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

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.

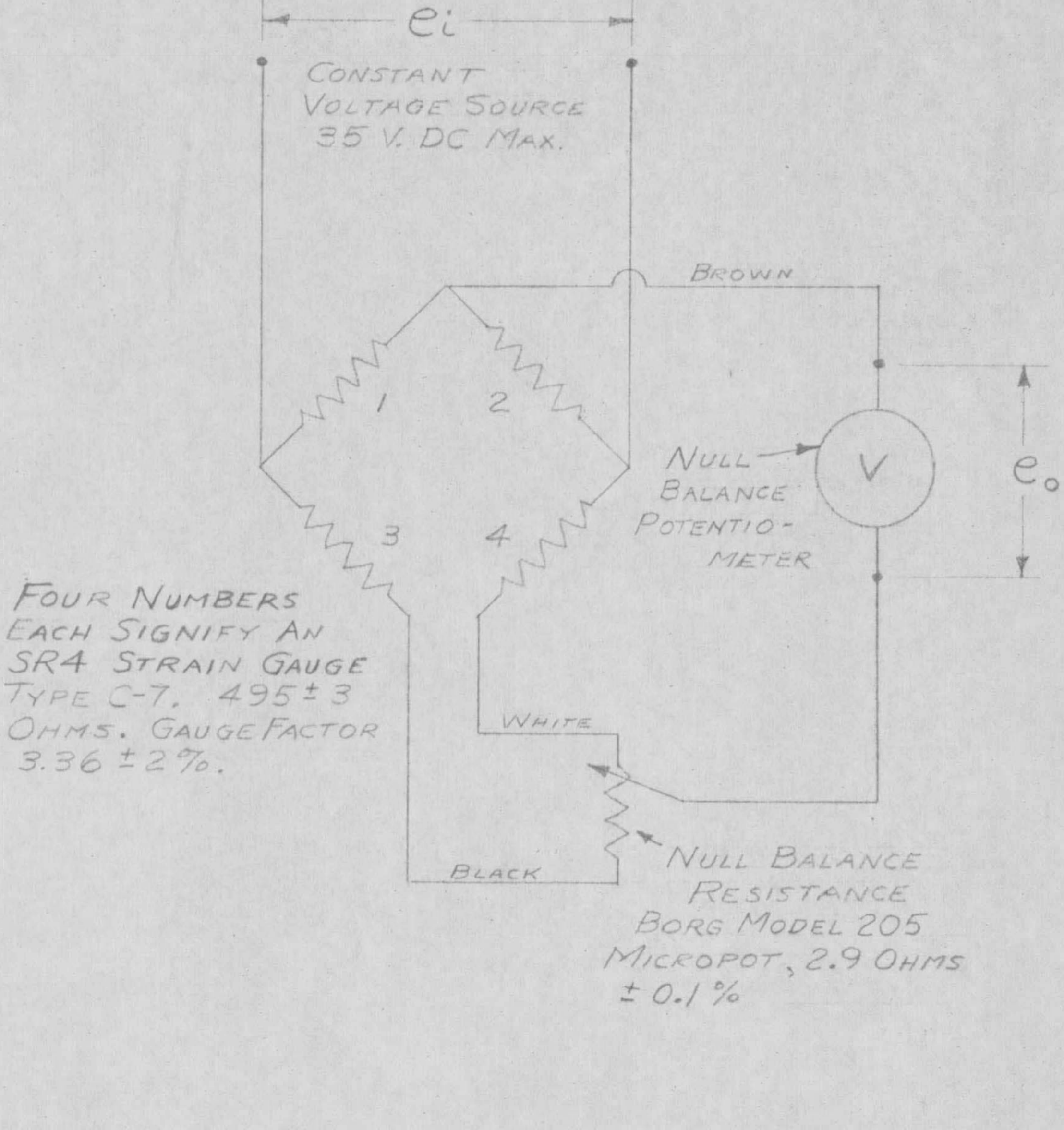

FIGURE 1

SPECIAL STRAIN GAUGE BRIDGE CIRCUIT