Abstract:
Gasoline internal combustion engines used in most engineering laboratories for teaching undergraduates the principles of engine operation have been, and are, of two general types: either multi-cylinder auto- mobile engines or very expensive, singlet-cylinder test engines. The former because of its complexity, is used mainly to test horsepower and fuel con-sumption and doesn't readily adapt to basic tests. The latter is quite expensive for most schools to purchase and is intended mainly for research into fuel performance and the effects of varying compression ratio.

This thesis shows that a laboratory test procedure on a small inexpensive single-cylinder engine can be used that will demonstrate the principles of a gasoline engine by making it possible to do the following:
1. Read pressure-time diagram.

2. Determine mean effective pressure and PV diagrams.

3. Measure torque and brake horsepower output.

4. Measure friction horsepower.

5. Measure fuel flow to the engine.

6. Measure air flow to the engine.

7. Vary air - fuel ratio.

8. Analyze exhaust gases.

9. Vary ignition timing.

10. Vary compression ratio.

11. Drive running engine (to simulate deceleration).

Many tests, both major and minor, can be run on the engine proving. the interdependence of one variable on another. All this can be done with a comparatively small investment in materials and with the use of standard laboratory instruments. Hence for a small amount complete tests may be run on an engine to demonstrate basic principles, to show the effect of engine tuning alterations, or even to do research into the effects of major or minor modifications.

A MORE COMPLETE AND INEXPENSIVE GASOLINE ENGINE TEST PROCEDURE

by

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A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Mechanical Engineering

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Bozeman, Montana

June, 1964

Acknowledgment

Special appreciation and many thanks are extended to David H. Drummond, Associate Professor, M. E. Dept., for concrete assistance and advice over the period of the development of the equipment and this thesis. Bernard Danhof, laboratory technician in the M. E. Dept., supplied many of his skills to the construction of the equipment. Dr. H. F. Mullikin, Head of the M. E. Dept., gave much calm advice and patience in the writing and completion of this thesis.

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Abstract

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INTRODUCTION

Mechanical engineering in years past has traditionally had two types of devotees to whom the word "combustion" meant different things. Combustion implies the generation of steam to some and a contraction of "internal combustion engines" to others. Many college hours were devoted to both subjects in lectures and labs until the middle and late fifties and then the overwhelming volume of science courses and the necessity of treating thermodynamics as one underlying science, have made it necessary to abbreviate single subject courses and make them part of a whole. Also the shortening of time available made it desirable to teach the very basics rapidly and in a manner not to be easily forgotten. One way is to allow the student to perform experiments himself, or in very small groups, with concurrent lectures and/or demonstrations. This requires multiple laboratory test set-ups.

The traditional method of approach to the subject of internal combustion engines was lecture and associated labs. In the lab an automotive engine was mounted on a test block and coupled to some sort of load. From this test set-up, horsepower and fuel consumption could be determined and their interdependence shown. These tests were generally demonstration to the majority of the students and certainly did not demonstrate fundamentals.

The affluent college may perhaps have had a Cooperative Fuels Research Committee engine (commonly called the CFR engine) whose main function is to test engine fuels and whose original cost, with allied equipment, exceeds ten thousand dollars. This CFR engine is more a research tool than it is a teaching tool. It is true that the CFR engine is as versatile as a test engine can be; timing, air-fuel ratio, compression ratio can be varied and supercharging can be done. The cost of the engine makes it very uneconomical to install multiple units. To trust this high-priced equipment to inexperienced students could be very costly.

The basic principles of engine operation, and the effects of altering essentially fixed features of an automotive engine on its performance could not readily be shown in the lab. Hence these features of engines had to be taught on the blackboard.

The testing equipment and procedures proposed herein will show a way to provide multiple testing arrangements at a cost amounting to a fraction of the cost of one CFR engine. The proposed testing methods are safe, simple and rugged. The equipment is arranged so that it is essentially fool-proof. Without deliberate effort the student cannot hurt himself or the equipment. If the deliberate effort were made to hurt the equipment, the loss would be minimal as compared to the CFR or automotive engines.

If the reader is not familiar with the necessity of the tests proposed herein, and a complete understanding is desired, he is referred to an elementary text on internal combustion engines. One such text is "Elements of Internal-Combustion Engines" by Rogowski, published by McGraw-Hill. A review of basic theory follows.

The definition of horsepower is that it is equal to work done per unit of time.

(a) HP = Work done/Unit of time

In the internal combustion engine it can be said that the horsepower developed is equal to the weight of the fuel burned per minute (w_f) times the heating value of the fuel (e_c) times the efficiency of the process in the cylinder (n_i) times the efficiency of the engine converting the energy in the cylinder to the energy coming out of the engine shaft (n_m). This may be written as:

(b) $HP = w_f \times e_c \times n_i \times n_m$

To put this equation into the proper units we will multiply by J(778 Ft Lb/Btu), divide by 33000 (Ft Lb/Min = 1 HP), state the pounds of fuel burned per minute, the heating value of the fuel in Btu per minute, efficiencies in decimal per cents and call the horsepower "brake-horsepower" (BHP).

(c) $$BHP = \frac{w_f(\text{Lb/Min}) \times e_c(\text{Btu/Lb}) \times n_i \times n_m \times J(\text{Ft Lb/Btu})}{33000(\text{Ft Lb/Min-Hp})}$$

In any engine, the fuel that can be introduced can be varied over a wide range. This does not do any good, however, since what really matters is how much air can be crowded into the cylinder to burn the fuel. There is a definite limit to this. To make equation c have more meaning, it would be reasonable to state the w_f as the weight of air per minute (w_a) times the fuel-air ratio in the cylinder (F) — a decimal per cent. Hence:

(d) $BHP = w_a \times F \times e_c \times n_i \times n_m \times J/33000$.

In this last equation, an examination of the terms will show that J and 33000 are fixed and e_c is dependent on the fuel. All that can be worked with, to improve the BHP output, are the efficiencies n_i, n_m and the (w_a x F) term. The efficiency n_i is called the indicated efficiency. This indicated efficiency is the ratio of the power produced in the actual cylinder as compared to the chemical energy of the fuel burned. One ideal cycle is called the Otto cycle and is actually unobtainable, but is approachable. This ideal cycle consists of four major processes: constant volume combustion and heat rejection, frictionless adiabatic expansion and compression of an ideal gas. The constant volume combustion is the one process most difficult to attain and the deviation from constant volume combustion, in the actual cycle, is most responsible for a low indicated efficiency when compared to ideal cycle efficiency.

The testing procedure that reveals what is going on in the cylinder is the determination of a pressure-volume (PV) diagram. A PV diagram taken of an engine on test can be compared to an ideal PV diagram. The area enclosed in a PV diagram (actual or ideal) represents the energy developed (or ideally developed). Anything that happens to decrease the area in a PV diagram is decreasing the energy developed.

The actual engine operating variables that affect the shape of the PV diagram and can be detected as proper or improper are: ignition timing, fuel-air ratio, compression ratio, valve timing and speed.

As mentioned previously, the ideal cycle has a constant volume combustion process. To attain a constant volume combustion the combustion must take place while the engine piston is at top-dead-center (TDC). To make combustion take place at TDC, the combustion must be rapid (within limits) and the speed of combustion is increased by the following:

1. Increased compression ratio (higher temperatures and less residual gas dilution).
2. Higher engine speeds (greater gas turbulence).
3. Increased inlet pressure (greater gas density).
4. Optimum fuel-air ratio (greater temperatures).

Engine speed has its effect on the PV diagram more indirectly than directly. An increase in engine speed means there is less time per cycle for each event to occur. This makes it necessary to adjust other variables, such as ignition timing, to get optimum timing.

Mechanical efficiency of an engine is equal to the brake horsepower (BHP) divided by the indicated horsepower (IHP). If BHP is known, IHP may be found by adding the friction horsepower (FHP) to the BHP. FHP consists of mechanical friction horsepower (MFHP) losses caused by sliding internal parts and pumping friction horsepower (PFHP) losses caused by pumping gases in and out of the cylinder.

FHP total may be found by motoring the engine and measuring the horsepower required. This common method is not as accurate as could be, however. FHP is slightly different when the engine is firing because of different pressures, temperatures, lubrication conditions and pumping losses. A PV diagram will give the IHP and the PFHP. PFHP is represented by the difference in the areas under the intake and exhaust strokes. If the BHP is measured at the time the PV diagram is made, then the MFHP can be found by the following formula:

BHP = IHP - PFHP - MFHP.

This cursory review of some of the fundamentals of the internal combustion engine theory was done primarily to show to the reader the necessity of being able to perform the basic tests and make the separate adjustments so that the student can "see" the engine theory. The reader is again referred to any standard text on internal combustion engine fundamentals for more complete explanations, if desired.

It is apparent that the changing of engine variables, such as compression ratio, is very difficult on a multi-cylinder automobile engine and also that the measuring equipment becomes unreasonably large and expensive for high horsepower output engines. The advantages of the small engine, the small inexpensive instruments and testing equipment will become more apparent in later chapters.

CHAPTER 1

BASIC EQUIPMENT AND PURPOSE

The equipment necessary to run tests on a gasoline engine breaks down into the following basic categories:

1. Engine
2. Dynamometer
3. Torque measuring equipment
4. Fuel measuring apparatus
5. Air measuring apparatus
6. Cylinder pressure measuring apparatus

The equipment, finally settled on as best serving the intents of an inexpensive test procedure, is shown in the photographs in Figures 9 through 14.

The engine selected was a Briggs and Stratton, air-cooled, single-cylinder, 4-cycle, L-head engine, Model 80432. This engine developed a maximum of 3 HP at 3600 RPM and at sea level.

A DC compound-wound, 3 HP, Westinghouse motor was selected to be used as a dynamometer. See Chapter 8. This motor was coupled to the engine with a "soft" Dodge Para-flex coupling.

The torque was measured by suspending the dynamometer on ball bearings and preventing its rotation with a cantilever beam mounted on the dynamometer case. The beam had strain gauges mounted on it to read any strain that occurred. Strain was read on a potentiometer and read directly in foot pounds of torque. See Chapter 2.

The fuel measuring apparatus was a pair of balance scales on which the fuel tank was set and the time for a fixed amount of fuel to flow was measured. In the fuel line to the engine was mounted a variable-area flow meter to give a rough indication of fuel flow rate to facilitate flow rate adjustment. See Chapter 4.

The air flow measurements were approached in two different ways. The original method was to use sharp-edged orifice in a piping arrangement that included a blower supplying air to a surge chamber, then to the orifice and on to a second surge chamber which was connected to the engine intake. This method was difficult to control and calculations of air flow were comparatively lengthy. At the time of this writing a laminar air flow element was on order to replace the sharp-edged orifice. This laminar air flow element gives a linear relation between weight flow and pressure drop, is very accurate and can be rapidly read. Control of air flow should be much easier since the laminar flow element was originally designed for internal combustion engine air measurement. See Chapter 3.

The reading of cylinder pressures was accomplished with a strain gauge diaphragm transducer. Interpretation of the transducer signal was made by feeding the signal through a pressure monitor for calibration purposes and then to an oscilloscope. Permanent records can be made of the pressure and time diagram by photographing the oscilloscope trace with an attached Polaroid camera. Pressure-volume diagrams can then be made from the pressure-time diagrams. See Chapter 5.

The equipment described above was selected after unsuccessful attempts to use different equipment. The first error in judgment that cost much wasted time and effort was to start with a 6 HP engine with a compressor ratio of 4.76:1. To raise the compression ratio it became necessary to cast and machine new cylinder heads. This was done. A 3-HP DC motor, to be used as a dynamometer, was purchased for nearly $400. The thought was that for short periods the DC motor could stand a 100% overload and thereby be used with the 6-HP engine. The error in this thinking was not apparent at full load speeds because at full speeds the motor would stand 100% overload. However, at low speeds where generated voltage fell off and current increased, a 100% power overload could not be tolerated because of high currents.

The price of a new 3-HP engine was about $40 and the price of a new motor was over $500, so a new engine was purchased. This meant that the time and effort spent casting and machining new heads for the 6-HP engine was wasted. The new engine had a 6.2:1 compression ratio, hence new heads were not necessary. The compression ratio could be lowered by adding spacers under the cylinder head.

CHAPTER 2

READING HORSEPOWER OUTPUT OR INPUT

Originally it was decided to read output of the rigidly mounted dynamometer and add to this the dynamometer losses and thereby arrive at the output of the engine. The losses of the dynamometer were determined and curves were drawn, just for this purpose. Professor D. H. Drummond pointed out that the losses of the dynamometer varied not only with speed but with the load, because of different temperature of the windings. He went on to suggest the method finally used; that was the mounting of the entire dynamometer on ball bearings so that the reaction of the dynamometer to any torque applied would represent the entire output or input of the engine. The ball bearing mounting of the dynamometer was accomplished by machining its end bells to fit the inner races of the ball bearings and the dynamometer base was machined to fit the outer races. The dynamometer thus was free to react to any torque, but was kept from rotating by sticking a carefully machined cantilever beam, mounted solidly to the dynamometer case, down into a slot in the dynamometer base. The cantilever beam had about 1/8" clearance in the slot. Mounted on the beam were four strain gauges comprising the four resistances of a Wheatstone bridge circuit. See Figures 1 and 2. Any load on the beam caused a deflection and hence strain on the strain gauges. Strain on the gauges caused an unbalance in the Wheatstone bridge and the unbalance could be read on a null balance potentiometer. The proper selection of voltage supply to the bridge circuit made it possible to make the potentiometer read 1 millivolt for each foot-pound of torque. This meant that changes of torque could be read directly as adjustments were made to the engine.

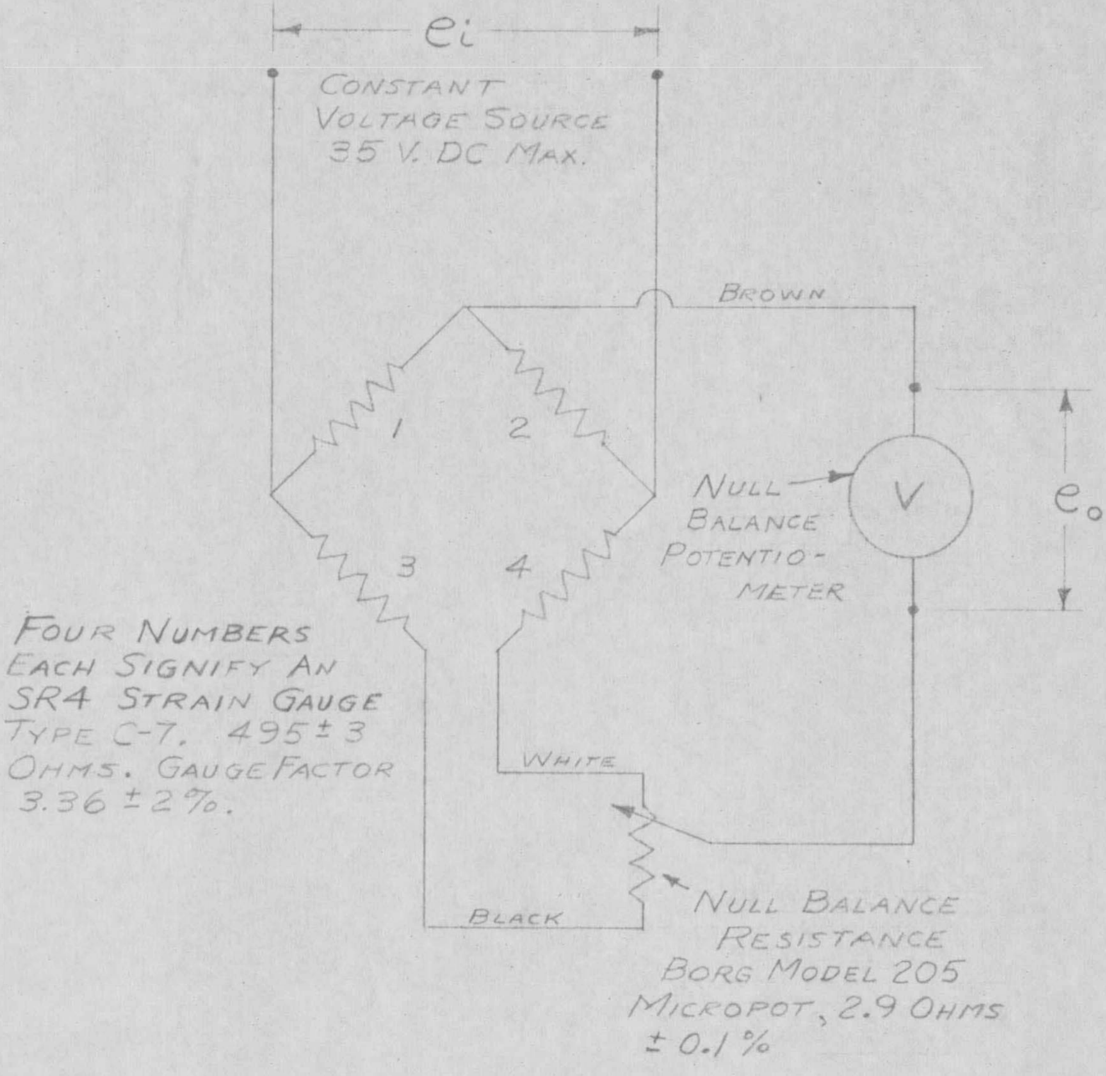


FIGURE 1

SPECIAL STRAIN GAUGE BRIDGE CIRCUIT

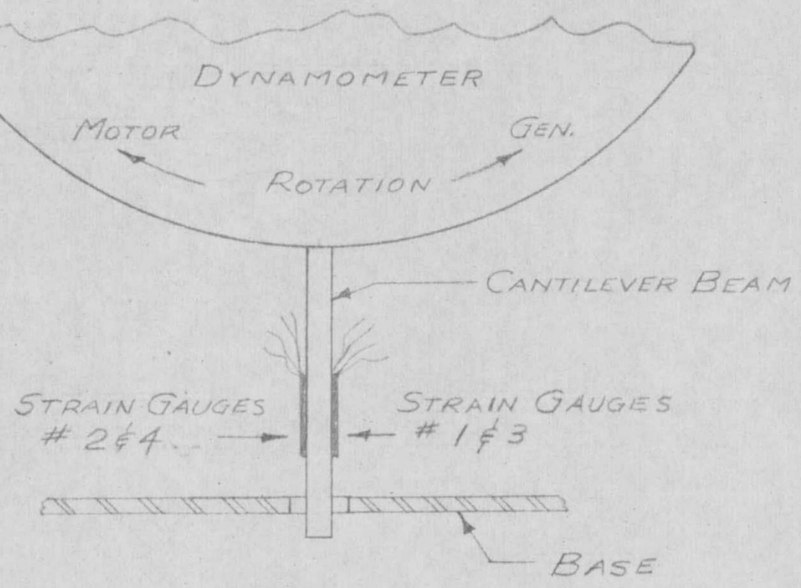


FIGURE 2.

STRAIN GAUGE INSTALLATION

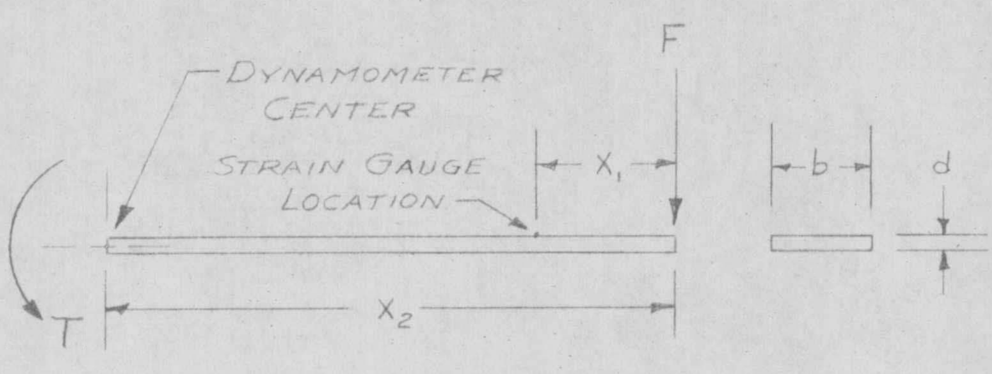


FIGURE 3.

CALCULATION DIAGRAM

The mounting of the dynamometer as described made it not only possible to readily read torque but also made the torque readings independent of variations in dynamometer modes of operation, such as internal or external excitation.

An adjustable counterweight balances the dynamometer in its bearings so that it supplies no torque when not running. Calibration is performed by hanging known weights a known distance from the dynamometer center on the dynamometer case.

The formula for relating input and output voltage for the circuit in Fig. 1 when only one resistance is variable is:

(1) $e_o/e_i = \epsilon f/4$

If all four resistances are strain gauges and vary, as has been done to quadruple e_o, then:

(2) $e_o/e_i = \epsilon f$

where e_o is the output voltage

e_i is the input voltage

f is the strain gauge factor

ϵ is strain

Strain is proportional to force (F) applied at the end of the cantilever beam and torque (T) is equal to force applied times the radius arm and proportional to force alone.

(2a) $e_o/e_i = \epsilon f \propto F$

(3) $T = F x \propto F$ where x is the radius arm

So then we can write:

(4) $T \propto e_o/e_i$

(5) $T = k\, e_o/e_i$

To prove this relation is true and linear the following may be written about Fig. 3. Here we let S be stress, E is the modulus of elasticity of steel, c is the distance from neutral axis, M is the moment and I is the moment of inertia. Other symbols are dimensions as shown.

(6) $$S = E\epsilon = \frac{M_c}{I}$$

(7) $$\epsilon E = \frac{F\, x_1\, (d/2)}{bd^3/12} = \frac{6\, F\, x_1}{b\, d^2}$$

(8) $$\epsilon = \frac{6\, F\, x_1}{E\, b\, d^2}$$

From equation 2

(9) $$e_o = e_i\, f\epsilon$$

Substituting 8 in 9

(10) $$e_o = \frac{6\, F\, x_1\, e_i\, f}{E\, b\, d^2}$$

Multiply right side by x_2 over x_2

(11) $$e_o = \frac{6\, x_1\, e_i\, f\, F\, x_2}{E\, bd^2 \qquad x_2}$$

Since $T = F_x$ by definition and all terms in equation 11 are constant except e_o, e_i, and T, we may write:

(12) $$K = \frac{6\, x_1\, f}{E\, b\, d^2\, x_2}$$

and

(13) $$T = F\, x_2$$

Substituting in 11

(14) $$e_o = K\, e_i\, T$$

or

(5) repeated $T = k\ e_o/e_i$

This shows that equation 5 is linear and that K or k can be solved for. Instead of solving for K, however, we just connected a voltmeter to e_i and calibration weights to the dynamometer and found that when e_i equalled 11 volts, then T in foot pounds equalled e_o in millivolts.

If 11 volts of constant DC is put into leads to the bridge circuit, null balance is adjusted so that at zero torque the potentiometer (e_o) reads zero; then as torque is applied to the dynamometer the potentiometer will read one millivolt for every foot pound of torque.

It may be more advantageous, under some circumstances, to read the dynamometer output in horsepower. To do this we may say that we will continue to put 11 volts DC into bridge circuit and then solve for an output representing HP at different RPM. Being able to read output voltage on the potentiometer and RPM from a tachometer, we can read HP from a family of curves as shown in Fig. 4. Calculations for curves are as follows:

(5) $T = K\ e_o/e_i$

when $e_i = 11$ then

(15) $T = K\ e_o/11$

and

(16) $T = e_o$

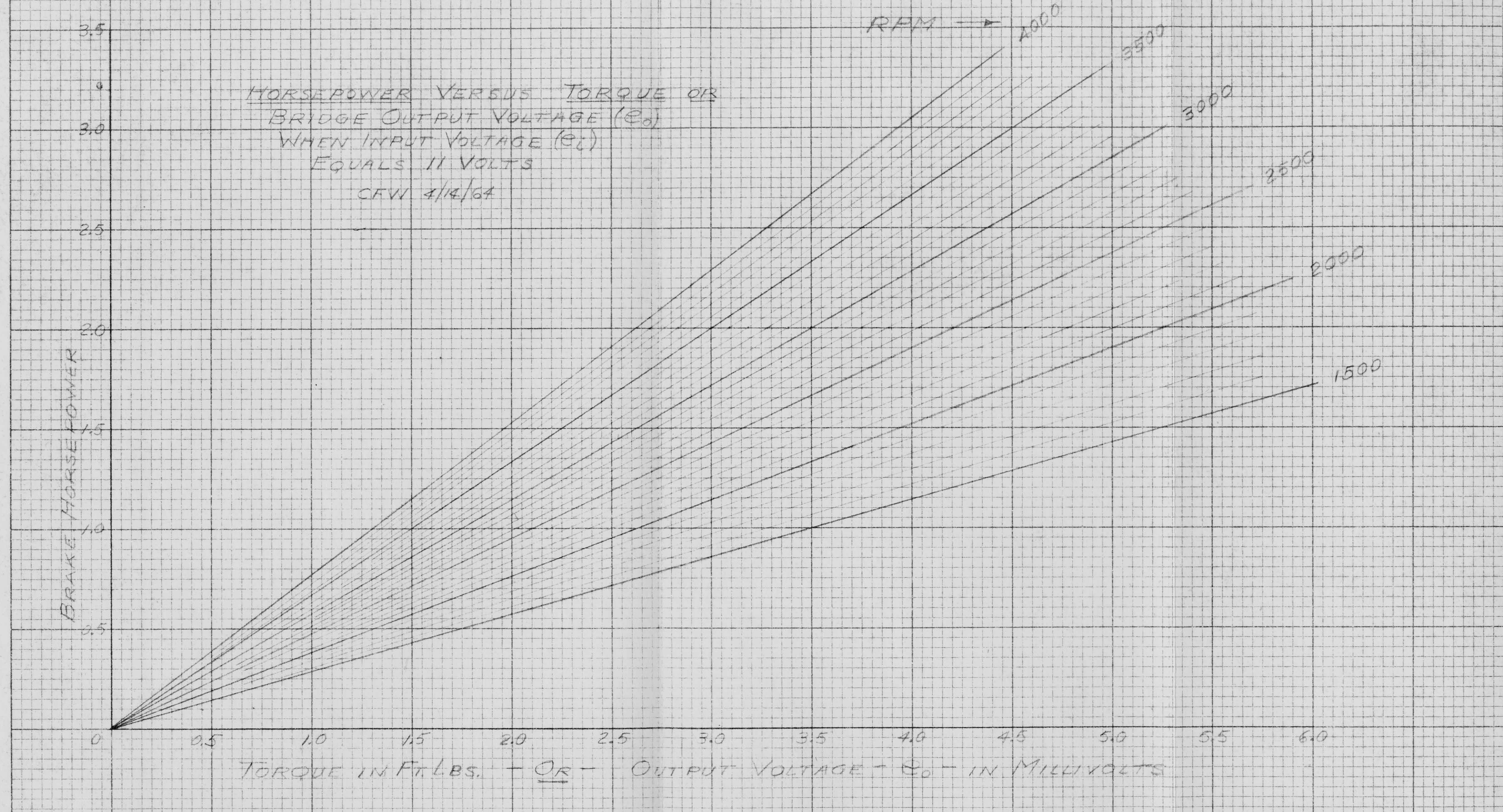
so

(17) $K = 11$

and

(18) $T = 11\ e_o/e_i$

by definition



HORSEPOWER VERSUS TORQUE OR
BRIDGE OUTPUT VOLTAGE (e_o)
WHEN INPUT VOLTAGE (e_i)
EQUALS 11 VOLTS
CFW 4/14/64
RPM →
4000
3500
3000
2500
2000
1500
BRAKE HORSEPOWER
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
TORQUE IN FT. LBS. - OR - OUTPUT VOLTAGE - e_o - IN MILLIVOLTS

FIGURE 4.

(19) $$HP = \frac{2\pi T N}{33000}$$

where N = RPM and HP = horsepower. Substituting 18 in 19

(20) $$HP = \frac{2\pi N (11\ e_o)}{33000\ e_i} = \frac{22\pi N\ e_o}{33000\ e_i}$$

Solving for e_o

(21) $$e_o = \frac{HP\ 33000\ e_i}{2\pi N}$$

Solving this equation for different RPM, a family of curves was drawn for different RPM on a plot of e_o versus HP. e_o is read from a potentiometer and the chart is entered at the e_o value, proceed to proper RPM curve and then read HP.

The above equations may also be solved for an input voltage at some definite RPM that will cause the potentiometer to indicate horsepower directly. The input voltage would have to be set (reading values from a table) for every change in RPM, but horsepower would be read directly from the potentiometer.

CHAPTER 3

MEASURING AIR FLOW TO ENGINE INTAKE

The small engine that was chosen made it no problem to build equipment that would measure air flow to the engine. Since flow of air to a reciprocating engine is not a steady flow process, it was necessary to construct surge chambers. The engine air cleaner was removed and in its place was connected a ten-inch cubical sheet metal box sealed against leakage. See Fig 5a. Air entered this surge chamber through two-inch copper tubing. A manometer connection was made on this box to make it possible to read air pressure as it entered the engine. Ten inches upstream on the copper tubing and at its end was mounted a flange. A matching flange was located on the end of another piece of copper tubing forty inches long. Between the two flanges was located a sharp-edged orifice, properly sized for the job to be done. In the flanges were located taps to read the differential pressure across the orifice in inches of water. See Fig. 5b.

At the other end (or upstream) of the 40" piece of copper tubing was another 10" cubical box. Air entered this surge chamber from a piece of tubing run from an old vacuum cleaner which was used as a blower. This surge chamber was also equipped with a waste valve to permit excess air to escape to the atmosphere.

Air had to be supplied at a pressure above atmospheric to assure flow through the orifice and to make it possible to maintain a pressure in the surge chamber just upstream of the engine that was as near atmospheric as possible so that operating conditions were normal atmospheric conditions. To provide air to the system the blower from an old upright vacuum cleaner

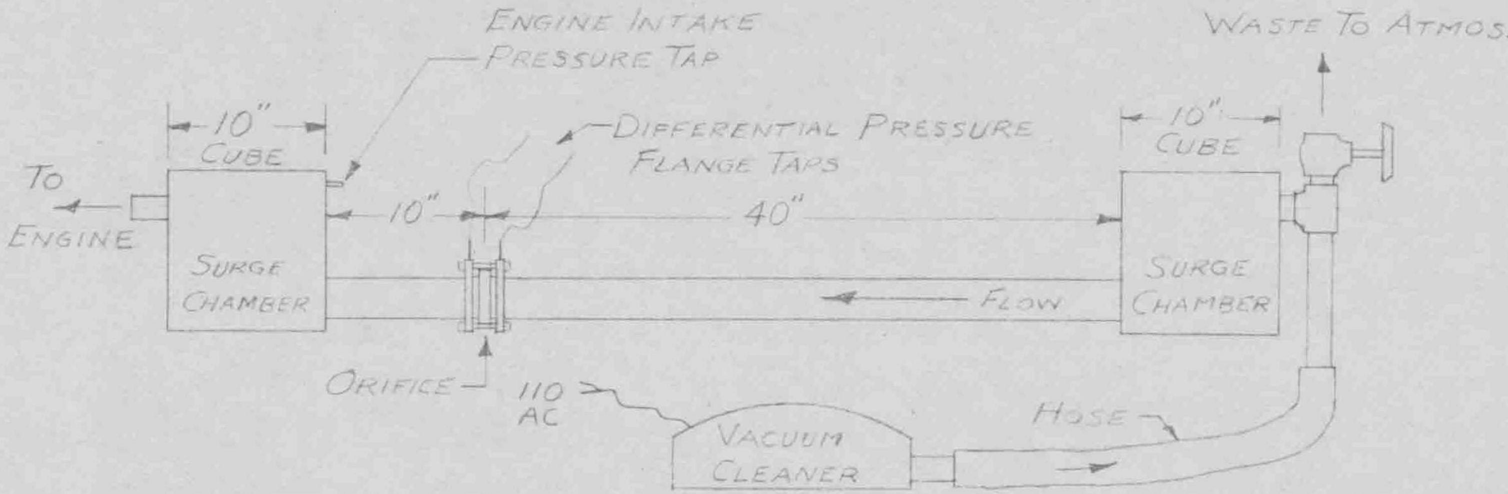


FIGURE 5a. AIR FLOW MEASURING EQUIPMENT

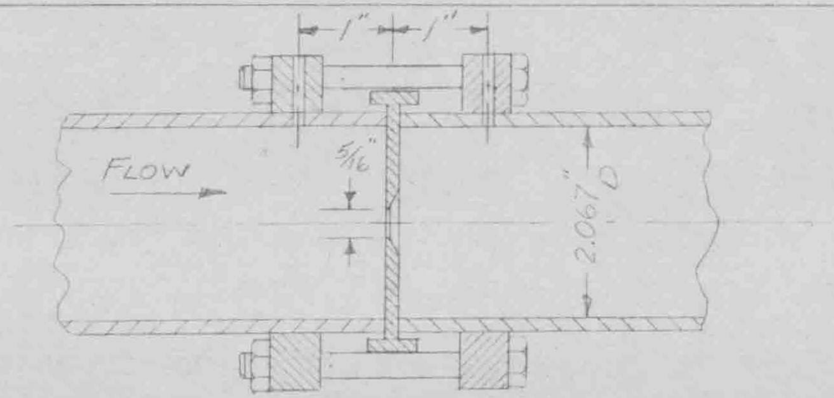


FIGURE 5b. SECTION OF ORIFICE & FLANGE TAPS

was used. The air from this blower was essentially at room temperature since the air was not compressed to any great degree and it did not pick up heat from its motor.

This system of supplying air was used for many trials and was not considered successful. While air could be measured this way, the Reynolds number was so low that the orifice coefficient of discharge was not in the "flat" portion of the curve and also to go from maximum to minimum flow would require changing orifice sizes to keep Reynolds number in the turbulent flow region. The most difficult part of this arrangement was the actual operation of it. Adjustment of air flow with the waste valve, and with a variac to vary blower speed, was extremely difficult and was almost impossible for one man to do. If the air flow was not just right for the speed at which the engine was running, then the engine would start to hunt, the air flow would start to "bounce", aggravating the engine hunting and usually the water would be blown from the manometers.

To more easily and accurately measure the engine air flow it was decided to purchase a laminar flow element from the Meriam Instrument Co. This company makes a device consisting of parallel, capillary-size tubes through which the air flows and the pressure drop across the tubes has a straight-line relation with the mass air flow. These devices are used in research work to measure air flow to automobile engines and cause about the same intake restriction as an engine intake air cleaner.

There is no reason why the engine operation could not be made to simulate atmospheric conditions at any altitude or to simulate supercharged conditions. Perhaps the most ambitious plan, but in the end easiest to use, would be to put the engine and dynamometer in a box that could be pressurized or evacuated to suit conditions desired. All connections to the engine are flexible and could easily be brought from the box. The main problem that would be encountered would be the supplying of air at the proper pressure and in sufficient quantities to cool the engine. The carburetor on the engine as supplied will not operate properly when the pressure outside the carburetor is less than the pressure inside. There may be a carburetor available that could stand the supercharging process and be adaptable to this engine.

CHAPTER 4

MEASURING FUEL FLOW TO THE ENGINE

The usual method of measuring fuel flow to an engine is to weigh fuel used over the duration of the test run. This then can be converted to any units desired if the specific gravity of the fuel is measured. This method was chosen to be used.

To assist in the rapid reading and coarse adjustment of fuel flow, a variable area fluid flowmeter was put into the fuel line. This permits a rapid assessment of the change of conditions caused by throttle adjustment or by fuel-air ratio adjustment. The flowmeter used was a product of Fischer and Porter Co., their Flowrater Model No. 02-F 1/8 - 16 - S/35. This flowmeter was the variable-area type; the gasoline flows up through a vertical tube that is tapered from small at the bottom to larger at the top. As the gasoline flows it lifts a small ball in the tapered tube and the ball rises until the force of gravity is balanced by the force of the upward flowing gasoline. The tube is graduated for reading.

The fuel tank on the engine was removed and put high on a set of balance scales to be used as a part of the fuel-weighing procedure. This left the engine neater and easier to work on -- particularly to change heads. The fuel tank on the scales has its own shutoff valve and is connected by plastic tubing to the Flowrater which in turn has plastic tubing running to the engine carburetor. A shutoff valve (really a gas cock) was mounted on the carburetor to provide fuel shutoff and a way to attach plastic tubing.

CHAPTER 5

PRESSURE - TIME INDICATOR DIAGRAMS

There are currently available, on the market, a number of methods to measure combustion pressures in an internal combustion engine cylinder. Two of the most common of these are the quartz crystal transducer and the strain gauge diaphragm transducer. The latter was already in use in our laboratory, so for obvious financial reasons we chose it.

The simple, flat head of the Briggs and Stratton engine made it possible to mount the pressure transducer directly over the piston center. The engine head costs about two dollars, as a spare part, so we ordered a spare with the engine, so that when tests were run that did not require the transducer, its special head could be left off and the standard head used.

The engine head was milled flat in the area over the center of the piston -- the air cooling fins were removed. The head was thin in this area so it was deemed necessary to add metal, by welding, to provide a boss for the transducer. The boss was then drilled, spotfaced and tapped to receive the transducer. The spotfacing was done accurately so that the transducer face (or diaphragm) was flush with the inside surface of the head, hence no clearance volume was taken away or added to the cylinder.

The pressure transducer used was a Norwood Model 101-1-1500-26-61 strain gauge type. Pressure acting on the diaphragm of this transducer compresses a sensitive strain tube. The strain tube is wound longitudinally and circumferentially with two strain gauge wires whose change of resistances are opposed. The strain gauges are two arms of a bridge circuit and their unbalance causes a voltage signal. This signal is fed to a Norwood Model 5AC pressure monitor where a zero pressure pulse and an adjustable pressure pulse are superimposed on the signal. The signal is then fed to a Tektronix Type 503 oscilloscope which traces the pressure-time (PT) diagram. The oscilloscope is equipped with a Polaroid camera so that a permanent record of the diagram can be made.

To accurately indicate a point in the engine cycle on the PT diagram, so a conversion to a PV diagram can be made later, use was made of the original points on the engine, to close and send a pulse to the oscilloscope. This gave a pip on the oscilloscope 25° before TDC.

There is a definite disadvantage in not being able to get a PV diagram directly from the oscilloscope. To get a PV diagram, there has to be an input to the oscilloscope horizontal sweep that locates the piston and thereby indicates volume on the horizontal axis. Instruments that will do this are available, but their cost is in the neighborhood of $2000 and therefore considered prohibitive for this procedure. If such equipment is available in the laboratory, this problem is solved.

It should be noted that the transducer used requires a small quantity of cooling air. This air is piped (plastic tubing) to the transducer so that it cools the transducer internally.

The equipment use can be seen in the photographs that follow.

CHAPTER 6

VARYING ENGINE TIMING

The timing of the Briggs and Stratton engine is not variable. Covered and protected by the flywheel are the points, condenser and the cam that operates the points. Imbedded in the flywheel itself is the magnet that induces the current in the stationary core, also mounted solidly to the engine, outside and above the flywheel rim. The cam is simply a flat spot on the crankshaft that allows a small pushrod to fall once a revolution and close the points, thereby discharging the condenser into the coil and firing the sparkplug. This plug is fired twice a cycle -- once at the end of the compression stroke and once at the end of the exhaust stroke.

Nothing in the foregoing lends itself to simple modification so that the timing will be variable, hence something new had to be designed.

On the opposite side of the engine from the flywheel (power takeoff side) two 1/4" thick aluminum discs were mounted, concentric with and in a plane perpendicular to the crankshaft axis. Next to the engine the inner disc was screwed solidly to the engine. The outer disc was mounted to the inner disc with spring-loaded screws set in elongated slots so that the outer disc could be rotated through about 30°. On the outer disc a set of gap-adjustable automotive points were mounted along with the original condenser from the other side of the engine. The points were mounted so that its fiber follower would ride on a sleeve slipped over and keyed to the crankshaft. The sleeve had a flat spot on it so the points would close once a revolution. The movable disc had a handle mounted on it to make turning the disc easier. The outer disc rim was scribed so that it was graduated in degrees and a stationary mark was put on the inner disc rim so that movement of the outer disc could be measured.

The wiring on this arrangement was not different from the original except that to facilitate stopping the engine a small grounding switch was put in the primary circuit.

The foregoing arrangement to vary timing does not work as well as anticipated for large timing changes. The reason for this is that the magnet and core are still fixed in the flywheel and on the engine respectively. When the timing is changed many degrees from its normal 25° before top dead center, the flux generated by the magneto has either not reached or has passed its peak, hence the spark generated is too weak to be effective. For this reason large changes of timing require a different arrangement.

For a "Fat" spark at settings 5° before and 10° after normal, all that need be done is to hook up a standard 6 or 12 volt battery and a matched coil and condenser. These are then connected to the points mounted on the outer disc on the engine and to the sparkplug; then the timing change is only limited by the amount the outer disc can be rotated. It will be found, if this is tried, that the battery, coil and condenser arrangement will not give as hot a spark as the magneto arrangement. This is becausethe points are not closed long enough to permit a buildup of stored electrical energy in the condenser. This can be corrected by leaving the points closed longer; this will entail making a different cam for the movable points.

CHAPTER 7

VARYING COMPRESSION RATIO AND SPEED

The Model 80432 Briggs and Stratton engine has a compression ratio of 6.2 : 1. This was sufficiently high to permit a series of tests to be run by lowering the compression ratio simply by adding clearance volume to the engine. This was readily done by adding head gaskets and spacers under the head. The head can be removed and spacers changed in about five minutes. The area inside the head gasket is 7.5 square inches. This means that the addition of a gasket or spacer 1/16" thick would add 0.468 cubic inches of volume to the 1.5 cu in clearance volume that already exists. Steps downward of approximately one-half a compression down to a compression ratio of 4.0 : 1 would cover a range sufficiently large to show the effect of compression ratio on efficiency. Compression could be raised to about 7.2 : 1 by reducing existing head gasket from 1/16" thick to 1/32" thick.

Speed of the engine was set by screw throttle adjustment. It was soon discovered that the mechanical governor often caused the engine to hunt. The mechanical governor was disconnected and the throttle was then just controlled by a rigid screw adjustment. To prevent overspeed, a grounding mercury switch was placed on the governor lever arm so that high speeds would tilt the mercury switch and ground the ignition system temporarily. This prevented overspeed.

There was available an electric tachometer in our laboratory and so this tachometer was attached to the free end of the dynamometer and speed interpreted from a voltmeter. Since this is not an essential part and a standard laboratory tachometer will work just as well, the electric tachometer will not be considered as a permanent part of this test arrangement.

CHAPTER 8

DYNAMOMETER CIRCUIT AND CONTROL

The schematic wiring diagram for the dynamometer is shown in Figure 6. All electrical components and circuits are shown in this figure. The main breaker and the line starter were purchased with the dynamometer from Westinghouse. The push button station was purchased from General Electric. The field rheostat and the 15-amp armature current circuit breaker were purchased from other sources. The excitation switch is a small two-pole, double-throw, toggle switch. The motor-generate switch is an old three-pole, double-throw, knife switch that happened to be lying about and served the purpose well because it has the advantage of having exposed terminals and when in the neutral mode makes a handy way to check voltages, with a separate instrument.

The load rack is portable and consists of twenty 600-watt heating elements, each element has a single-pole, double-throw knife switch so that each element can be put into the line either in series or in parallel.

To facilitate the understanding of the circuits for different modes of operation, other drawings were made. Figure 7 is a schematic of the circuit when the dynamometer is used for motoring. Unnecessary detail has deliberately been left out. The procedure for arriving at this mode of operation is also listed on this drawing. It should be noted that the series field is not used for motoring.

The circuit as shown is "foolproof". Improper procedure will cause no damage -- only failure of the dynamometer to operate.

Figures 8a and 8b are the schematic wiring diagrams for operation of the dynamometer as a generator, either externally excited or self excited.

The externally excited arrangement tends to be steadier since the shunt field current will not vary with motor speed. If the DC source is not steady, it may be advisable to supply DC shunt field power with a small rectifier and a voltage regulator.

Note that the power consumed or generated does not have to be measured. Excitation power has no effect on engine output horsepower readings whether the excitation power comes from external or internal sources. Horsepower put out of, or into the engine is recorded by the reaction of the dynamometer on the cantilever beam as described in Chapter 2.

The compound motor was purchased as a dynamometer since the speed of the unit has to vary over quite a range -- 1500 to 4000 RPM. It was feared that at low RPM a shunt dynamometer would not have sufficient flux to maintain adequate load when self-excited and acting as a generator. When used for motoring the dynamometer is straight shunt motor. When used as an externally-excited generator, the series field is not necessary because the shunt field flux is always at full value. When used as a self-excited generator, the shunt field flux varies directly with speed; at low RPM the series field flux is necessary to maintain torque. In brief, the series field is only necessary during self-excited generating at low RPM. This means that if self-excitation during generation were not necessary or desired, the dynamometer could be made from a shunt motor and the extra price for compounding could be saved.

It will be noticed, in Chapter 9, that the field rheostat used is only 150 ohms. Greater speed regulation could be obtained if a larger resistance were used. The reason for not using a larger resistance is that when starting the dynamometer as a motor, all resistance in the field rheostat should be removed; this keeps the flux high and the armature current down. If high resistance is left in the shunt field circuit, armature current and torque increase rapidly until the counter-emf regulates the armature current. This means if the shunt motor (dynamometer) is started with high resistance in the shunt field, the starting current will be high -- perhaps high enough to cause damage. To prevent this the 150-ohm field rheostat was selected. If the 150-ohm resistance is inadvertently left in the shunt field, the maximum starting current will be safe if some armature load is present. Full load current for this particular dynamometer is 11 amps.

Speed regulation of the shunt motor is normally done with the field rheostat. A large spread of speed regulation is obtained by adding resistance to the armature circuit to get major changes and the fine adjustment is then done with the field rheostat. The load rack, used for generating load, is conveniently used for the added armature resistance.

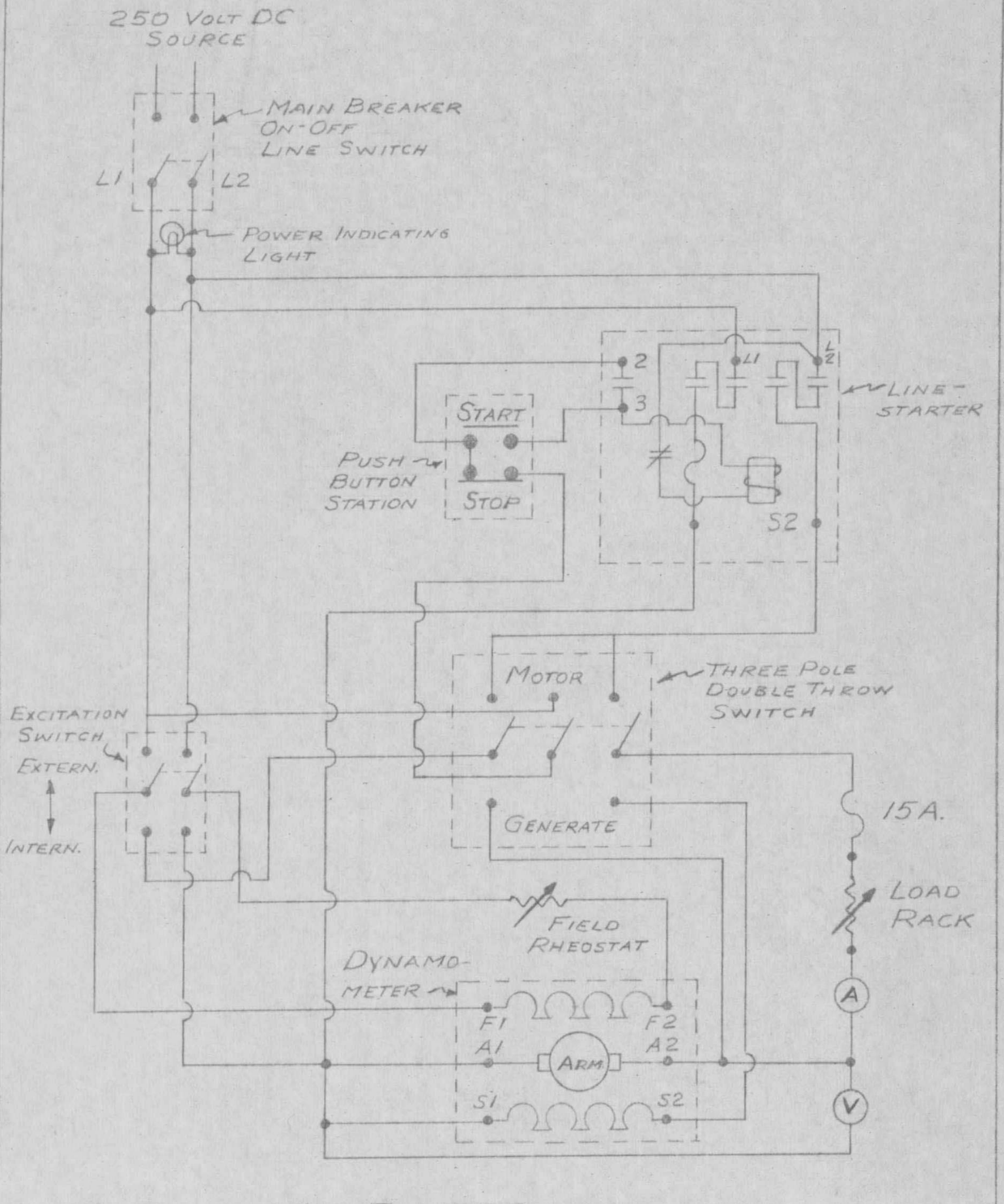
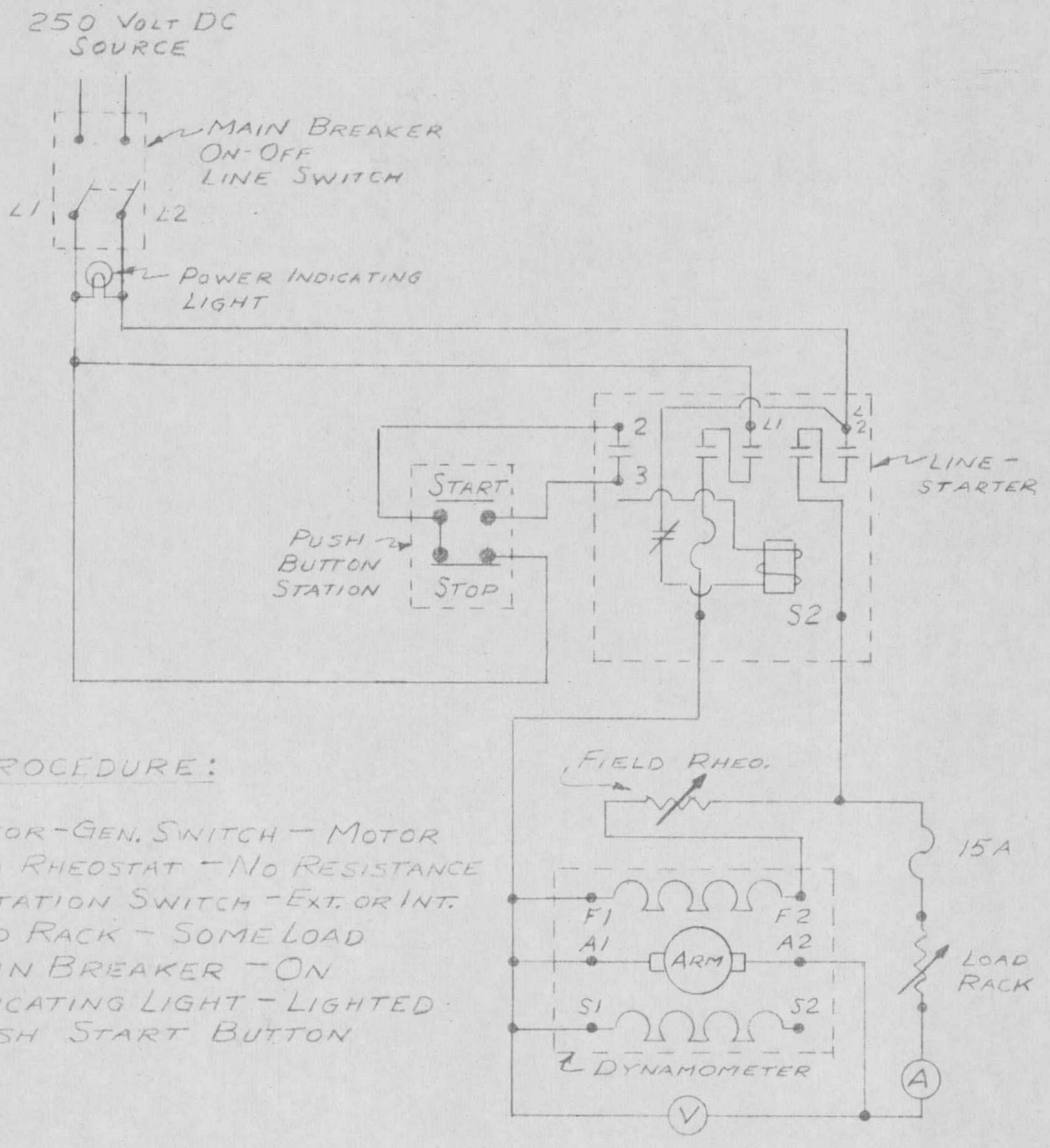


FIGURE 6.

SCHEMATIC WIRING DIAGRAM

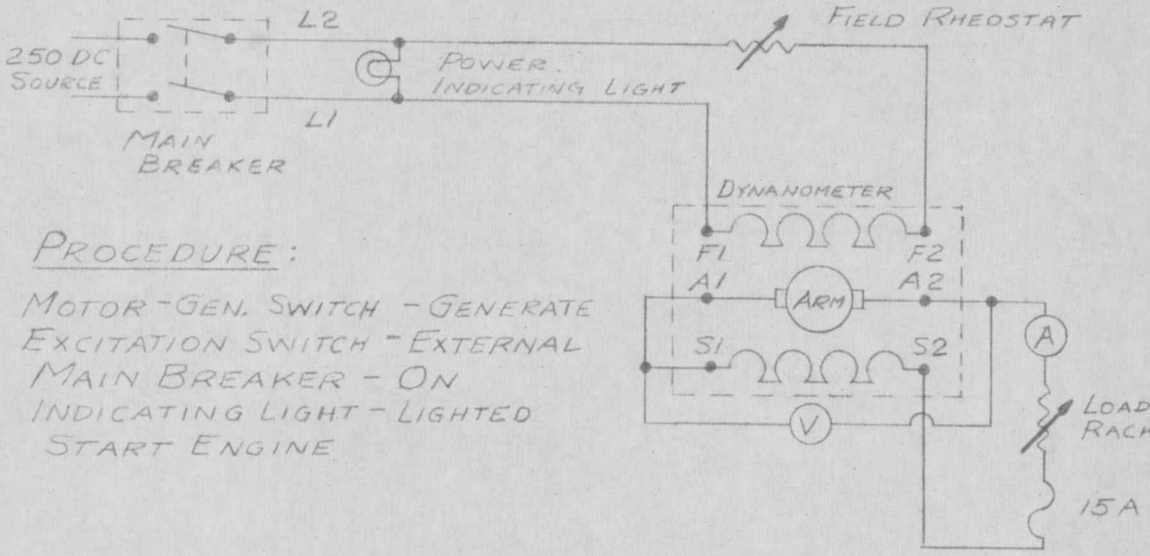


PROCEDURE:

MOTOR-GEN. SWITCH – MOTOR
FIELD RHEOSTAT – NO RESISTANCE
EXCITATION SWITCH – EXT. OR INT.
LOAD RACK – SOME LOAD
MAIN BREAKER – ON
INDICATING LIGHT – LIGHTED
PUSH START BUTTON

FIGURE 7.

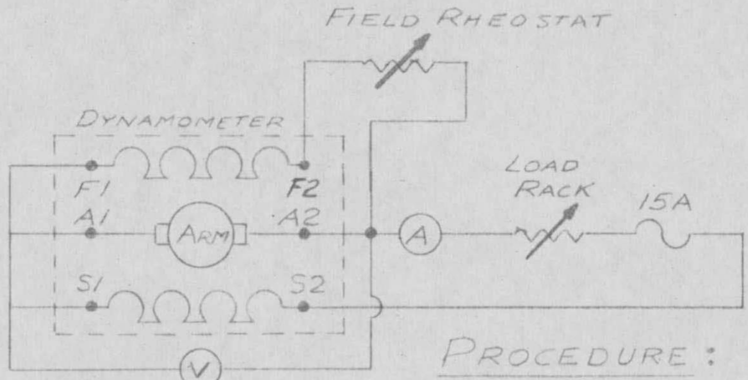
SCHEMATIC WIRING DIAGRAM – MOTORING



PROCEDURE:

MOTOR-GEN. SWITCH - GENERATE
EXCITATION SWITCH - EXTERNAL
MAIN BREAKER - ON
INDICATING LIGHT - LIGHTED
START ENGINE

a. EXTERNALLY EXCITED



PROCEDURE:

MOTOR-GEN. SWITCH - GEN.
EXCITATION SWITCH - INTERNAL
MAIN BREAKER - OFF
INDICATING LIGHT - OUT
START ENGINE

b. SELF EXCITED

FIGURE 8.

SCHEMATIC WIRING DIAGRAM - GENERATING

CHAPTER 9

MATERIAL DESCRIPTION, SOURCE AND COST

The following equipment was purchased specifically for this gasoline engine test arrangement and is a permanent part of it:

1. Single-cylinder gasoline engine

   Briggs and Stratton Model 80432, type 943067 with mechanical governor, stellite exhaust valve and seat and crankshaft extension "B".

2. Spare cylinder head for gasoline engine above.

3. Coupling

   Dodge Mfg. Co., Para-flex Model PX-60

4. DC Motor

   Westinghouse 3 HP, 3500 RPM, open drip-proof compound-wound DC motor, Frame 187, 240 volts, class B insulation, 60° rise, ball bearing, series field amp turns equal to 25% of shunt field amp turns.

5. Main breaker

   Westinghouse EH circuit breaker, 2-pole, 30-amp, 250-volts DC, catalog #EH 0230.

   Can for this breaker, surface mounted.

6. Line starter

   Westinghouse magnetic starter, Class 8502S1NNNT, NEMA size 1, 3 HP, 250 volts, NEMA 1 enclosure, non-reversing, 16-amp heater element.

7. Push button station.

   General Electric CR2943NA102A, 600 volts

8. 15-amp armature circuit breaker

   Heinemann Circuit Breaker Co.

9. Field rheostat

   Westinghouse Type LR Rheostat Style 1557795, 150 ohms; 2-9 amps, 250 volts, 6243112WL.

10. Power indicating light

    250-volt, candelabra-type screw base and lamp.

11. Excitation switch

    DPDT toggle switch, 2 amp/250 v, Cutler-Hammer type 7591-K6.

12. Strain gauges

    Four (4) SR-4 strain gauges, type C-7, 495 ± 3 ohms, gauge factor 3.36 ± 2%. Baldwin-Lima-Hamilton Co.

13. Null balance resistance

    Borg Model 205 Micropot, 2.9 ohms ± 0.1%.

14. Auto ignition points

    Any auto supply store.

15. Miscellaneous material

    110 v AC switches and receptacles, wiring, outlets, steel angle, particles board, concrete, BX cable, conduit and conduit fittings, Tygon plastic tubing.

16. Labor

    120 hours estimated for a technician to construct with plans as they now exist.

The purchase price of the foregoing equipment, correct to within a few percent, is as follows:

1.	Engine	$ 39.05
2.	Cylinder head	2.02
3.	Coupling	30.23
4.	Motor	297.83
5.	Mainbreaker and can	32.00
6.	Line starter	50.22
7.	Push button	9.72
8.	Armature circuit breaker	7.24
9.	Field rheostat	47.40
10.	Power indicating light	.60
11.	Excitation switch	.73
12.	Strain gauges (4 at $2.50 each)	10.00
13.	Null balance resistance	16.20
14.	Auto ignition breaker points	1.60
15.	Miscellaneous material (estimated)	50.00
16.	Labor (120 hours at $3.00 per hour)	360.00
	#1 Total	$954.84

The following listed equipment was used as a permanent part of the test equipment. It was not purchased but was obtained from a stock of parts found in the laboratory. Since this is not a thing that can be counted on as a source and since the true value of the equipment can only be determined if all the parts are priced, we have shown a price for the item that is current. List follows:

1. Ammeter

   Simpson Model 68F067, 30-0-30 amps $ 14.55

2. Voltmeter

Simpson Model 68F858, 0-300 volts $ 13.05

3. Three-pole double throw switch

30 amp 125 v 5.60

#2 Total $ 33.20

In the "gray area" of items that may or may not be in the lab, may or may not have other uses and are not a permanent part of the test arrangement are the following:

1. Fuel flowmeter

Fischer and Porter Co. -- Flowrater

No. 02-F 1/8 - 16 - 5/35 $ 37.22

2. Laminar Air Flow Element

Meriam Instrument Co. Model 50MH10-1 175.00

#3 Total $212.22

The other equipment used to make test runs is considered to be standard laboratory equipment and generally available in any well-equipped laboratory. It is not believed that such equipment should have its original cost charged against this testing arrangement. Unless a battery of such test arrangements were to be run doing the same tests simultaneously, there would be no need to buy any of the following equipment specifically for these tests. None of the following items are a permanent part of the test arrangement.

Instruments used for specific testing and not previously listed follow:

1. Horsepower output or input

(a) DC constant voltage source (11 volts)

(b) Voltmeter to indicate above

(c) Millivoltmeter or millivolt indicator and recorder to read output or input

(d) Tachometer

(e) Load rack for generator output.

2. Measuring Air Flow to Engine

(a) Inclined manometer

(b) Barometer

3. Measuring Fuel Flow to Engine

(a) Balance scales and weights

(b) Stop watch

4. Pressure-Time Indicator Diagram

(a) Transducers

(b) Pressure monitor (amplification of transducer output)

(c) Oscilloscope

(d) Polaroid camera and film

(e) Cooling air for transducers

5. Varying engine timing (under certain circumstances)

(a) 6 or 12 volt auto battery

(b) Coil

(c) Condenser

6. Miscellaneous testing

(a) Orsat exhaust gas analyzer

If the #1 total and #2 totals are added, they give $988.04. If the

#3 total is also added, the grand total is $1200.26. Thus the maximum that need be put out if this arrangement were made from "scratch", would be about $1200. This is much less than the cost of setting up a large auto engine and gives much more varied and complete testing data. The price for one such laboratory setup is just about one tenth of the cost of a CFR engine.

CHAPTER 10

EXPLANATION OF PHOTOGRAPHS

The photographs of the whole test arrangement are collected after this chapter for quick reference.

Figure 9 shows the complete test arrangement. At the time of the photographing, the air flow was still being measured with the sharp-edged orifice and this equipment can be recognized from the description in Figure 5 and Chapter 3. Sitting on the control ledge is a stop watch mounted in a block of wood. Over the engine can be seen a vertical section of flexible tubing which carries away exhaust gases. Mounted, above the photo, in this exhaust tubing, is a blower to assure exhaust gases are removed. The exhaust pipe from the engine sticks loosely into the flexible tubing, so that the blower does not lower exhaust pressures. Behind the control panel can be seen part of the portable load rack; the numerous single-pole, double-throw switches (one for each load element) are visible.

Figure 10 is a closeup of the control panel. The air flow measurement manometers are on the extreme left. The left-hand one reads differential pressure drop across the orifice; the right-hand one reads static intake pressure to the engine. Near the bottom of the right-hand manometer is the valve handle used to waste excess air and help adjust air flow. The gasoline weighing scales, with the engine fuel tank, are just to the right of the manometers at the top of the picture. The fuel line goes from the fuel tank to the flowmeter and then through the panel to the rear and across the back of the panel to the extreme right-hand edge, where it can be seen dropping to the engine.

The switchgear right next to the scales is the linestarter. Underneath it is the armature current circuit breaker and the pushbutton station. To the left of the linestarter is the mainbreaker. In the upper right hand corner of the panel is the power-indicating light. Underneath it are the voltmeter and the ammeter. Tight against the right side of the mainbreaker is the triple-pole, double-throw knife switch; up position is "motor" and shown position is "generate". To the right of the top of the "motor-generate" switch is the excitation toggle switch. Directly under the "motor-generate" switch is the field rheostat.

Under the mainbreaker are connections for the torque reading apparatus. The two jacks to the left of the nameplate are for input-voltage connections. The two to the right are for output-voltage readings connections. The knob just over the nameplate is the control knob of the null balance resistance.

At the right edge of the panel are two 110-volt AC convenience outlets. Above them are two single-pole switches; the left one is for the exhaust blower and the right for the air blower.

Figure 11 shows more detail of the engine and dynamometer. On the engine head can be seen the strain-gauge transducer with its air and wire connections (both in the black tube). On the near side of the engine is mounted the microswitch to ground engine ignition. At the bottom of the engine is the connecting cable that carries the timing pulse to the pressure monitor. The counterweights to balance the dynamometer are the washers on the stud sticking out of the dynamometer case. The dynamometer mounting, bearing housing, next to the coupling can be seen. At the opposite end of the dynamometer is the electric tachometer.

The instruments sitting on the table just behind the dynamometer are the pressure monitor and the oscilloscope for measuring torque. (These are not a permanent part of the arrangement.)

A closeup of the engine alone is shown in Figure 12. This picture shows the detail of the arrangement for varying timing; note the cam-sleeve on the crankshaft to operate the points. The bolts that hold the outer discs on are spring-loaded and set in elongated slots. The disc is rotated (timing is varied) by pulling the handle up or pushing it down.

Figure 13 was taken to show the location and the method of installation of the cantilever beam and its strain gauges. Notice that the beam is mounted on a flat bar of steel which is bolted to the dynamometer feet. The strain gauges are on the beam, under the tape. The beam sticks down into a slot in a bar of steel bolted to the base. The bolts in the other two feet stick down to where the bar of steel, pivoted on a single screw can be swung under the bolts and lock the dynamometer in place; then the cantilever beam is centered in its slot and inoperative.

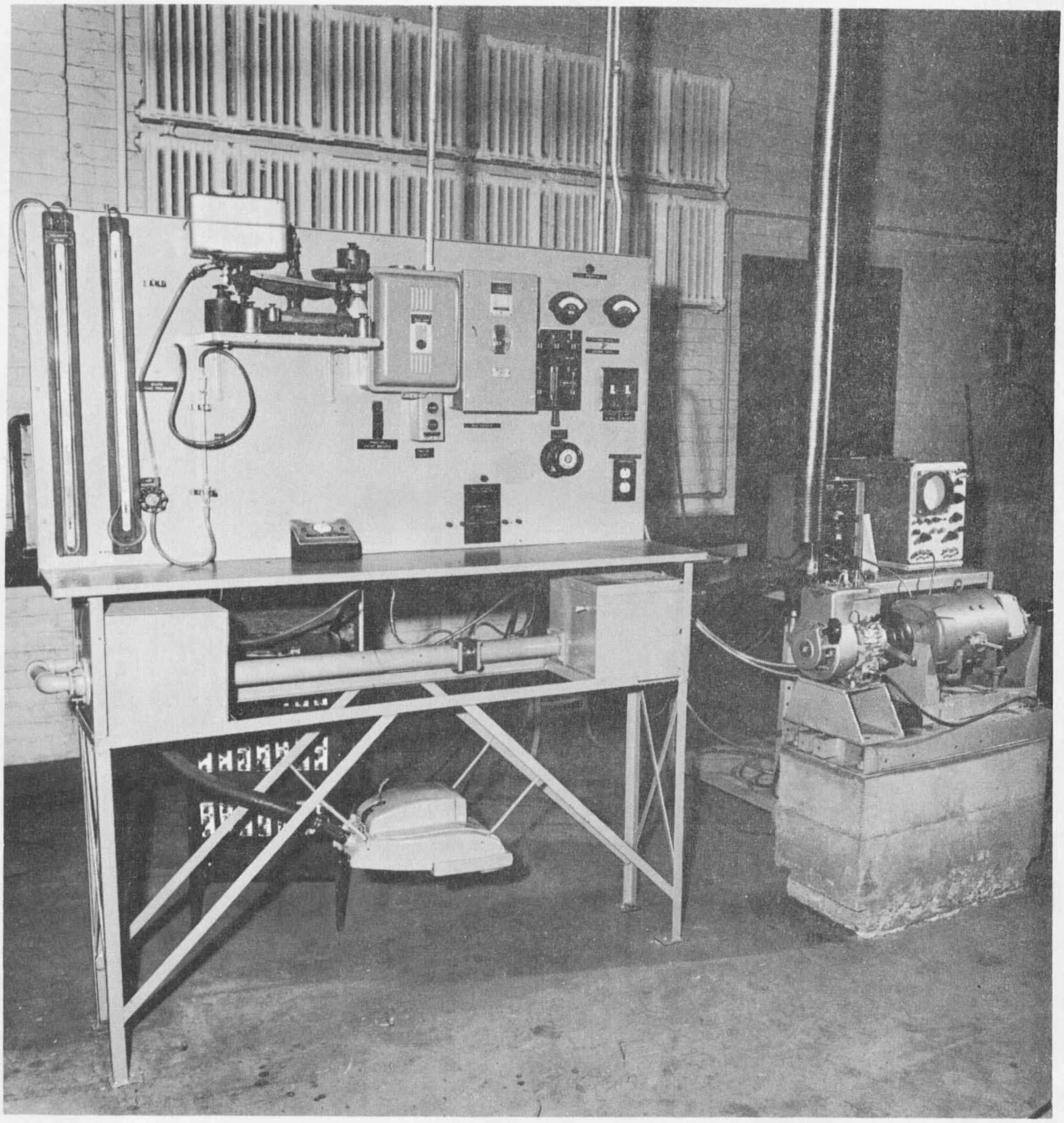


Figure 9

All Permanent Test Equipment

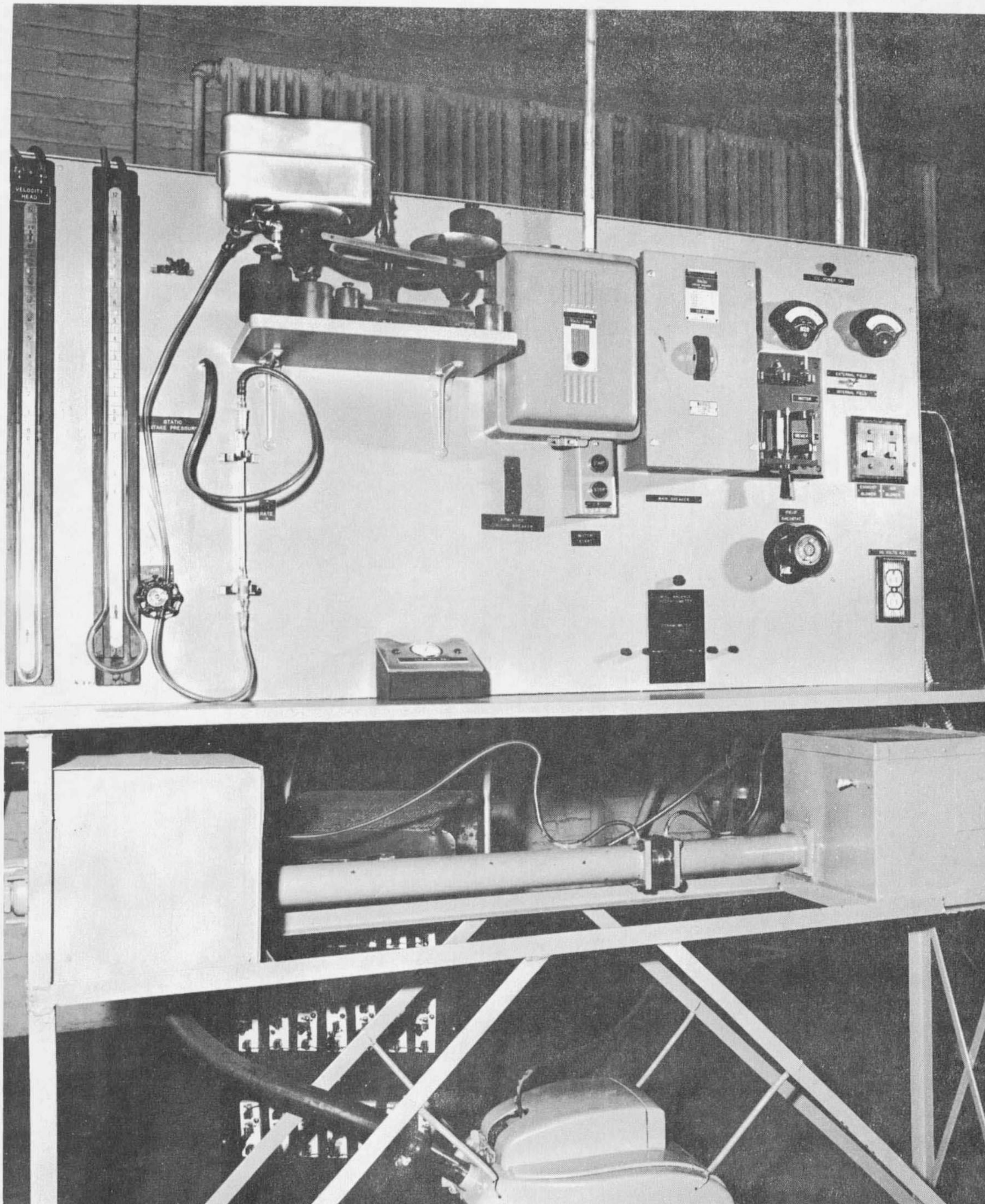


Figure 10

Control Panel

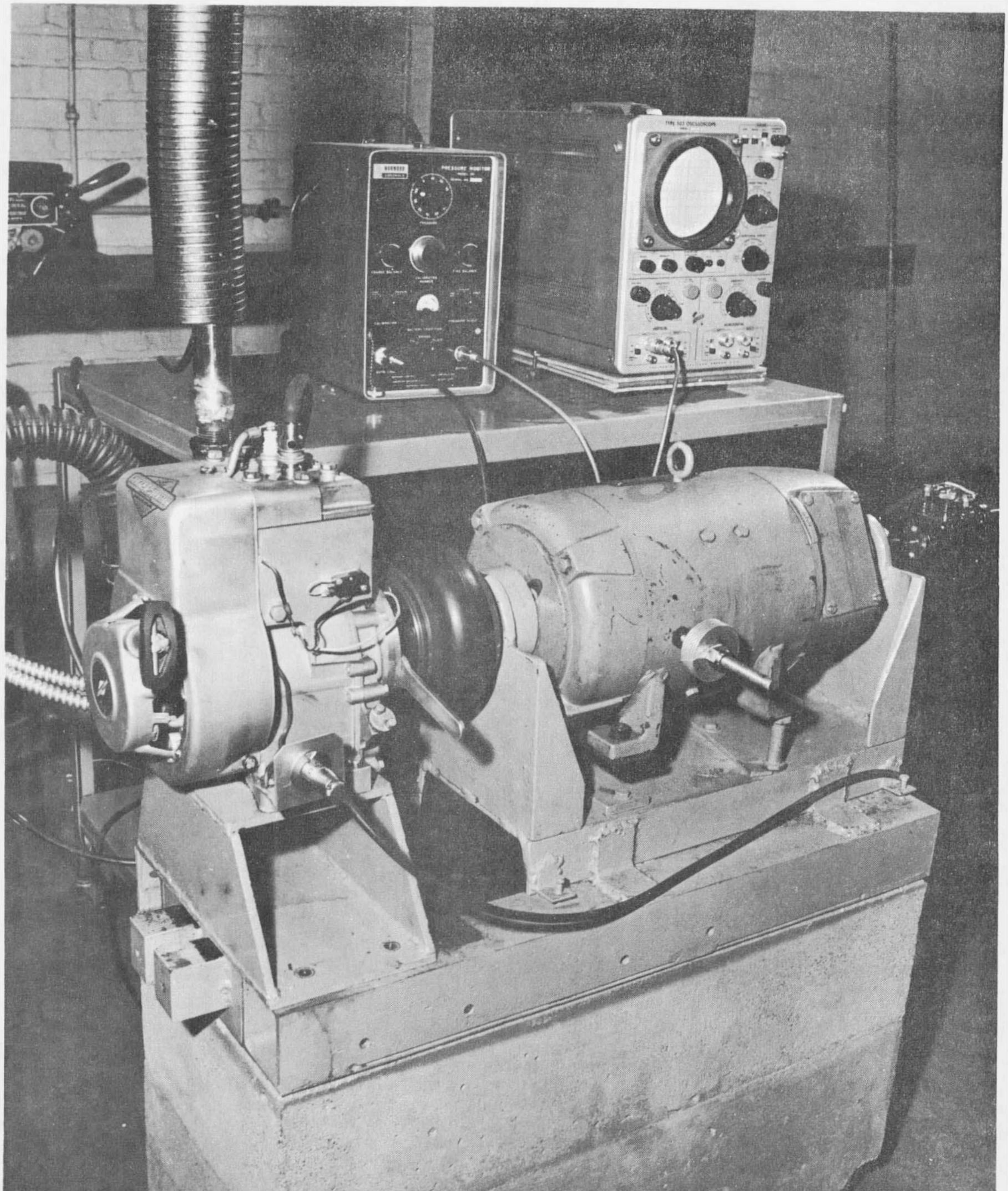


Figure 11

Engine and Dynamometer

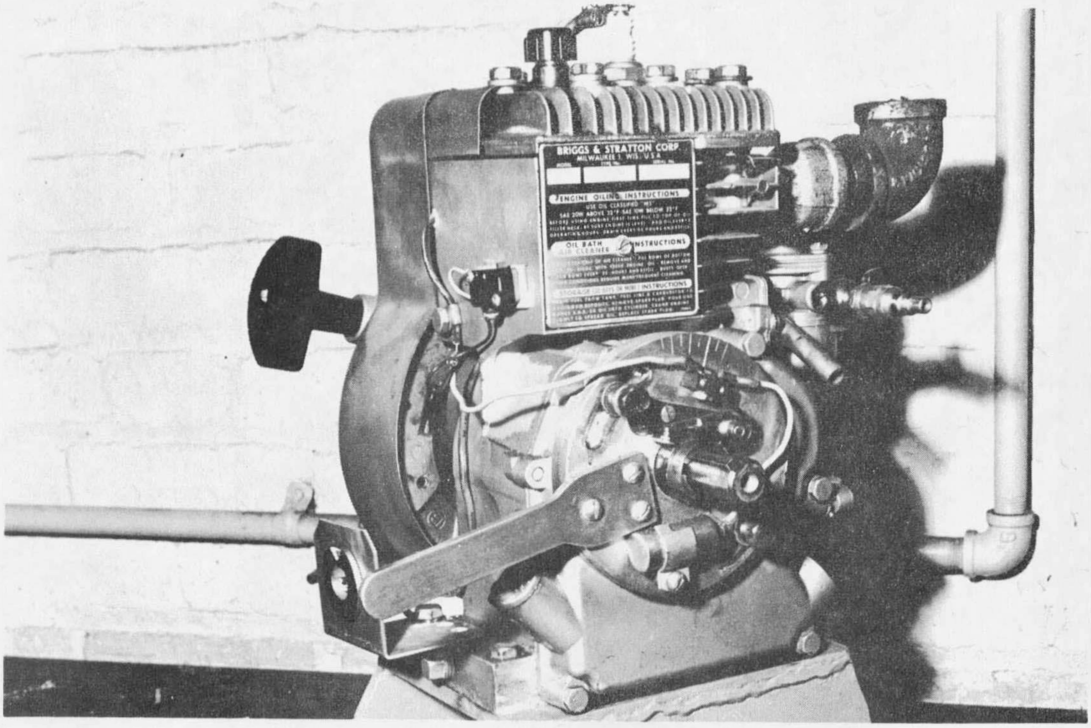


Figure 12

Engine Detail

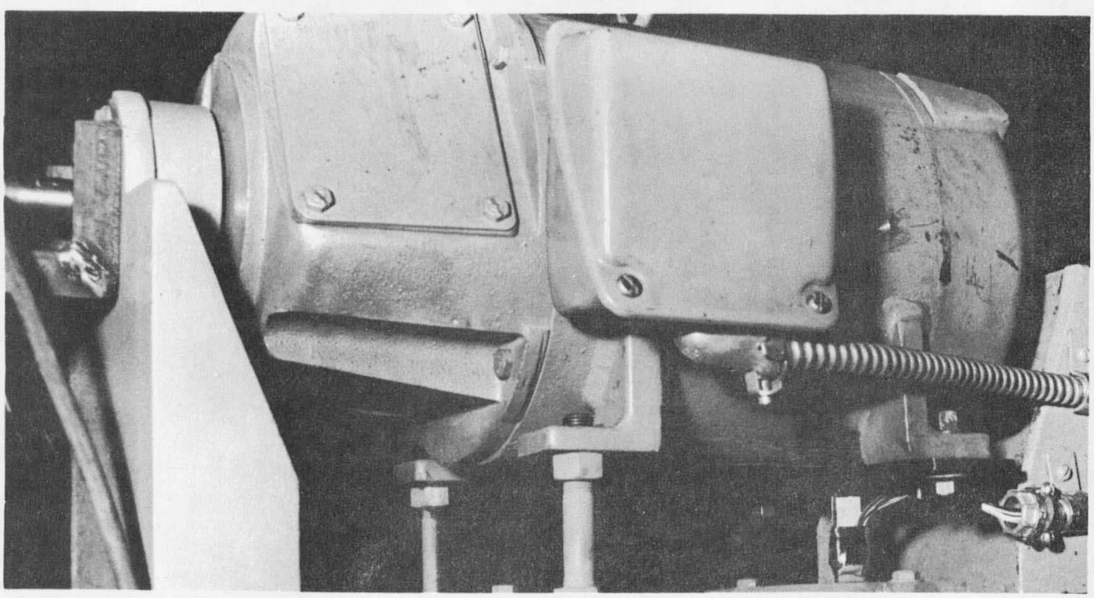


Figure 13

Dynamometer & Strain Gauge Location

CHAPTER 11

SUGGESTED TESTS

It is not always possible to run the exact tests that would give us curves and data that could be compared exactly with performance that is predicted by ideal cycles. However, it is possible to get data that indicate what is happening. For instance, it is not easy or practical to get the temperature of the gases at the end of the expansion stroke; but the exhaust gas temperature will give an indication of how the end expansion temperature varies under different conditions.

Different tests that may be run are listed. From this list tests deemed important may be selected.

Different tests are listed under general headings:

1. Make a PT diagram and from it make a PV diagram. Compare to ideal cycle for a fixed compression ratio, fuel-air ratio, inlet pressure and inlet temperature. This may be done at a constant speed with spark timing set for maximum power and then again with timing set for best economy.
2. Vary compression ratio and:
   (a) Read exhaust temperatures
   (b) Read peak pressure
   (c) Read BHP
   (d) Find pounds of fuel per BHP hour.
3. Vary fuel-air ratio and:
   (a) Read peak pressures
   (b) Read exhaust gas temperatures
   (c) Read BHP.

4. Vary ignition timing and:

    (a) Study effects on PT diagram

    (b) Read BHP

    (c) Find when detonation occurs at different loads and RPM.

5. Reading horsepower output:

    (a) Make a plot of pounds of fuel per BHP hour vs BHP

    (b) Plot BHP vs RPM

    (c) Adjust timing and fuel-air ratio to get maximum BHP at 3600 RPM.

    (d) Do same to get maximum economy.

6. Measure friction horsepower as follows:

    (a) Plot motoring friction horsepower vs RPM

    (b) Do same with cylinder head removed

    (c) Get pumping FHP from PV diagram and compare to above

    (d) Compare indicated HP obtained by above tests to that read from a PV diagram at same conditions.

    (e) Plot mechanical efficiency vs RPM at maximum load.

7. Analyze exhaust gases and find:

    (a) Percent CO at various fuel-air ratios

    (b) Percent CO when decelerating - drive idling engine with motor

    (c) Percent CO at best fuel economy setting

    (d) Percent CO at maximum load at 3600 RPM.

Many variations of the above tests may be made. Many of the tests will have to be combined, or may be combined for convenience. Different tests will appeal to different instructors' method of presenting the theory. Some trying of the different tests will have to be done to determine which are too time consuming or fallible because of equipment used or available.

CHAPTER 12

SUMMARY

Many false starts and blind alleys were experienced in attempting to arrive at a workable solution to this testing problem. In its present form the testing arrangement is workable and can be used by students to run tests and prove the theory they learn in lectures. Minor improvements are constantly being made and there are some inconveniences that still have no obvious solution. They make running tests awkward in some instances. It is believed that as time goes by the suggestions of people working on the tests will contribute much to the refinement of the operation.

It is very well recognized that in its present form the physical arrangement or layout of the test equipment could be much better. It seems, for instance, that the engine and dynamometer could be located so that the dynamometer was under the control panel and the engine stuck out to the left of the panel. This would make the engine still accessible but take up less floor space.

The simplicity of the engine tends to reassure the student when starting to test - he has run this type before. The instructor will be pleased with the relatively low noise level; conversation is still possible and instruction and advice can still be given while the test is under way.

Anyone constructing a similar test setup would surely have ideas of his own - perhaps modifications or improvements that would better suit his own facilities. Regardless of its final form, the basic idea and procedures will well serve an internal combustion engine course or experiment. A battery of testing stands, say five, would serve 15 or 20 students and require participation and understanding from all of them. Five such stands would cost $6000, or less in such quantity. Current costs of laboratory equipment make this investment look very reasonable when teaching potential is considered.

APPENDIX

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