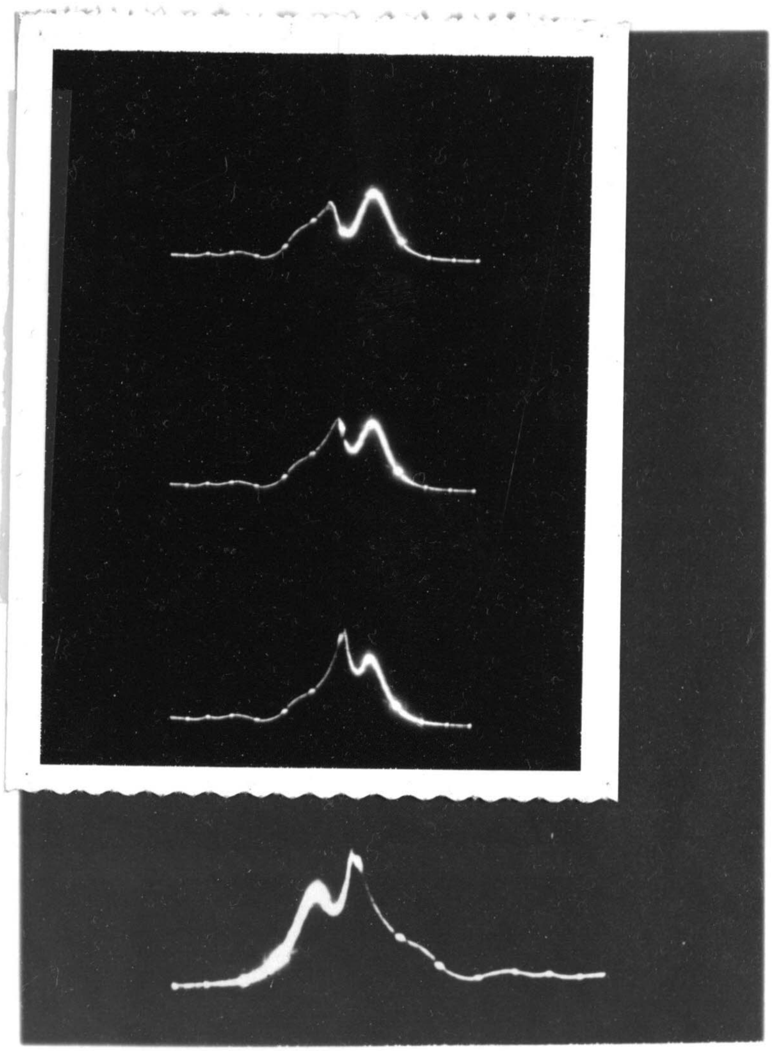


(a)

(b)

(c)

Figure 14. Pressuregram. Varied Ignition Spark Timing. (a) Ignition 30 degrees after TDC. (b) Ignition 20 degrees after TDC. (c) Ignition 10 degrees after TDC.



(a)

(b)

(c)

Figure 14. Pressuregram. Varied Ignition Spark Timing. (a) Ignition 30 degrees after TDC. (b) Ignition 20 degrees after TDC. (c) Ignition 10 degrees after TDC.

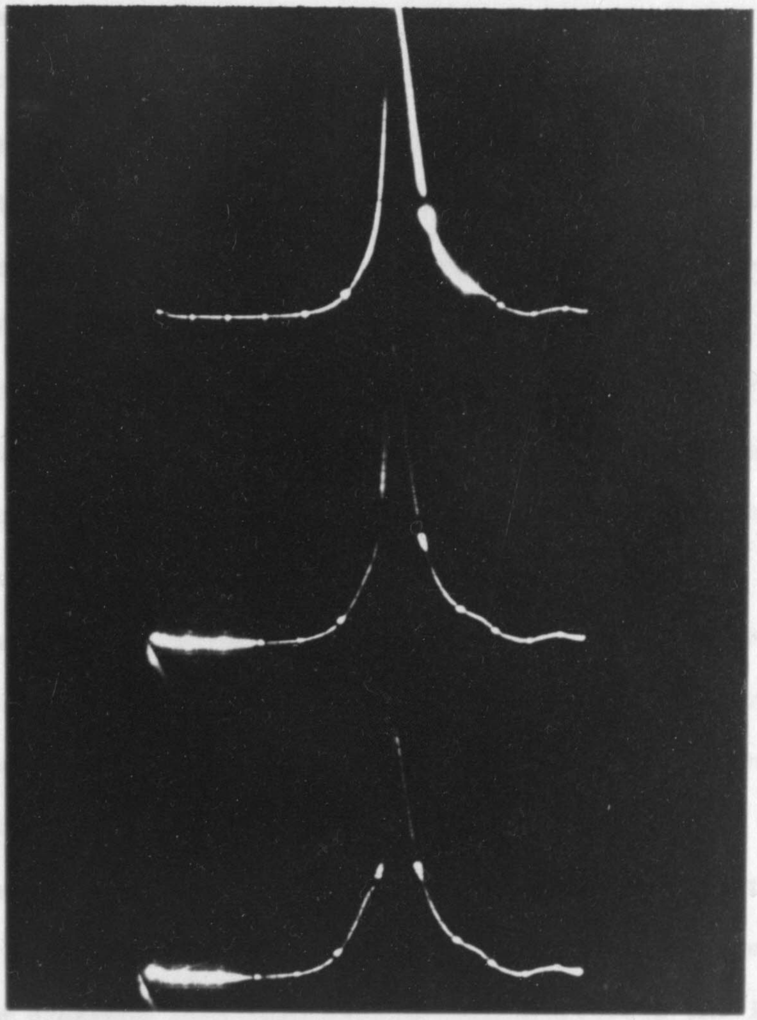
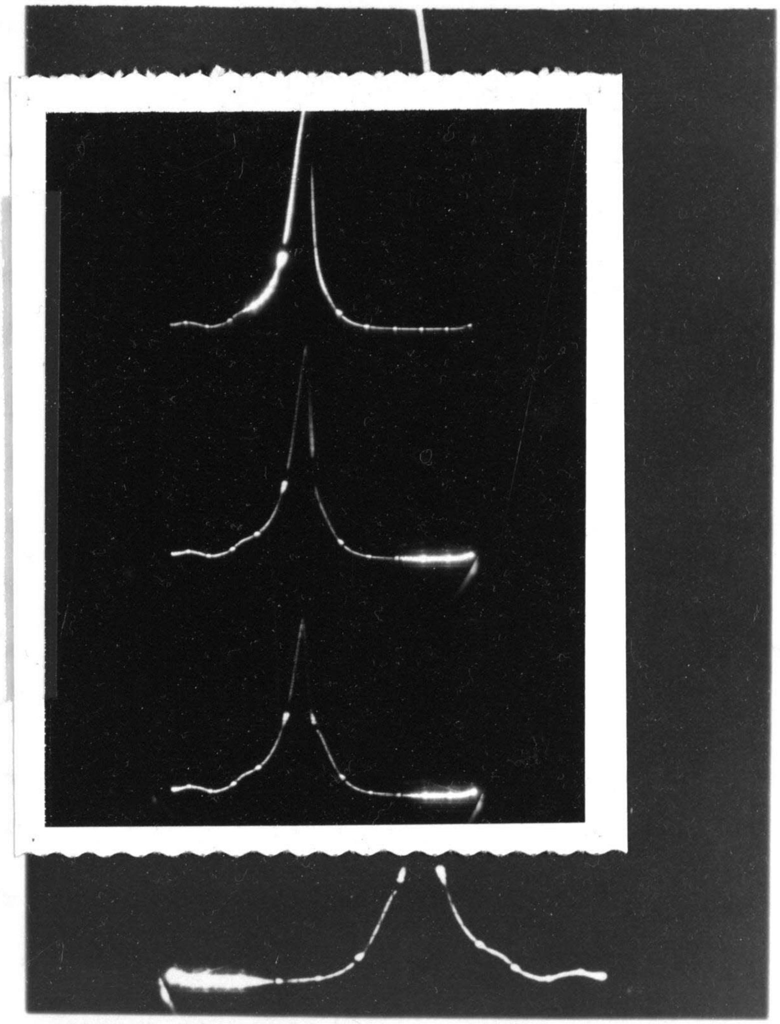


Figure 15. Pressuregram. Varied Ignition Spark Timing. (a) Ignition 30 degrees before TDC. (b) Ignition 20 degrees before TDC. (c) Ignition 10 degrees before TDC.



(a)

(b)

(c)

Figure 15. Pressuregram. Varied Ignition Spark Timing. (a) Ignition 30 degrees before TDC. (b) Ignition 20 degrees before TDC. (c) Ignition 10 degrees before TDC.

Figure 14-a, producing a maximum pressure of 450 psi.

Figure 16-c is a pressuregram with ignition beginning when the piston is at top dead center. This trace denotes the time lag involved in the cylinder from ignition until the maximum pressure occurs. In this photograph, it appears to be about 45 crankshaft degrees from the time of ignition until the maximum pressure of 275 psi materializes.

Varied Engine Load. Figure 17, page 49 , shows the effect of varied engine load on the pressure diagram. The throttle was modulated to maintain the speed at approximately 1030 rpm and the ignition was set at 16 degrees before TDC.

With a 1/3 load and the engine producing 3.26 pound-feet of torque, the trace of Figure 17-a was obtained. The maximum pressure was 212 psi.

Figure 17-b was obtained for a 2/3 load with the engine developing 7.2 pound-feet of torque and a peak pressure of 300 psi.

Figure 17-c was obtained for full load conditions, with the engine developing a torque of 11.6 pound-feet. The maximum pressure was 413 psi. These diagrams show that partial output reduces the indicated work or the area under the trace by reducing the amount of combustible mixture for different throttle valve positions.

Varied Compression Ratio. The pressure diagrams pictured in Figure 18, page 51 , were obtained from operation at various compression ratios. Heavy detonation was present at a compression ratio of 9.01 to 1 as pictured in the trace of Figure 18-a. The maximum cylinder pressure was fluctuating near 610 psi.

With the engine operating at a compression ratio of 7.0 to 1, the

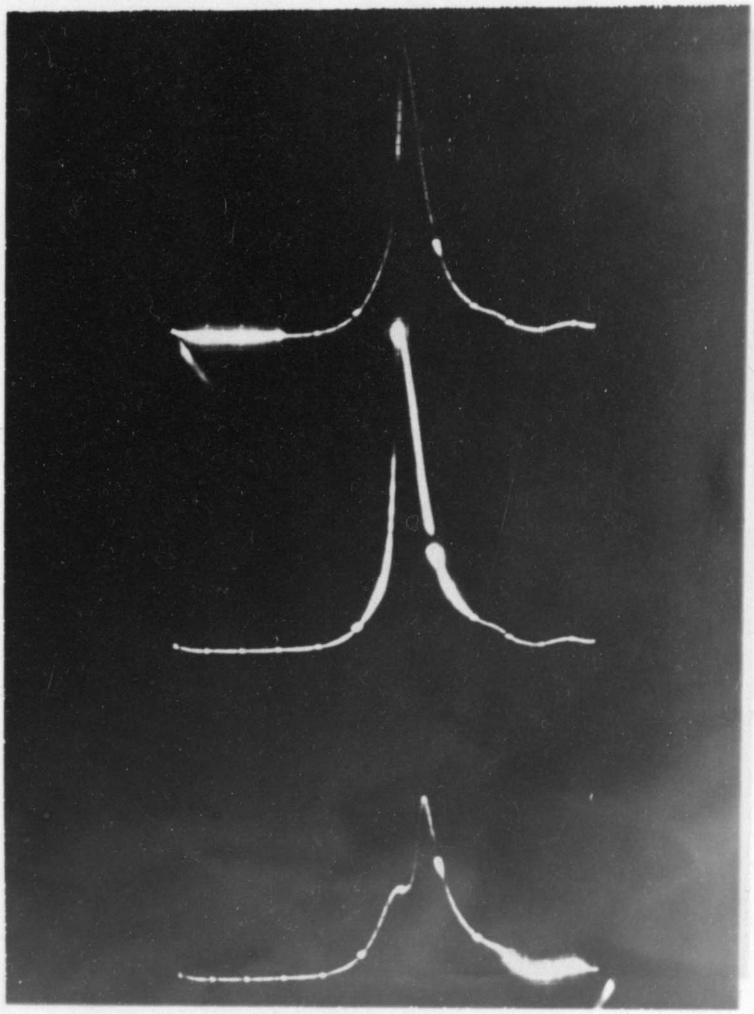
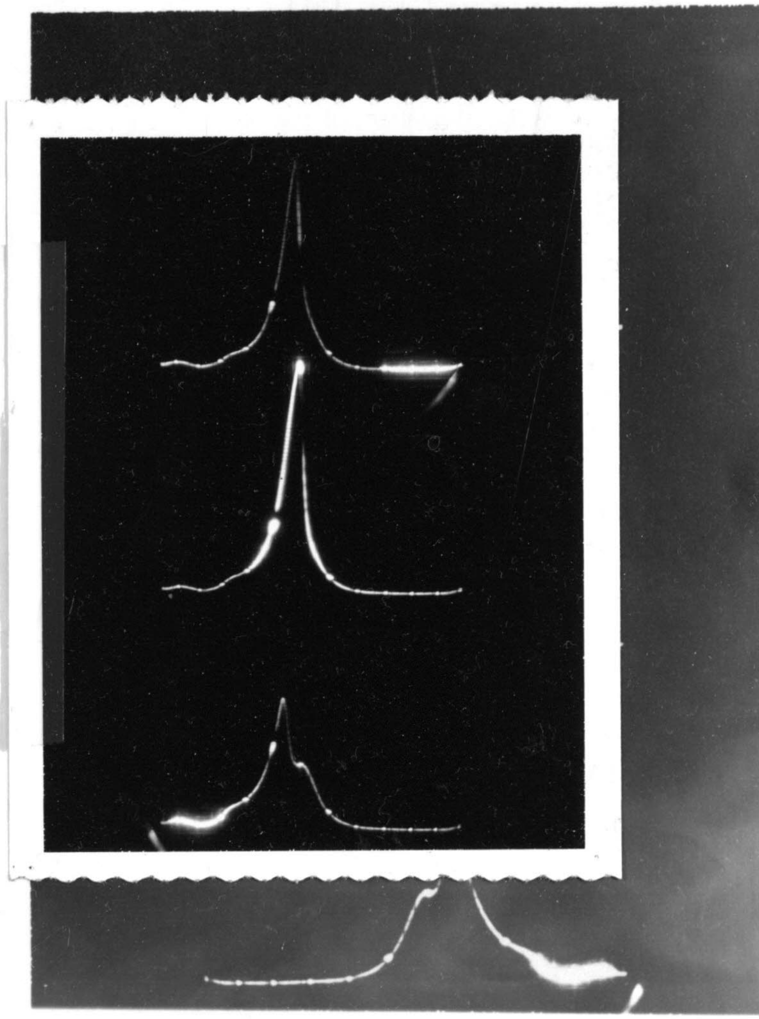


Figure 16. Pressuregram. Varied Ignition Spark Timing. (a) Very lean mixture ratio with ignition 30 degrees before TDC. (b) Very rich mixture ratio with ignition 30 degrees before TDC. (c) Ignition at TDC.

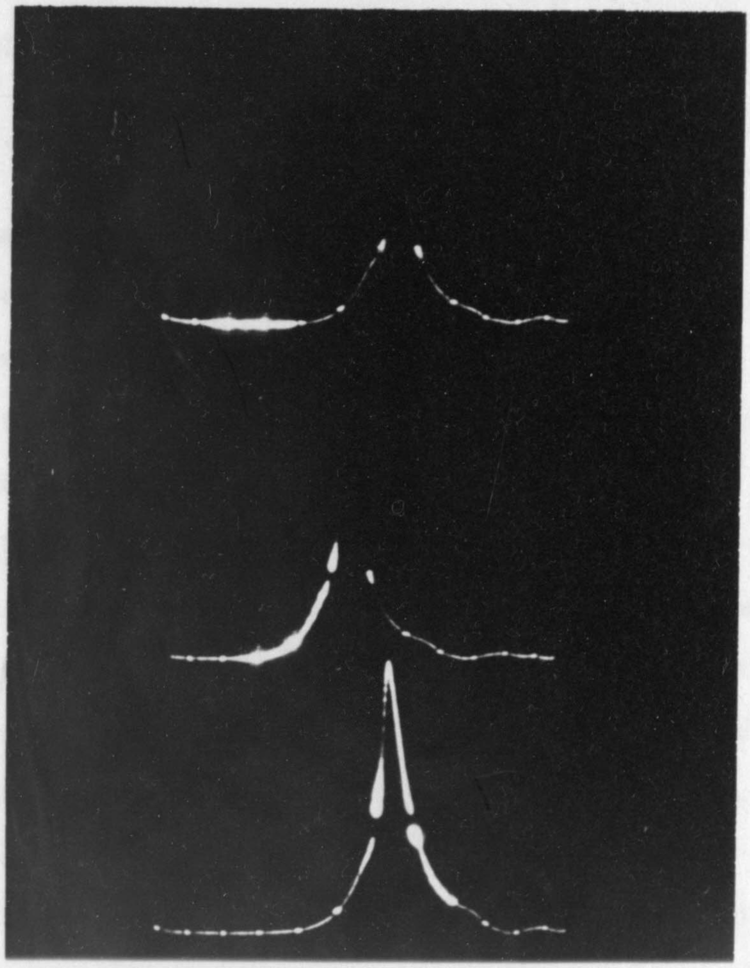


(a)

(b)

(c)

Figure 16. Pressuregram. Varied Ignition Spark Timing. (a) Very lean mixture ratio with ignition 30 degrees before TDC. (b) Very rich mixture ratio with ignition 30 degrees before TDC. (c) Ignition at TDC.



(a)

(b)

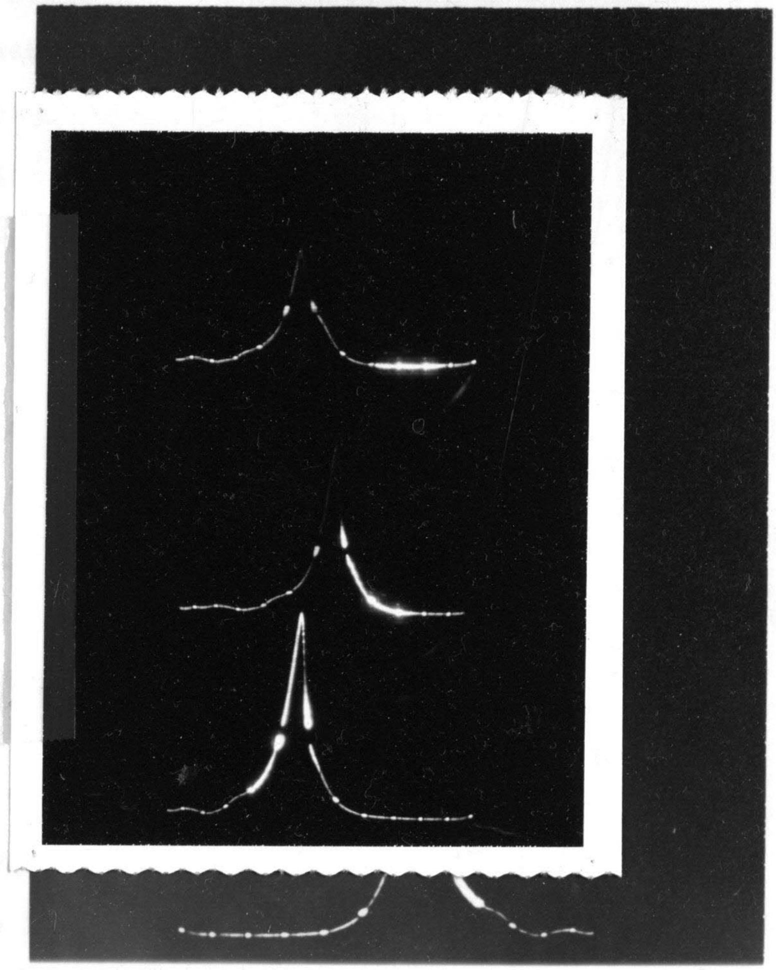
(c)

Figure 17. Pressuregram. Varied Engine Load.

(a) 1/3 load, normal mixture and spark advance.

(b) 2/3 load, normal mixture and spark advance.

(c) Full load, normal mixture and spark advance.



(a)

(b)

(c)

Figure 17. Pressuregram. Varied Engine Load

(a) 1/3 load, normal mixture and spark advance.

(b) 2/3 load, normal mixture and spark advance.

(c) Full load, normal mixture and spark advance.

trace of Figure 18-b was obtained. No detonation occurred at this setting, yielding a maximum cylinder pressure of 437 psi.

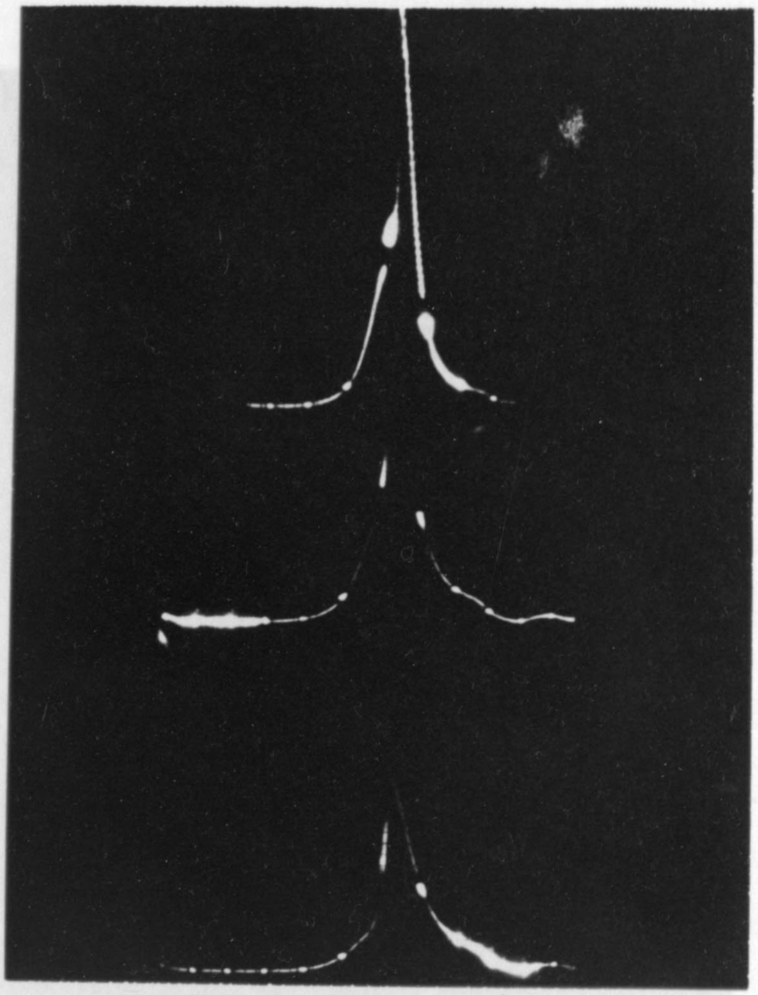
Figure 18-c shows the trace obtained for a compression ratio of 4.0 to 1. The maximum pressure was 275 psi. It can be seen from these diagrams that there is an increase in the rate of burning at the higher compression ratios. The reason is the rise of pressure and temperature at the end of compression and the direct effect of the reduced proportion of exhaust gas left in the combustion chamber to dilute the incoming charge.

Varied Rotative Speed. Figure 19, page 52 , shows the effects of varied rotative speed obtained by loading the engine with the dynamometer to maintain the desired speed. With the engine operating at 1500 rpm and ignition 22 degrees before TDC, the trace pictured in Figure 19-a was obtained. The maximum pressure was 312 psi while developing 3.46 pound-feet of torque.

Figure 19-b revealed a maximum cylinder pressure of 350 psi obtained with the engine developing a torque of 9.45 pound-feet at 1200 rpm and ignition occurring 16 degrees before TDC.

Figure 19-c was obtained at a speed of 900 rpm and the ignition set at 16 degrees before TDC. The maximum cylinder pressure was 412 psi while developing a torque of 15.1 pound-feet. These diagrams substantiate the results obtained in the full-load, variable-speed test, which has been discussed.

Varied Octane Number Fuels. Figure 20, page 54 , shows diagrams obtained with the engine operating at a compression ratio of 8.5 to 1,

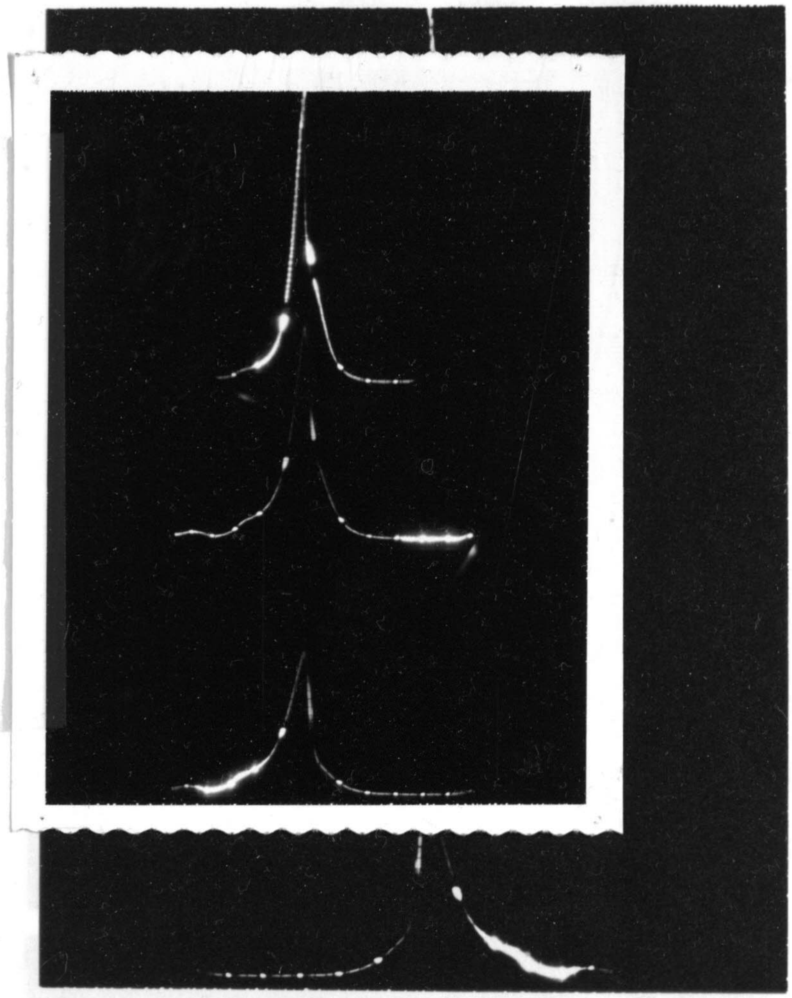


(a)

(b)

(c)

Figure 18, Pressuregram. Varied Compression Ratio. (a) Compression ratio 9.01:1. (b) Compression ratio 7.0:1. (c) Compression ratio 4.0:1.

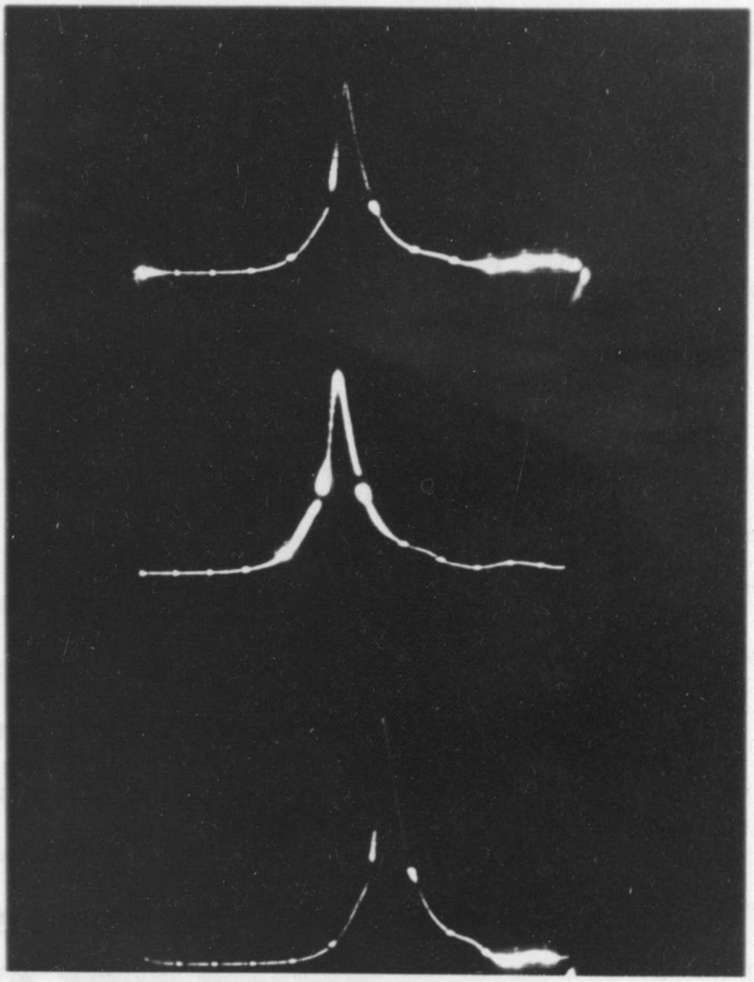


(a)

(b)

(c)

Figure 18. Pressuregram. Varied Compression Ratio. (a) Compression ratio 9.01:1. (b) Compression ratio 7.0:1. (c) Compression ratio 4.0:1.



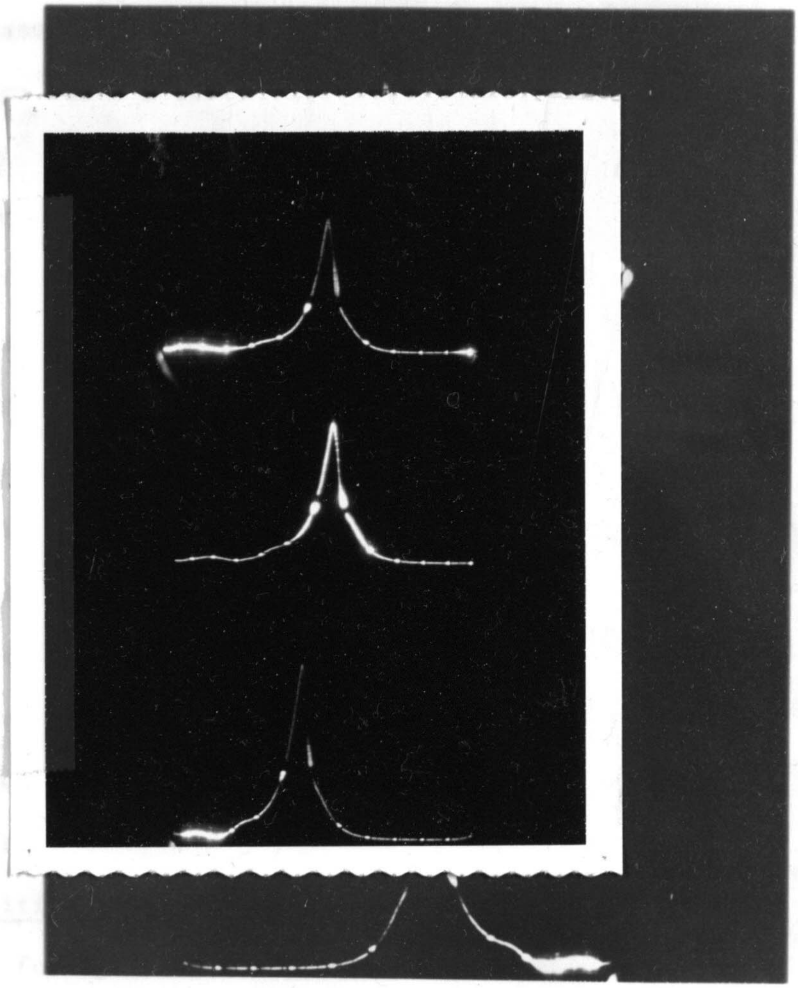
(a)

(b)

(c)

Figure 19. Pressuregram. Varied Rotative Speed

(a) 1500 rpm. (b) 1200 rpm. (c) 900 rpm.



(a)

(b)

(c)

Figure 19. Pressuregram. Varied Rotative Speed

(a) 1500 rpm. (b) 1200 rpm. (c) 900 rpm.

using different octane rating fuels. This illustrates the effect of fuel octane rating on detonation pressures experienced in the engine combustion chamber.

Operating the engine on a premium grade fuel resulted in the trace pictured in Figure 20-a. This fuel had a Research octane rating of 100.4 and a Motor octane rating of 90.3. The maximum pressure varied from 525 to 613 psi. The vibrating pressure traces did not photograph, probably due to their rapid occurrence.

Figure 20-b was obtained when operating the engine on Aviation fuel with a Research octane rating of 80 - 87. Heavy detonation resulted with maximum pressures ranging from 525 to 762 psi.

Figure 20-c was obtained using a regular grade fuel with a Research octane rating of 93.2 and a Motor octane rating of 84.8. Very heavy detonation occurred, which did not photograph. The peak pressures ranged from 525 to 775 psi.

<u>Ignition Study</u>. Figure 21, page 56 , illustrates the results obtained for ignition studies that may be made either singly or in connection with pressure diagrams. Figure 21-a pictures the ignition pattern superimposed on the pressure diagram for ignition occurring at TDC. The first vertical spike, from left to right, represents when the points close and the spark starts (unlike automotive engines) and appears coincident with the "pip" representing TDC. The second vertical spike represents when the points open and the condenser begins to be charged. Thus, the distance between the two vertical spikes is the dwell angle.

Figure 21-b pictures the ignition spikes superimposed on the normal

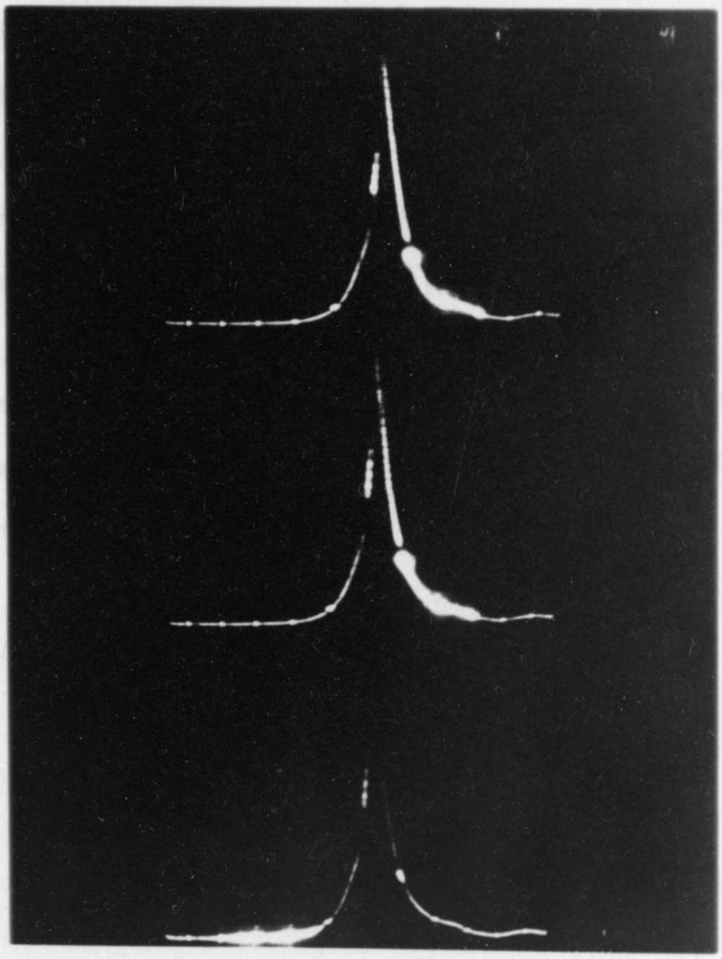
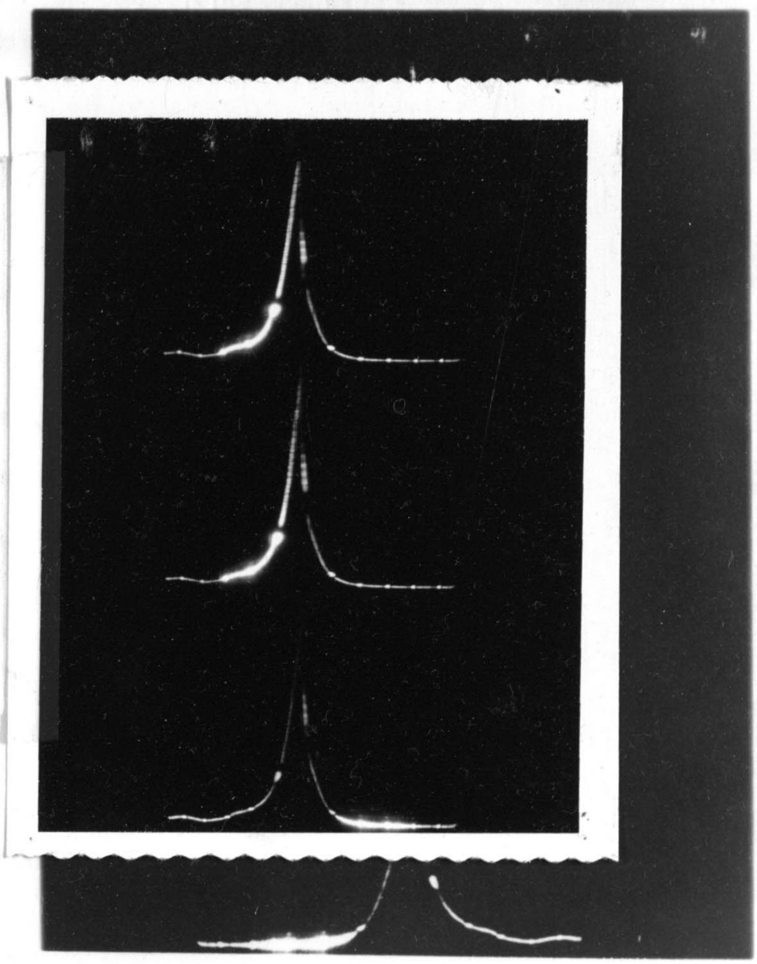


Figure 20. Pressuregram. Varied Octane Number Fuels. (a) Premium grade fuel. (b) Aviation fuel. (c) Regular grade fuel.



(a)

(b)

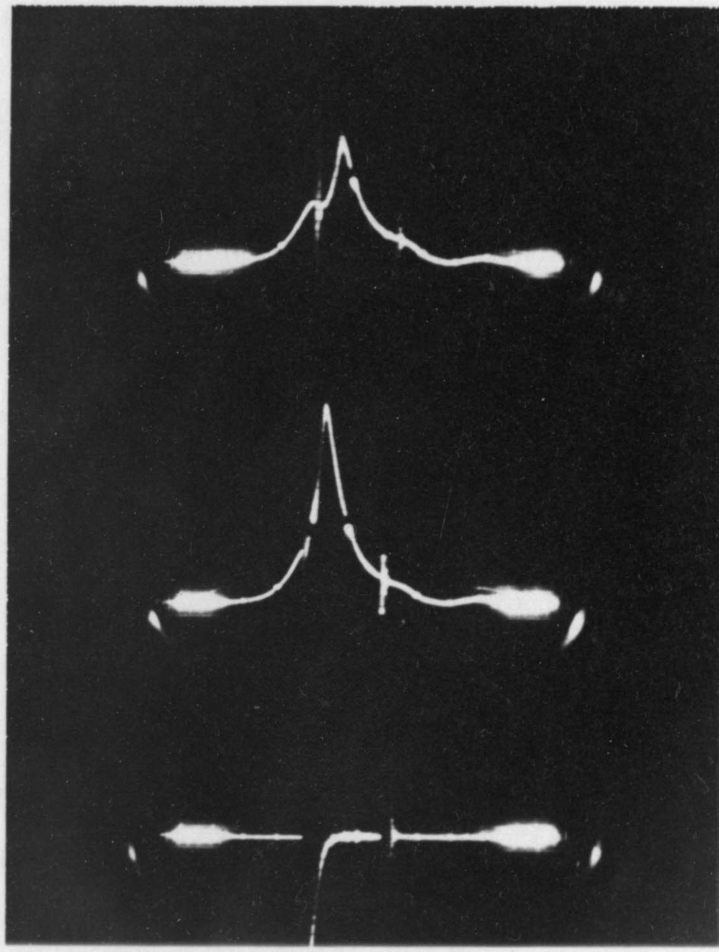
(c)

Figure 20. Pressuregram. Varied Octane Number Fuels. (a) Premium grade fuel. (b) Aviation fuel. (c) Regular grade fuel.

pressure diagram. The first vertical spike therefore appears 17 degrees before the "pip" representing TDC.

Figure 21-c shows the ignition pattern or spark voltage response for normal ignition at 17 degrees before TDC. The voltage surge can be seen when the points close, and after a corona or fuzzy series of vertical lines, followed by the vertical spike representing when the points open.

The ignition pattern was not used on all diagrams since the pickup and calibrator are sensitive to electrical interference, causing imminent vertical drift of the oscilloscope display.

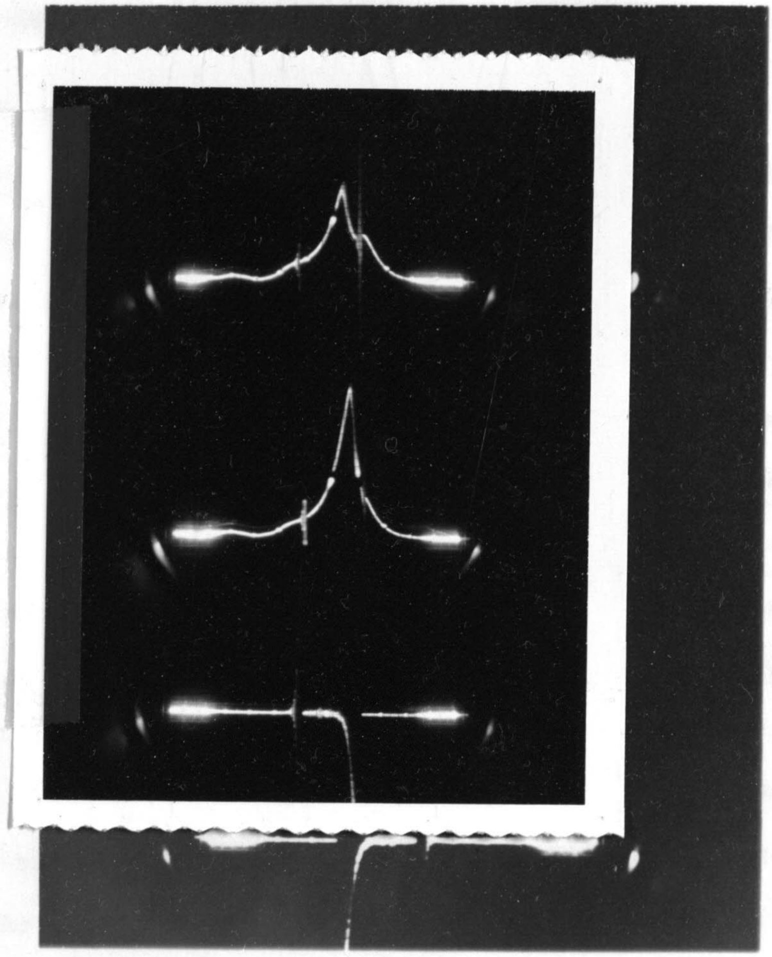


(a)

(b)

(c)

Figure 21. Pressuregram. Ignition Study.
(a) Ignition pattern on diagram for ignition at TDC. (b) Ignition pattern on normal diagram.
(c) Ignition pattern for normal spark.



(a)

(b)

(c)

Figure 21. Pressuregram. Ignition Study.
(a) Ignition pattern on diagram for ignition at TDC. (b) Ignition pattern on normal diagram. (c) Ignition pattern for normal spark.

EFFECT OF VARIED SPARK ON POWER AND ECONOMY

There is a definite spark timing for best engine operation. This experiment illustrates and brings about a thorough appreciation of the important bearing of ignition timing upon the performance of the engine, both in respect to power and running costs, which, of course, depend upon the specific fuel consumption.

For each run, the engine was adjusted with respect to load to give maximum torque at 1000 rpm. Ignition was varied at intervals of 5 degrees and the brake reading and rate of fuel consumption were noted. The results obtained are recorded on page 59 and illustrated graphically in Figure 22, page 61 , to show the effects of ignition timing upon brake horsepower and specific fuel consumption.

It must be understood that the best timing is not dependent upon power alone, but also upon engine speed and certain other variables concerning the state and composition of the combustion charge. The next three experiments will illustrate some of these effects.

DATA SHEET

EFFECT OF VARIED SPARK ON POWER AND ECONOMY

Barometer 29.43 in. Hg. Date December 20, 1961

Dry Bulb 72 °F. Oil Temp. 135 °F.

Tare 3.5 pounds Coolant Temp. 210 °F.

Fuel Level 1.3 (Bowel 1) in. Intake Air Temp. 100 ± 25 °F.

Fuel Consumption 200 ml/run = 0.30 lb/run Mixture Temp. 300 ± 2 °F.

Throttle position wide open Compression Ratio 6.5:1

Speed Approx. 1000 rpm. Micrometer Reading 0.318

1.	Run No.	1	2	3	4	5	6	7
2.	Spark Timing, °BTDC	35	30	25	20	15	10	5
3.	Time, seconds	572	586	590	567	549	562	581
4.	Ave. Speed, rpm.	1020	1025	1020	1040	1020	1015	1000
5.	Brake load obs., lbs.	10.00	10.00	10.25	10.75	12.00	12.00	11.50
6.	Brake load corr., lbs.	6.50	6.50	6.75	7.25	8.50	8.50	8.00
7.	Bhp. obs.	1.26	1.27	1.31	1.43	1.65	1.64	1.52
8.	Correction Factor	1.23	1.23	1.23	1.23	1.23	1.23	1.23
9.	Bhp. corr.	1.55	1.56	1.61	1.76	2.03	2.02	1.87
10.	SFC, lb/hr.	1.89	1.84	1.83	1.90	1.97	1.92	1.86
11.	BSFC, lb/Bhp-hr.	1.50	1.45	1.40	1.33	1.19	1.17	1.22

DATA SHEET

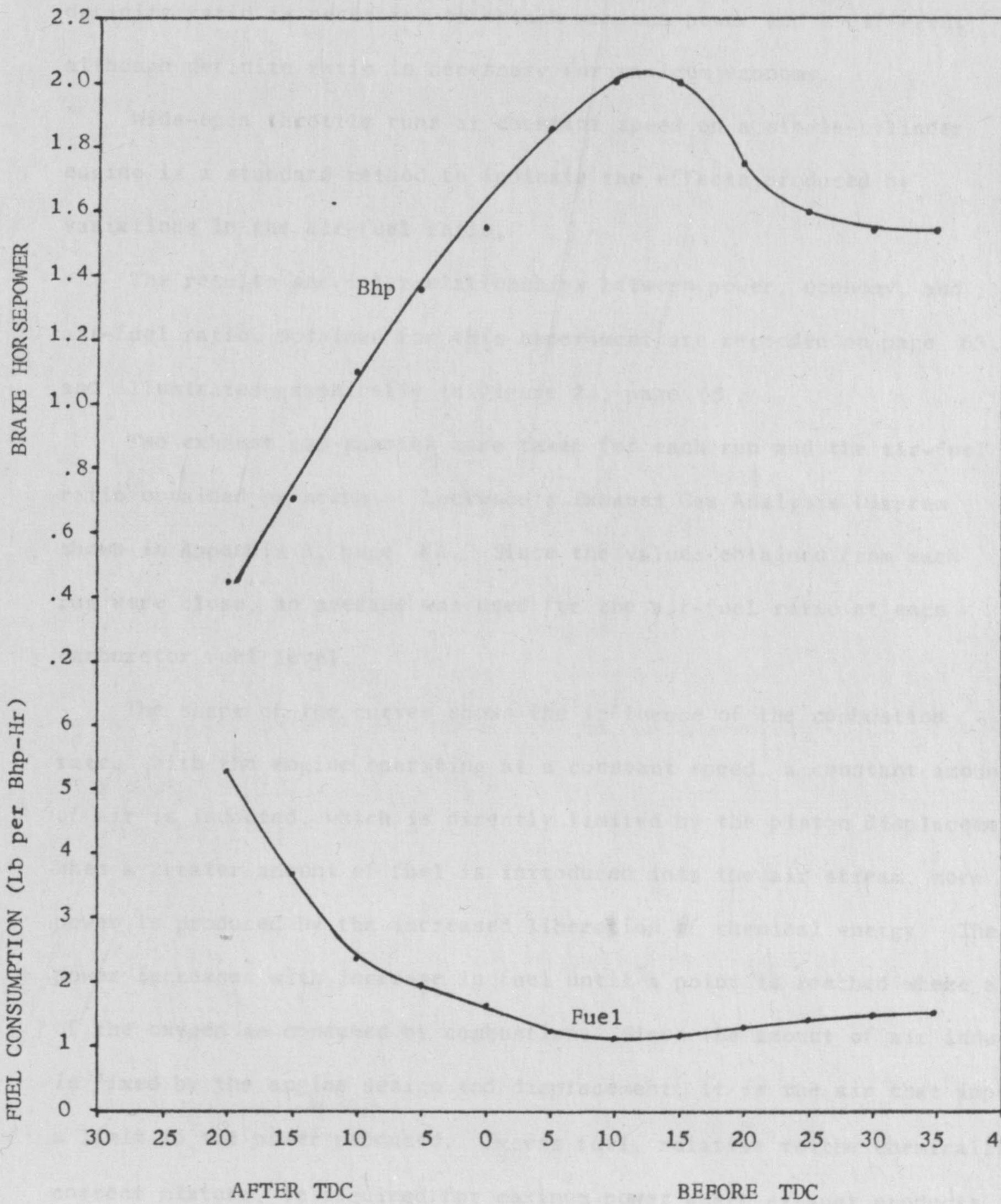
EFFECT OF VARIED SPARK ON POWER AND ECONOMY

(continued)

1. Run No.	8	9	10	11	12	13	14
2. Spark Timing, °ATDC	0	5	10	15	20	25	30
3. Time, seconds	524	490	490	504	536	510	609
4. Ave. Speed, rpm.	1020	1020	1010	1020	1000	1010	870
5. Brake load obs., lbs.	10.00	9.25	8.25	6.50	5.50	3.50	3.50
6. Brake load corr., lbs.	6.50	5.75	4.75	3.00	2.00	0.0	0.0
7. Bhp. obs	1.26	1.11	0.91	0.58	0.38	0.0	0.0
8. Correction Factor	1.23	1.23	1.23	1.23	1.23	1.23	1.23
9. Bhp. corr.	1.55	1.36	1.12	0.71	0.46	0.00	0.00
10. SFC, lb/hr.	2.06	2.20	2.20	2.14	2.01	2.12	1.77
11. BSFC, lb/Bhp-hr.	1.63	1.98	2.42	3.70	5.30	—	—

Figure 22. Effect of Varied

Spark on Power and Economy



EFFECT OF VARIED AIR-FUEL RATIO ON POWER AND ECONOMY

An engine can use various ratios of air and fuel, although a definite ratio is necessary to obtain maximum power and a different, although definite ratio is necessary for maximum economy.

Wide-open throttle runs at constant speed on a single-cylinder engine is a standard method to indicate the effects produced by variations in the air-fuel ratio.

The results and interrelationships between power, economy, and air-fuel ratio, obtained for this experiment are recorded on page 63, and illustrated graphically in Figure 23, page 65.

Two exhaust gas samples were taken for each run and the air-fuel ratio obtained by means of Lockwood's Exhaust Gas Analysis Diagram shown in Appendix A, page 83. Since the values obtained from each run were close, an average was used for the air-fuel ratio at each carburetor fuel level.

The shape of the curves shows the influence of the combustion rate. With the engine operating at a constant speed, a constant amount of air is inducted, which is directly limited by the piston displacement. When a greater amount of fuel is introduced into the air stream, more power is produced by the increased liberation of chemical energy. The power increases with increase in fuel until a point is reached where all of the oxygen is consumed by combustion. Since the amount of air inducted is fixed by the engine design and displacement, it is the air that imposes a limit to the power produced. Excess fuel, relative to the chemically correct mixture, is required for maximum power where exhaust products

DATA SHEET

EFFECT OF VARIED AIR-FUEL RATIO ON POWER AND ECONOMY

Barometer 29.76 in. Hg.
Dry Bulb 73 °F.
Tare 0.5 pounds
Fuel Consumption 200 ml/run
= 0.30 lb/run (run 1 thru 12).
100 ml/run = 0.15 lb/run
(run 13 and 14). (Bowel 1).
Speed Approx. 1000 rpm.
Throttle position wide open

Date January 17, 1962
Oil Temp. 135 °F.
Coolant Temp. 210 °F.
Intake Air Temp. 100 ± 25 °F.
Mixture Temp. 300 ± 2 °F.
Compression Ratio 6.0:1
Micrometer Reading 0.400
Correction Factor 1.216
Spark Timing 17 °BTDC

1. Run No.	1	2	3	4	5	6	7
2. Fuel level, in.	0.2	0.4	0.6	0.8	1.0	1.2	1.4
3. Time, minutes	7.342	7.578	8.014	8.449	8.713	9.309	9.869
4. Rev. obs.	15,419	15,675	16,620	17,723	18,607	19,340	20,721
5. Rev. corr.	7,709	7,837	8,310	8,861	9,303	9 670	10 360
6. Ave. Speed, rpm.	1050	1030	1035	1050	1067	1040	1050
7. Brake load obs., lbs.	10.00	10.25	10.75	11.00	11.00	11.50	11.50
8. Brake load corr., lbs.	9.50	9.75	10.25	10.50	10.50	11.00	11.00
9. Bhp. obs.	1.90	1.91	2.02	2.10	2.13	2.18	2.20
10. Bhp. corr.	2.31	2.32	2.46	2.55	2.59	2.65	2.68
11. SFC, lb/hr.	2.46	2.38	2.24	2.13	2.06	1.93	1.82
12. BSFC, lb/Bhp-hr.	1.29	1.24	1.10	1.01	0.96	0.88	0.82
13. Orsat No. 749 CO_2, %	7.2	8.3	9.4	9.9	11.0	12.0	11.8
14. O_2, %	0.1	0.1	0.2	0.2	0.1	0.3	0.2
15. CO, %	9.3	7.4	6.6	5.5	4.2	2.3	0.8
16. AF ratio, lb/lb.	10.0	11.0	11.5	12.1	12.5	13.7	14.5
17. Orsat No. 750 CO_2, %	8.0	9.5	10.2	11.2	11.7	12.9	14.3
18. O_2, %	0.3	0.1	0.4	0.3	0.2	0.2	0.3
19. CO, %	8.5	7.9	6.6	5.2	4.6	2.7	0.9
20. AF ratio, lb/lb.	10.5	11.0	11.5	12.3	12.7	13.0	15.0
21. Ave. AF ratio, lb/lb.	10.2	11.0	11.5	12.2	12.6	13.3	14.7

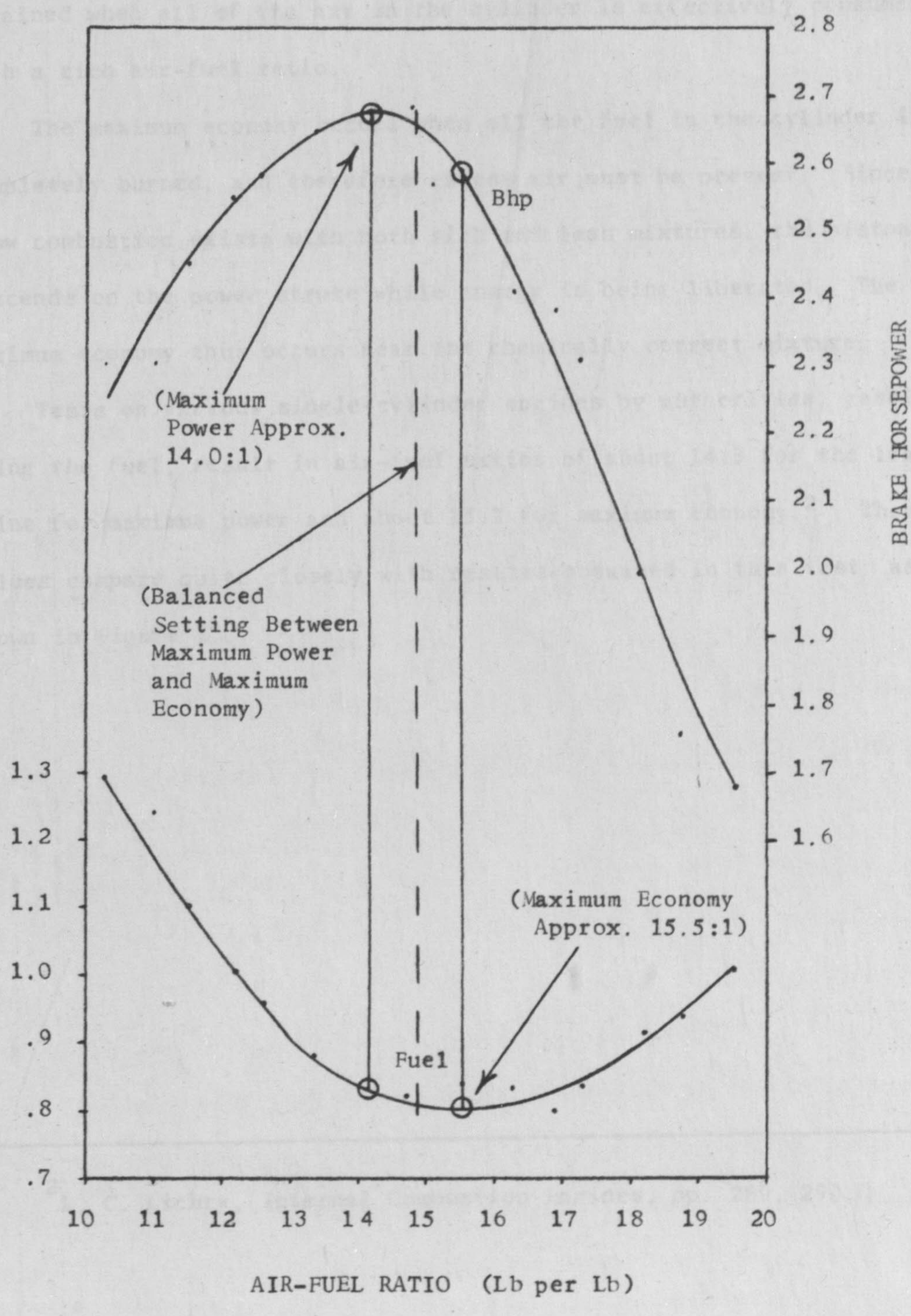
DATA SHEET

EFFECT OF VARIED AIR-FUEL RATIO ON POWER AND ECONOMY

(continued)

1. Run No.	8	9	10	11	12	13	14
2. Fuel level, in.	1.6	1.8	2.0	2.2	2.4	2.6	2.8
3. Time, minutes	10.121	10.815	11.542	11.276	11.953	6.579	6.294
4. Rev. obs.	21,196	22,550	23,748	24,379	25,861	13,398	14,000
5. Rev. corr.	10,598	11,275	11,874	12,189	12,930	6,699	7,000
6. Ave. Speed, rpm.	1045	1040	1030	1080	1080	1015	1115
7. Brake load obs., lbs.	11.00	10.50	10.50	9.75	8.50	8.00	7.00
8. Brake load corr., lbs.	10.50	10.00	10.00	9.25	8.00	7.50	6.50
9. Bhp. obs.	2.09	1.98	1.96	1.90	1.64	1.45	1.38
10. Bhp. corr.	2.54	2.41	2.38	2.31	1.99	1.76	1.68
11. SFC, lb/hr.	1.78	1.66	1.56	1.60	1.50	1.37	1.43
12. BSFC, lb/Bhp-hr.	0.85	0.83	0.79	0.84	0.91	0.94	1.03
13. Orsat No. 749 CO_2, %	12.4	12.6	13.0	12.9	12.0	11.6	11.0
14. O_2, %	0.9	1.1	2.2	2.7	3.6	4.4	5.1
15. CO, %	0	0	0	0	0	0	0
16. AF ratio, lb/lb.	15.5	16.0	16.7	17.5	18.2	19.0	19.7
17. Orsat No. 750 CO_2, %	14.7	14.3	13.9	14.2	13.1	12.7	11.9
18. O_2, %	0.6	1.5	2.2	2.0	3.4	4.1	5.0
19. CO, %	0	0	0	0	0	0	0
20. AF ratio, lb/lb.	15.5	16.5	17.0	17.0	18.0	18.5	19.5
21. Ave. AF ratio lb/lb.	15.5	16.2	16.8	17.2	18.1	18.7	19.6

Figure 23. Effect of Varied Air-fuel Ratio on Power and Economy



dilute the fresh charge, when fuel is not completely vaporized, and if the fuel and air are not perfectly mixed. Maximum power is therefore obtained when all of the air in the cylinder is effectively consumed with a rich air-fuel ratio.

The maximum economy occurs when all the fuel in the cylinder is completely burned, and therefore excess air must be present. Since slow combustion exists with both rich and lean mixtures, the piston descends on the power stroke while energy is being liberated. The maximum economy thus occurs near the chemically correct mixture.

Tests on various single-cylinder engines by authorities, gasoline being the fuel, result in air-fuel ratios of about 14.3 for the leanest value for maximum power and about 15.7 for maximum economy.[2] These values compare quite closely with results obtained in this test as shown in Figure 23.

---

[2] L. C. Lichty, Internal Combustion Engines, pp. 289, 290.

EFFECT OF SPARK TIMING ON BMEP AT VARIOUS SPEEDS, FULL THROTTLE

The timing in the cycle where the spark occurs is significant for optimum efficiency and output of the engine. This has already been seen by the appearance and variation in areas under the pressure-time diagrams at different ignition settings. Any variation in ignition timing varies the amount of charge burned before or after top dead center position of the piston.

The desirable ignition timing depends upon various factors that affect the rate of burning or the time available for the combustion process. Since the time of combustion is a function of the speed of rotation as well as volumetric efficiency, fuel, load, temperature, pressure, and mixture ratio, the relationship is complicated. Mathematical relationships for optimum spark advance have been proposed, but since they are empirical and since experimental determination is very easy, they are of little value. Both this test and the following test illustrate methods of obtaining correct ignition timing for different operating conditions. The experimental results are recorded on page 68 and represented in graphical form in Figure 24, page 69, to show the effect of spark timing on BMEP at various speeds for full throttle operation. It can be seen that higher mean effective pressures occur near 900 rpm and decline with increased speed for reasons as stated in the full load test.

The degree of advance for maximum power at any speed is indicated by the line joining the highest points of each individual curve. This optimum spark pattern shows, spark advanced at 900 rpm, retarded a few degrees at 1000 and 1200 rpm, then advanced at 1400 rpm. This may be

DATA SHEET

EFFECT OF SPARK TIMING ON BMEP AT VARIOUS SPEEDS, FULL THROTTLE

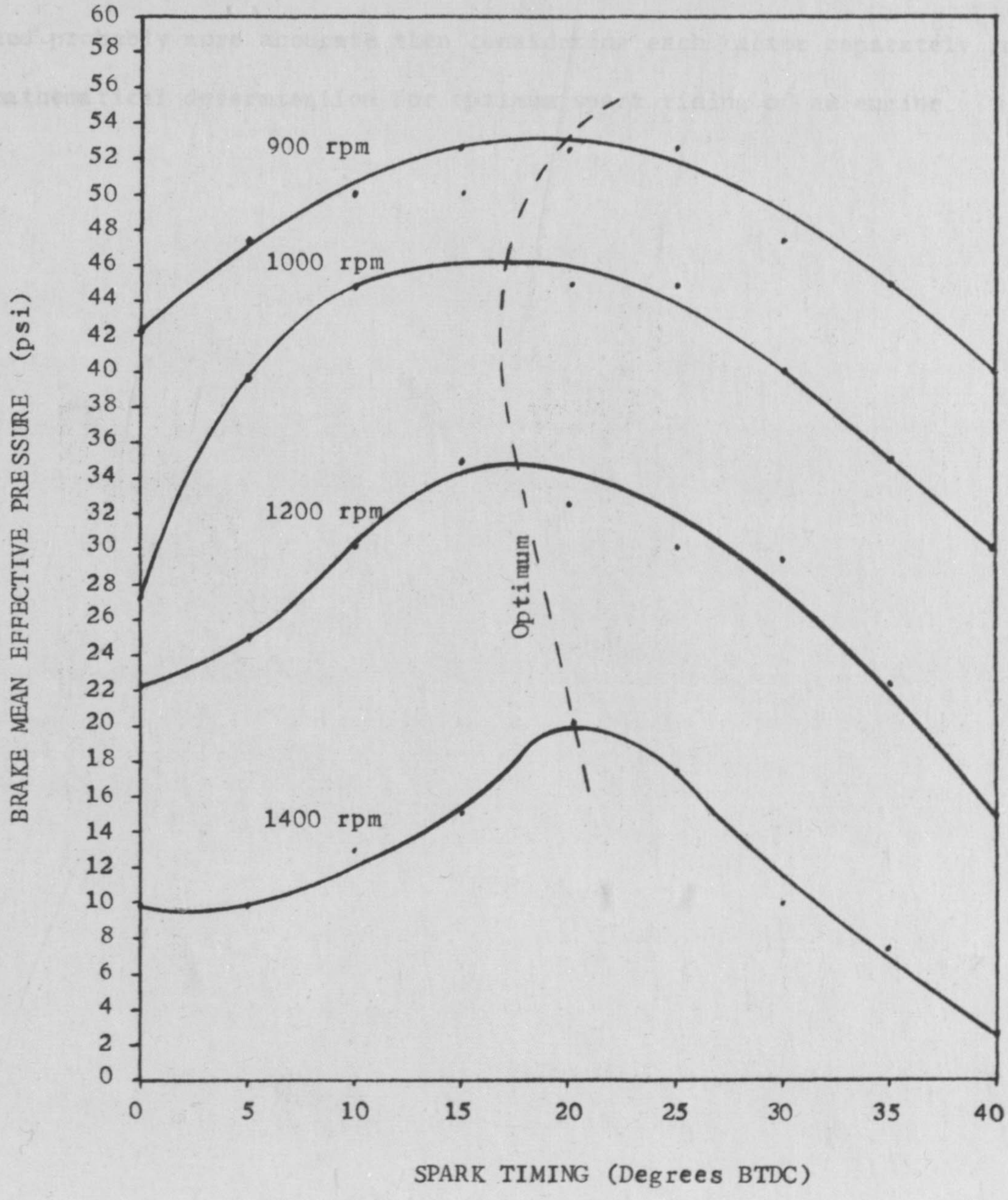
Date December 28, 1961

Barometer 29.14 in. Hg.
Dry Bulb 62 °F.
Tare 2.0 pounds
Fuel Level 1.3 (Bowel 1) in.
Throttle position wide open
Correction Factor 1.24

Oil Temp. 135 °F.
Coolant Temp. 210 °F.
Intake Air Temp. 100 ± 25 °F.
Mixture Temp. 300 ± 2 °F.
Compression Ratio 6.0:1
Micrometer Reading 0.400

1.	Run No.	1	2	3	4	5	6	7	8	9
2.	Spark Timing, °BTDC	0	5	10	15	20	25	30	35	40
3.	Speed, rpm	900	900	900	900	900	900	900	900	900
4.	Brake load obs., lbs.	10.5	11.5	12.0	12.5	12.5	12.5	11.5	11.0	10.0
5.	Brake load corr., lbs.	8.5	9.5	10.0	10.5	10.5	10.5	9.5	9.0	8.0
6.	BMEP, psi.	34.2	38.3	40.3	42.4	42.4	42.4	38.3	36.2	32.2
7.	BMEP, corr., psi.	42.3	47.5	50.0	52.5	52.5	52.5	47.5	44.9	39.9
8.	Speed, rpm.	1000	1000	1000	1000	1000	1000	1000	1000	1000
9.	Brake load obs., lbs.	7.5	10.0	11.0	12.0	11.0	11.0	10.0	9.0	8.0
10.	Brake load corr., lbs.	5.5	8.0	9.0	10.0	9.0	9.0	8.0	7.0	6.0
11.	BMEP, psi	22.2	32.2	36.2	40.3	36.2	36.2	32.2	28.2	24.2
12.	BMEP, corr., psi.	27.5	39.9	44.9	50.0	44.9	44.9	39.9	35.0	30.0
13.	Speed, rpm.	1200	1200	1200	1200	1200	1200	1200	1200	1200
14.	Brake load obs., lbs.	6.5	7.0	8.0	9.0	8.5	8.0	7.5	6.5	5.0
15.	Brake load corr., lbs.	4.5	5.0	6.0	7.0	6.5	6.0	5.5	4.5	3.0
16.	BMEP, psi.	18.1	20.1	24.2	28.2	26.2	24.2	22.2	18.1	12.1
17.	BMEP, corr., psi.	22.4	24.9	30.0	35.0	32.5	30.0	27.5	22.4	15.0
18.	Speed, rpm.	1400	1400	1400	1400	1400	1400	1400	1400	1400
19.	Brake load obs., lbs.	4.0	4.0	4.5	5.0	6.0	5.5	4.0	3.5	2.5
20.	Brake load corr., lbs.	2.0	2.0	2.5	3.0	4.0	3.5	2.0	1.5	0.5
21.	BMEP, psi.	8.0	8.0	10.0	12.1	16.1	14.1	8.0	6.0	2.0
22.	BMEP, corr., psi.	9.9	9.9	12.4	15.0	19.9	17.5	9.9	7.4	2.4

Figure 24. Effect of Spark Timing on
BMEP at Various Speeds, Full Throttle



attributed to more then one of the influencing factors mentioned. When increased load alone is considered, the spark is retarded as illustrated in the next test. If increased speed alone is considered, the spark must advance to allow time for complete combustion. Thus considering all these factors together in experimental performance, provides a means much simpler and probably more accurate then considering each factor separately in a mathematical determination for optimum spark timing of an engine.

EFFECT OF SPARK TIMING ON BMEP AT DIFFERENT THROTTLE SETTINGS

At a given speed, the optimum spark timing varies with load. This is due to the variation pressure, as illustrated on the pressuregrams, and also the effect of throttling on the proportion of residual exhaust gas. Both decreasing pressure and increasing dilution by the exhaust gas, lengthen the time of combustion and therefore require increasing spark advance. These effects have been mentioned in the Constant Speed Test, page 37.

This test illustrates the experimental method of obtaining optimum spark timing for different load demands, at a constant speed. The test was performed the same as the Constant Speed Test, except the spark advance was varied at intervals of 5 degrees for each run. The data sheet, page 72, indicates the necessary data, and illustrates the results obtained in this test. These results are represented graphically in Figure 25, page 73.

As an extension of this experiment, different engine speeds could be investigated. The curve of BMEP may equally well represent brake horsepower or engine torque to different scales.

DATA SHEET

EFFECT OF SPARK TIMING ON BMEP AT DIFFERENT THROTTLE SETTINGS

Date December 29, 1961

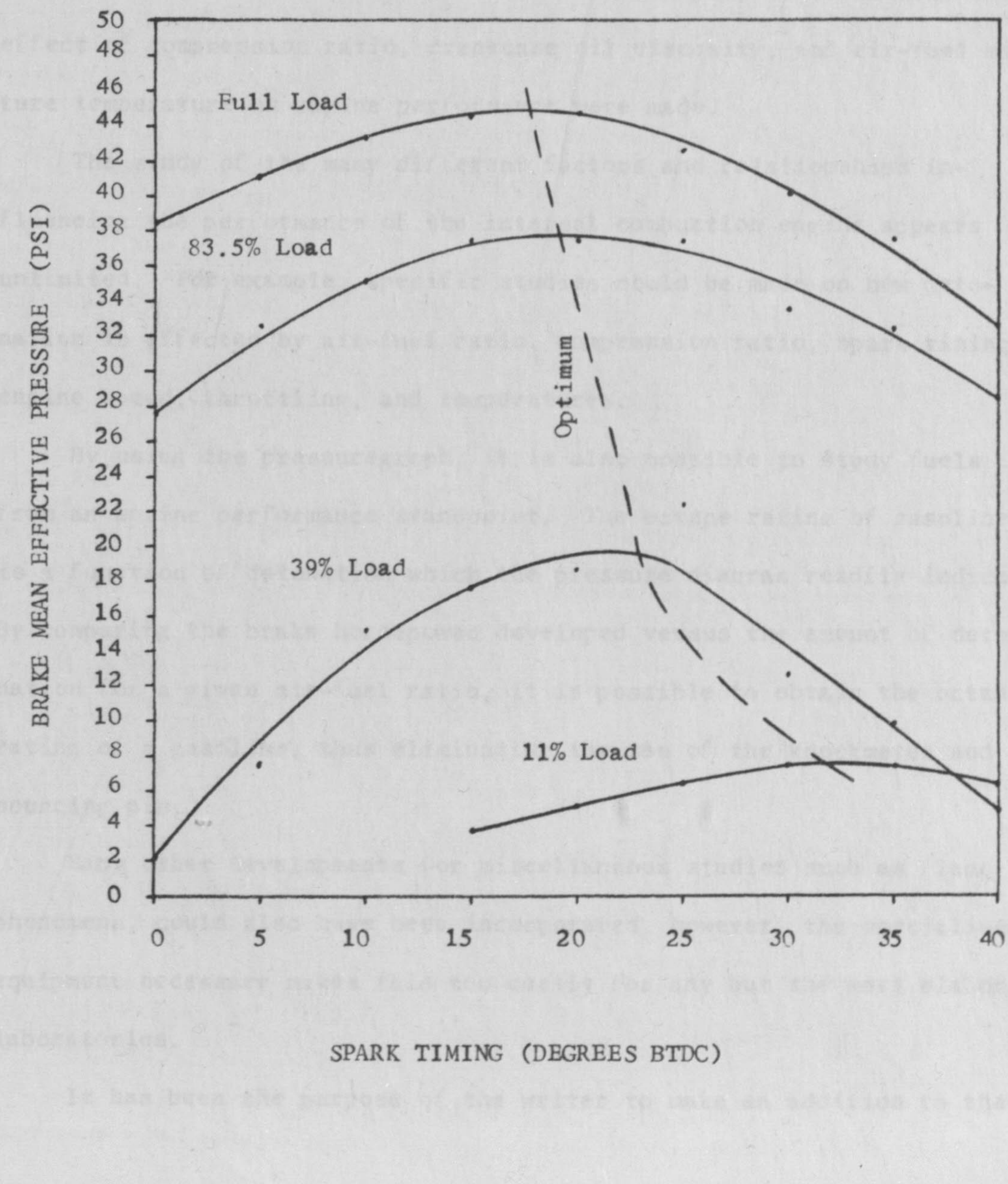
Barometer 29.26 in. Hg.
Dry Bulb 66 °F.
Tare 1.50 pounds
Fuel Level 1.3 (Bowel 1) in.
Speed 1000 (Approx) rpm.
Correction Factor 1.24

Oil Temp. 135 °F.
Coolant Temp. 210 °F.
Intake Air Temp. 100 ± 25 °F.
Mixture Temp. 300 ± 2 °F.
Compression Ratio 6.0:1
Micrometer Reading 0.400

1.	Run No.	1	2	3	4	5	6	7	8	9
2.	Spark Timing, °BTDC	0	5	10	15	18	25	30	35	40
3.	Engine Load, %	100	100	100	100	100	100	100	100	100
4.	Brake load lbs., lbs.	9.25	9.75	10.25	10.50	10.50	10.00	9.50	9.00	8.00
5.	Brake load corr., lbs.	7.75	8.25	8.75	9.00	9.00	8.50	8.00	7.50	6.50
6.	BMEP, psi.	31.2	33.2	35.2	36.2	36.2	34.2	32.2	30.2	26.2
7.	BMEP, corr., psi	38.7	41.2	43.6	44.8	44.8	42.4	39.9	37.4	32.5
8.	Engine Load, %	83.5	83.5	83.5	83.5	83.5	83.5	83.5	83.5	83.5
9.	Brake load obs., lbs.	7.00	8.00	8.50	9.00	9.00	9.00	8.25	8.00	7.25
10.	Brake load corr., lbs.	5.50	6.50	7.00	7.50	7.50	7.50	6.75	6.50	5.75
11.	BMEP, psi	22.2	26.2	28.2	30.2	30.2	30.2	27.2	26.2	23.1
12.	BMEP, corr., psi.	27.5	32.5	34.9	37.4	37.4	37.4	33.7	32.5	28.6
13.	Engine Load, %	39	39	39	39	39	39	39	39	39
14.	Brake load lbs., lbs.	2.00	3.00	4.50	5.00	5.25	6.00	4.00	3.50	2.50
15.	Brake load corr., lbs.	0.50	1.50	3.00	3,50	3.75	4.50	2.50	2.00	1.00
16.	BMEP, psi.	2.0	6.0	12.1	14.1	15.1	18.1	10.0	8.0	4.0
17.	BMEP, corr., psi	2.4	7.4	15.0	17.5	18.7	22.4	12.4	9.9	4.9
18.	Engine Load, %	11	11	11	11	11	11	11	11	11
19.	Brake load obs., lbs.	1.50	1.50	1.50	2.25	2.50	2.75	3.00	3.00	2.75
20.	Brake load corr., lbs.	0.00	0.00	0.00	0.75	1.00	1.25	1.50	1.50	1.25
21.	BMEP, psi	—	—	—	3.0	4.0	5.0	6.0	6.0	5.0
22.	BMEP, corr., psi.	—	—	—	3.7	4.9	6.2	7.4	7.4	6.2

Figure 25. Effect of Spark Timing on

BMEP at Different Throttle Settings



SECTION IV

CONCLUSIONS

It is apparent that not all of the applications of the test unit have been utilized or illustrated in the few tests included in this paper. Several other tests were performed with equally satisfactory results and could have been included. For example, tests showing the effect of compression ratio, crankcase oil viscosity, and air-fuel mixture temperature on engine performance were made.

The study of the many different factors and relationships influencing the performance of the internal combustion engine appears unlimited. For example, specific studies could be made on how detonation is effected by air-fuel ratio, compression ratio, spark timing, engine speed, throttling, and temperatures.

By using the pressuregraph, it is also possible to study fuels from an engine performance standpoint. The octane rating of gasoline is a function of detonation which the pressure diagram readily indicates. By comparing the brake horsepower developed versus the amount of detonation for a given air-fuel ratio, it is possible to obtain the octane rating of a gasoline, thus eliminating the use of the knockmeter and bouncing pin.

Many other developments for miscellaneous studies such as flame phenomena, could also have been incorporated, however, the specialized equipment necessary makes this too costly for any but the most elaborate laboratories.

It has been the purpose of the writer to make an addition to the laboratory facilities of the Mechanical Engineering Department by developing a test unit which will enable engineering students to perform experimental and varification studies in the curriculum of internal combustion engines. This has included designing, fabricating, selecting, installing, and adapting the equipment to instructional uses.

The writer considers this testing unit a valuable addition to the laboratory facilities of the Mechanical Engineering Department because of the benefit it will render in the education of the student engineer. For the opportunity to be of service in this way, the writer is very grateful.

SECTION V

RECOMMENDATIONS

1. A pulse generator or device to plot closer increments of shaft angle rotation on the pressure trace would permit a more accurate analysis of the absolute dynamic pressures within the cylinder. This could be accomplished, for example, by coupling a disc or tooth gear to the engine crankshaft. A magnetic pickup or transducer mounted adjacent to the disc or tooth gear would then furnish an electrical pulse every time a fin on the disc, or one of the gear teeth pass. For example, 5 degree timing marks could be obtained by a 72 tooth gear.

2. Timing marks could be superimposed on the pressure curve for actual duration time for the study of such phenomena as flame propagation and spark lag. The timing marks could be supplied by an oscillator, such as a one thousand-cycle oscillator which will put a "pip" on the trace every 1/1000 second.

3. Improved oscilloscope synchronization, with the rotation of the engine, could be accomplished by a separate magnetic pickup or transducer. A steel projection or fin could be mounted on the face of the gear mentioned in (1), or on the flywheel of the engine, and a magnetic rate of change pickup mounted so as to be energized each time the steel fin passes. The mounting should permit angular rotation of the pickup so as to control the angular position at which the pulse is produced. This will permit starting the scope sweep at any desired time during engine rotation and also will allow any portion of the pressure trace to be pulled to the center of the oscilloscope screen and held still for visual

observation and photographing.

4. An additional pickup could be mounted, as described in (3), to produce a mark or reference point on the pressure trace for determinimg the angular position of the phenomenon under observation with respect to some point, such as start of ignition or top dead center.

5. A duel-beam oscilloscope would permit pressure and ignition patterns to be observed separately and simultaneously for correlation and engine operation studies.

6. Friction in the stator mounting bearings could be reduced and the torque measuring sensitivity of the dynamometer increased by electric motor driven antifriction bearings.

7. A dial type dynamometer scale that will read in either direction from the zero point, would permit friction horsepower to be obtained. Accuracy would be improved with a capacity near 25 pounds.

At the time of this writing, the Mechanical Engineering Department is contemplating the purchase of a Textronix Type 502, duel-beam oscilloscope; a Textronix Type 182 B, Angle-Encoding Transducer; and a Textronix Type 183 B, Rotational Analyzer. The angle encoding transducer, used in conjunction with the rotational analyzer provides 1 degree, 10 degree and 360 degree pulses. The addition of this equipment is in accordance with recommendations 1, 3, and 5.

BIBLIOGRAPHY

ASTM Manual of Engine Test Methods For Rating Fuels, American Society For Testing Materials, Philadelphia, Pennsylvania, October 1952, 342 pp.

Annett, F. A., Electrical Machinery, McGraw-Hill Book Company, Inc., New York, 1921, 431 pp.

Gruber, Foster M., Automotive Engine Testing, Pitman Publishing Corporation, New York and Chicago, 1940, 441 pp.

Karlgaard, Wayne Alan, A Dynamic Engine Analyzer, Master's Thesis, North Dakota Agricultural College, Fargo, 39 pp.

Kistler Instrument Corporation, Operating and Service Instructions for Model 401 Quartz Pickup and Model 651 B Amplifier, Kistler Instrument Corporation, North Tonawanda, New York, n.d., bul.

Lichty, Lester Clyde, Internal Combustion Engines, McGraw-Hill Book Company, Inc., New York and London, 1939, 603 pp.

Marks, Lionel S., Mechanical Engineers' Handbook, McGraw-Hill Book Company, New York, 1951, pp. 2085-7, 1189-1250.

Melanson, Laurence LeRoy, A Dynamic Reactance Detector, Master's Thesis, North Dakota Agricultural College, Fargo, 1956, 40 pp.

Messersmith, Charles W., and others, "Internal Combustion Engines", Mechanical Engineering Laboratory, John Wiley & Sons, Inc., New York, 1958, pp. 149 - 155.

Murphy, Thomas E., and Lindeman, Myrl A., Engine Laboratory Manual, Mechanical Engineering Department, University of Minnesota, 1943.

Obert, Edward F., Internal Combustion Engines, International Textbook Company, Scranton, Pennsylvania, 1956, 596 pp.

Pye, D. R., The Internal Combustion Engine, Oxford University Press, 1931, 250 pp.

Taylor, Fayette C., and Taylor, Edward S., The Internal Combustion Engine, International Textbook Company, Scranton, Pennsylvania, 1938, 322 pp.

Young, S. J., and Pryer, R. W. J., The Testing of Internal Combustion Engines, D. Van Nostrand Company, Inc., New York, 1938, 200 pp.

APPENDIX A

FORMULAS AND DEFINITIONS OF TERMS USED IN CALCULATIONS

Torque. Torque is the turning moment of a tangential effort or the measure of the rotational tendency of a force. The common units of torque are pound-feet or pound-inches. Torque is readily obtained from the dynamometer since the rotational force is measured by the scale in pounds. Knowing the length of the lever-arm multiplied by the scale reading in pounds will thus give the torque delivered in pound-feet. Thus

$$T = P\,R$$

where T is the torque in pound-feet, P is the scale reading in pounds. R is the length of lever-arm in feet.

Brake horsepower. The brake horsepower is the useful power that an engine can supply to its load. The fundamental formula is

$$Bhp = \frac{2\pi P\,R\,N}{33{,}000} = \frac{P\,R\,N}{5{,}252}$$

in which Bhp is the brake horsepower, P R is the torque as already noted, N is the shaft speed in rotations per minute, π equals 3.1416, 2π equals one revolution, 33,000 equals foot-pounds per minute in one horsepower.

Brake mean effective pressure. Brake mean effective pressure is a hypothetical pressure which can be imagined acting on the engine piston during each power stroke to produce a power output equal to the brake horsepower. This factor, expressed in pounds per square inch, is determined from the formula

$$BMEP = \frac{33{,}000\ Bhp}{A\,L\,N}$$

in which A is the area of the piston in square inches, L is the length of the piston stroke in feet, and N is the number of working strokes per minute.

When applied to a four-stroke-cycle engine, the formula can be reduced to

$$BMEP = \frac{150.8\ T}{D}$$

in which T is the engine torque in pounds-feet, D is the total piston displacement in cubic inches.

Correction Factors. The performance of an engine varies with the barometric conditions surrounding the engine. To form a basis of comparison, the engine performance is corrected to standard conditions of temperature and barometric pressure of the air entering the carburetor. The standard conditions adopted by the Society of Automotive Engineers are 29.92 inches of mercury and 60 degrees Fahrenheit. The correction factor is

$$CF = \frac{29.92}{p_a} \times \sqrt{\frac{T_a}{520}}$$

where CF is the correction factor, p_a is the barometric pressure in inches of mercury, T_a is the absolute temperature of air entering the engine. Since the barometric pressure effects only the limitation of power, the correction factor from the formula above is used as a multiplying factor only in full throttle power calculations, for brake horsepower, brake torque and brake mean effective pressure.

Part throttle operation is corrected by the correction factor obtained as follows:

$$CF = \sqrt{\frac{T_a}{520}}$$

where T_a is again the absolute temperature of air entering the engine.

The specific fuel consumption test values are not corrected because supposedly the engine was supplied with the correct amount of fuel to burn the air which entered the engine.

Fuel Consumption. The fuel consumption is determined by recording the time required to consume a measured quantity of fuel. This fuel quantity is expressed in pounds and the specific fuel consumption computed by the following formula:

$$SFC = \frac{60\ W}{t}$$

where SFC is the specific fuel consumption in pounds per hour, W is the weight of fuel consumed in t minutes.

The fuel consumed may also be expressed with respect to the delivered power, computed by the following formula:

$$BSFC = \frac{60\ W}{Bhp\ t}$$

where BSFC represents the brake specific fuel consumption in pounds per brake horsepower hour.

Duration of Run. The duration of each run is determined by the elapsed time indicator of the electric tachometer which is started and stopped by a pushbutton switch.

Rotational Speed. The rotational speed is determined by means of a revolution counter and elapsed time indicator. The average rotational speed is calculated by the formula below for the electric tachometer employed in this project:

$$\text{Average rpm} = \frac{\text{Revolutions elapsed}}{2 \times \text{Time interval elapsed}}$$

The electric tachometer also has a dial that continuously indicates the instantaneous speed in rpm. The value should also be divided by 2, for the reason previously explained.

Brake load observed. Brake load observed is the scale reading of the dynamometer.

Brake load corrected. Brake load corrected equals the brake load observed minus the tare.

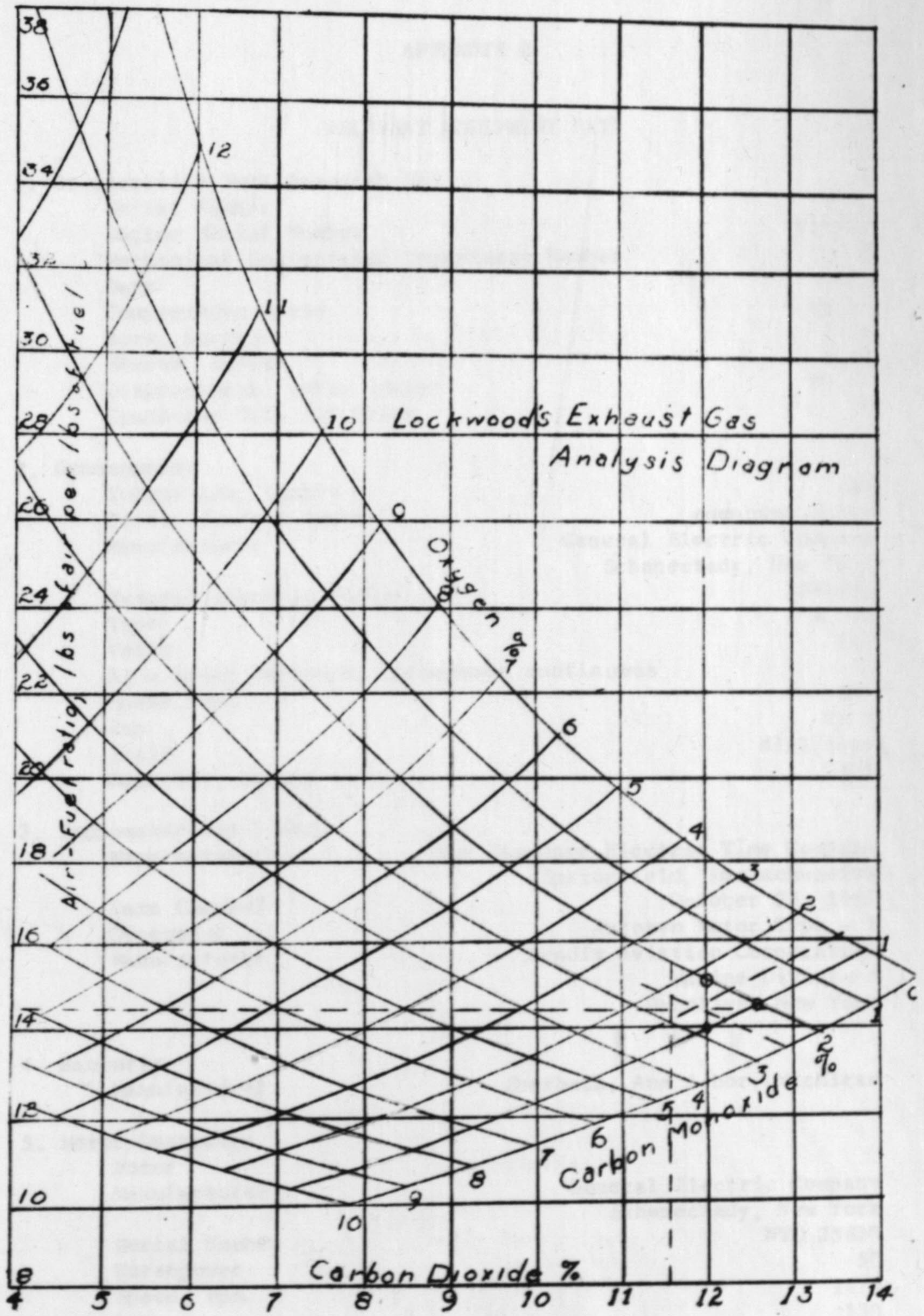


Figure 26. Lockwood's Exhaust Gas Analysis Diagram

APPENDIX B

RELEVANT EQUIPMENT DATA

1. Co-operative Fuel Research Unit

Serial Number	2284
Engine Serial Number	915047
Mechanical Engineering Department Number	2035
Date	1953
Compression Ratio	4 to 10
Bore, inches	3.25
Stroke, inches	4.50
Displacement, cubic inches	37.33
Crankcase Oil, SAE Grade	30

2. Dynamometer

Torque Arm, inches	12
Direct Current Motor	compound wound
Manufacturer	General Electric Company Schenectady, New York
General Electric Number	1248432
Type	RC 29
Volts	115
As a motor delivers, horsepower continuous	10
Speed, rpm	850
Amp	78.5
Scale	dial type
Capacity, pounds	100

3. Tachometer and Timer

Manufacturer	The Standard Electric Time Company Springfield, Massachusetts
Date Checked	October 23, 1961
Generator	Autosyn Motor Type - I
Manufacturer	Bendix Aviation Corporation Marine Division Brooklyn, New York

4. Barometer

Manufacturer	Eberbach, Ann Arbor, Michigan

5. Motor-Generator

Motor	
Manufacturer	General Electric Company Schenectady, New York
Serial Number	NTO 35S30
Horsepower	50
Speed, rpm	1770
Amp	130
Generator	

Manufacturer	General Electric Company Erie, Pennsylvania
Serial Number	NT1-523
Wound	shunt
Volts	250
Amp	132

6. Sun Motor Tester

Manufacturer	Sun Electric Corporation Chicago, Illinois
Serial Number	14989
Mechanical Engineering Department Number	2010

7. Orsat Apparatus (two)

Manufacturer	Central Scientific Company Chicago, Illinois
Mechanical Engineering Department Number	749 750

8. Pressure Indicating Equipment

Cathode-ray oscilloscope

Manufacturer	Allen B. Du Mont Laboratories, Inc. Passaic, New Jersey
Type	304 H
Serial Number	2124
Response	ac and dc
Full Scale Vertical Sensitivity, millivolts (approximately)	80
Electrical Engineering Department Unit Number	E-1

DuMont Oscillograph Record Camera Adapter

Manufacturer	Allen B. Du Mont Laboratories, Inc. Clifton, New Jersey
Serial Number	8052
Electrical Engineering Department Unit Number	E-14

Polaroid Land Camera

Type	2620
For pressuregram pictures of this report	
Lens Opening	f1 2.8
Speed, seconds	50/1000

401 Pressure Pickup

Pressure Range, psi	0.1 - 3000
Sensitivity, pico-coulomb/psi (approximately)	4
Linearity, per cent	1
Natural Frequency, cycles per second (approximately)	50,000
Maximum Temperature (continuous), degrees F.	500
Maximum Temperature (intermittent), degrees F.	3000

651-B Piezo Calibrator

Maximum Input Signal, volts	0.6
Maximum Output Signal, volts	0.6

Voltage Gain (approximately)	1.0
Input Impedance, ohms (approximately)	10^{14}
Output Impedance, ohms (approximately)	10^{5}
Linearity, per cent	1
Response, cycles per second	0 - 40,000

APPENDIX C

OPERATION PROCEDURES

A. What to do before starting unit. (Dynamometer connected)

1. Examine the test plant to disclose any improper conditions.
2. Check engine oil level and dynamometer oil cups.
3. Lubricate valve rocker-arm bearings, the push rod ends of the valve rocker arms, the valve stem ends of the rocker arms and the cylinder worm gear with SAE 30 oil.
4. Check coolant level. (Coolant liquid should show a 3/4 inch column in the sight gage.)
5. Turn on condenser water supply.
6. Open ice tower air inlet. (If ice is to be used, fill with no smaller than 2 inch cubes to a minimum depth of 18 inches.)
7. Set compression ratio so that warm-up fuel won't knock excessively.
8. Place gasoline in one or more of the fuel tanks.
9. Adjust fuel level to approximately 1.3 on the sight glass.
10. Open all dynamometer switches.
11. Place starting box switch in down position.
12. Lock dynamometer scale.
13. Place rheostat (Numbered 5) at zero resistance. (Clockwise)
14. Close fuse box switch.
15. Place motor-generator safety switch in off position.
16. Rotate flywheel by hand to see that all parts move freely.

B. Starting unit.

1. Place motor-generator switches in on position.
2. Press motor-generator starting buttons.
3. Adjust d-c voltage from motor-generator to 115.
4. Place motor-generator safety switch in on position for CFR unit.
5. Close switch Number 8.
6. Close line switch Number 6.
7. Slowly raise starting box switch to rotate engine.
8. Check engine oil pressure. (If the pressure is less than 20 pounds, the engine should be stopped immediately and the cause determined.)
9. Actuate CFR starting switch.
10. Adjust CFR generator voltage to 110.
11. Turn on ignition switch.
12. Turn fuel selector valve to draw fuel from filled tank.
13. Adjust temperatures of oil, intake air, mixture and coolant to those specified.

C. Loading engine. (Separately excited)

1. Open line switch Number 6.
2. Place starting box switch in down position.
3. Place rheostat (Numbered 5) at full resistance. (Counter-clockwise)
4. Close switch Number 7.
5. Raise starting box switch.
6. Unlock scale.
7. Close switches Number 1, 2, 3, and 4 in proportion to the load desired.
8. Load by turning rheostat (Numbered 5) clockwise.

D. Loading engine. (Self excited)

1. Open line switch Number 6.
2. Place starting box switch in down position.
3. Place rheostat (Numbered 5) at full resistance. (Counter-clockwise)
4. Close switch Number 9.
5. Close switch Number 10.
6. Close switch Number 7.
7. Unlock scale.
8. Close switches Number 1, 2, 3, and 4 in proportion to the load desired.
9. Load by turning rheostat (Numbered 5) clockwise.
10. Press motor-generator stop buttons.
11. Place motor-generator switches in off position.
12. Place motor-generator safety switch in off position.

E. Shutting down unit.

1. Turn selector valve to an intermediate position to cut off fuel supply to engine.
2. Turn off ignition switch.
3. Turn off air and mixture heater switches.
4. Actuate stopping switch.
5. Let engine be motored for two minutes to clear crankcase of fumes by methods of procedure B.
6. Shut down motor-generator as outlined in procedure D.
7. Turn off condenser water supply.
8. Set flywheel so that both valves are closed with piston at or near top dead center.
9. Turn oil heater switch off.
10. Turn off oil cooling water supply.
11. Drain all carburetor tanks.
12. Close ice tower air inlet.

NOTE: A good practice before starting the dynamometer and also after the dynamometer is running, but not loaded, is to remove the bottom pin in the scale and unlock the dynamometer arm. Then gently rock the motor frame to exercise the trunnion bearings and to make sure of unrestricted action of the dynamometer.

APPENDIX D

APPROXIMATE COST OF MATERIALS AND EQUIPMENT

½	yard sand	3.50
3	bags cement	4.65
2	pounds 12 gage black wire	.75
2	1 x 8 x 20 #3 white pine	1.70
1	1 x 8 x 6 #3 white pine	.52
1	1 x 3 x 12 #3 white pine	.52
2	2 x 4 x 18 construction fir	4.32
1	Kistler Model SLM 401 Pressure pickup	310.50
1	Kistler Model 427 Water Cooled Adaptor	31.50
1	Kistler Model 471 Low Noise Cable	13.50
1	Kistler Model 651-B Piezo Calibrator	279.00
2	Type 47 Polaroid Picture Rolls	4.18

NOTE: Materials acquired from the Mechanical Engineering Laboratories and many small items are not included in this list.