ANALYSIS OF PRESSURE VARIATIONS IN A VARIABLE COMPRESSION ENGINE CYLINDER

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1 _ INTRODUCTION

The Tecquipment Variable Compression Engine is a new test equipment brought to the college at the end of the last year. When it arrived at the school it was heavily destroyed during transportation and it was repaired and installed in place under the supervision of Prof. Necdet Eraslan. Unfortunately, before the installation was complete Prof. Eraslan went to the states and the engine has been left untouched since then. These were several problems to be solved.

The electric connections of the engine was a problem. The only DC source being an AC-DC motor-generator set with a rated capacity of 80 volts and 40 ampers, which was considered to be insufficient for the starter of the engine which had a nominal input of 75 ampers at 110 volts. A selenium Rectifier was proposed for the dinamometer but it was too expensive. Batteries of the EE department would be used in parallel with the AC-DC set but this turned out to be impractical. At last we decided to overload the AC-DC set. For a short starting period the set performance was satisfactory, but higher motoring power could not be obtained from this set without excessive loading of the generator.

To perform tests with various fuels, several letters have been written to the petrol companies but no satisfactory cooperation was possible.

The test rig was equipped with a pressure transducer.

The specifications and characteristics of this instrument was lacking. Letters have been written to the supplier but there hasn't been any answer. To get engine indicator diagrams the transducer is to be used in connection with a piston-motion indicator. The output of these two equipments are fed to a cathod ray osciloscope or a sensetive recorder. To study pressure variations in the cylinder either a piston-motion indicator or a crank-angle indicator is necessary. Various types of these indicators have been designed and discussed in the following pages.

2. STATEMENT OF THE OBJECTIVE:

To study the pressure variations and other engine characteristics of a variable compression infernal combustion engine, and installation, instrumentation and testing of a research equipment "Analysis of pressure variations in a variable compression engine" is chosen as the thesis subject. Several engineering problems in such a study requiring a strong knowledge in Mechanical, Electrical, Chemical and Civil Engineering sciences are to be tackled. Since extensive research on the internal combustion engines is being carried out by giant automative industries an original and comprehensive study of the internal combustion engine cannot be undertaken in a small laboratory, and will not be attempted here. However, developments and improvements of instrumentation of a research equipment on this subject by original additions and alterations are possible and we aimed at succeeding in such an investigation.

3. DESCRIPTION OF THE APPARATUS:

The Tecquipment - Lister Variable Compression Engine Test Rig is one of the most recently developed engine test-rigs. With this test-rig all the usual engine tests can be carried out to cover operation as either a petrol or diesel engine at various compression ratios. Comprehensive instrumentation is provided including pressure transducer for engine indicating using a cathode ray oscilloscope, electronic gear etc., or Farnborough high speed mechanical indicator. (1). Research can also be carried out to an extend by addition of some small instruments.

Since there was a pressure transducer but no cathode ray oscilloscope electronic gear supplied with the engine, it was necessary either to buy or design a pick-up for piston movements to feed an ordinary oscilloscope in connection with the pressure transducer to get the engine indicator diagrams. For this purpose several designs are made and advantages and disadvantages of eich are discussed. The most suitable and most economical one was chosen and manufactured by which some experiments were made.

To study the pressure variations with respect to the crank angle or time a recorder-called Recorder Mark II of Brush Instruments - was used. Since the sensitivity of the recorder was not proper we had to use an amplifier to amplify the voltage signals of the transducer. Unfortunately the scale and the speed of the recorder was not so suitable for detailed studies of the pressure variations. Nevertheless very useful and indicative informations were obtained by these available instruments.

I- a) The engine

"The engine around which the rig is built is the vertical, single cylinder, water cooled Lister FR1 diesel engine. This gives 3 B.H.P. at 1800 rpm. continiously rated when operating at its designed compression ratis of 18.7/1. The direction of rotation is anti-clockwise looking on the flywheel."

"The engine has the Ricardo swirl type combustion chamber and is normally fitted with a compression change-over valve which shuts off a secondary chamber thereby stepping up the compression ratios for starting. On the test engine this change-over valve is removed and the cylinder head based to receive the variable compression unit."(1)

b) The variable Compression unit.

"This unit consists of a piston with its diameter equal to the diameter of the spherical combustion chamber and having a hemi-spherically dished end so that at the inner position forms half of the combustion chamber."

"The piston slides in a hardened steel sleve in the cylinder head and is moved by means of a large diameter capstan head mounted on a fine seven thread. The assembly is mounted on the side of the engine cylinder head and the capstan head is arranged to be easily operated from the front of the rig." see the drawing No. 1

"The pressure transducer for engine indicating can be mounted inside the piston of the variable compression unit and a modified Southern Instruments Type G 243 resistance type transducer is supplied. Alternatively, the necessary tapping can be provided to mount the standard transducers on the cylinder head in the usual manner. Since the pressure transducer is fitted inside variable compression unit it is essential that cooling air is supplied to prevent demage being caused through overheating of the transducers. This air supply is provided by a small compressor."

"Due to the precise fit between the piston and the base of the steel sleeve these items are not interchangible. This means that if both electronic and mechanical indicating are required it is more convenient to have the two pistons made to fit the variable compression unit at the time of initial building of the rig. Alternatively, arrangements could be made to fit one type of transducer on the variable compression unit and the other on the side of the cylinder head. This would them allow the engine to be indicated simultaneously by two different methods"(1). Since the requirements of the experiments did not demand this kind of arrangements only the electronic indicating system was used.

"A plain shaft is fitted on the free end of the engine crankshaft to derive either the synchsonizing device for the electronic indicator or the Farnborough indicator drum shaft".(1) Different types of synchsonizers will be discussed extensively and the most suitable and economical one has been designed and manufactured to be used in experiments.

"When the rig is rigged to run as a diesel the compression ratis can be varied from approximately 23,8/1 down to 11,0/1. This can be done with the engine ticking over so experiments involving varying of the C. R. can go on continuously from start to finish without the need to stop and restart the engine.

c)Spark Ignition Conversion:

The engine is converted to a spark ignition by a kit which comprises the following items:

1. Special cylinder head complete with valves and springs.
2. Special piston with rings and gudgeon pin.
3. Magneto with mounting bracket, drive shaft, coupling and oil seal, and variable timing control.
4. Spark plug with mounting sleeve, lead and interference suppressor, and ignition switch.
5. Carburettor complete with variable needle and panel mounting mixture strength control and trottle level.
6. Set of three fuel tanks complete with fittings and mounting support brackets.
7. Ignition timing lamp which when connected in the engine ignition flashes simultaneously with the sparking at the plug. This lamp can be used to illuminate the degree scale marking on the engine flywheel.
8. An overspeed protection device consisting of a centrifugal switch set to switch off the ignition at an engine speed

of 1850 rpm. This includes a contactor with manual reset push button operated off the 230 volts, 50 cycles, single phase A. C. electricity supply.

d) Dynamometer and torque measuring arrangements

"The dynamometer consists of a special Higgs 220 v. D. C. shunt wound interpolar machine without cooling fan. Trunnion shafts are fitted on the ends of the machine case and these are mounted in self-aligning ball beaning plummer blocks on cast iron pedestal brackets. Thus the casing of the machine is free to swing about the shaft centre-line. A torque arm of 12" radius is mounted on the fromt of the casing and a (30 -lb x 2 Oz.). Salter spring balance is provided to measure the torque - reaction."

"Five 10-lb cast iron weights are provided. When the dynamometer is being used to absorb the power from the engine these weights are suspended from the weight pan under the torque arm and the torque re-action such that the tendency is to lift the weights. Thus, the actual torque re-action is given by:

T_a = 1ft x (Dead weight + Zero reading - Balance reading)

in the anti-clockwise direction looking on the engine flywheel

See Fig: 1

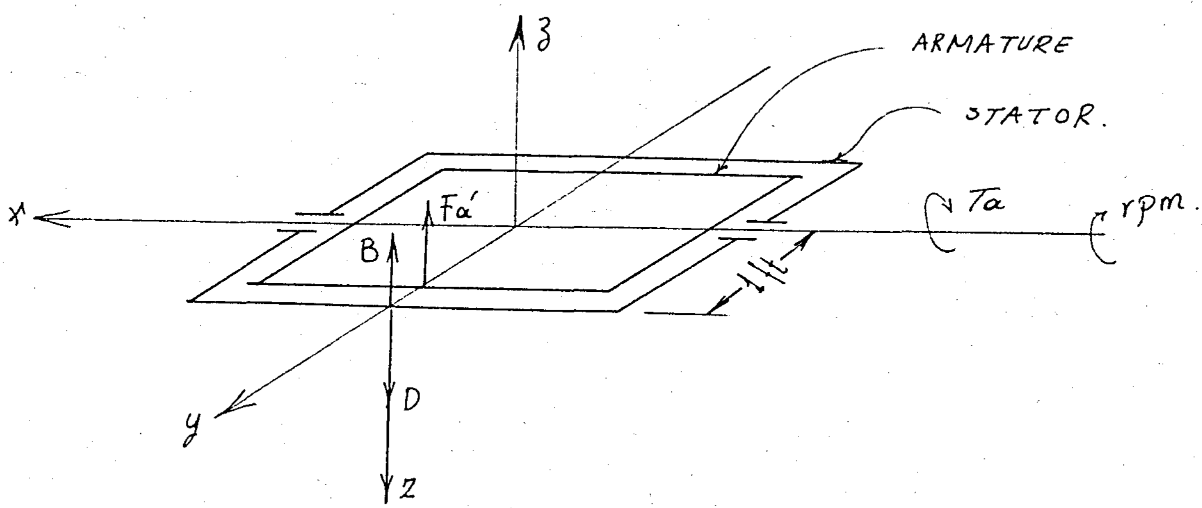


Fig: 1

Ta= Re-action torque for absorption

D = Dead weight

B = Balance Reading

z = Zero reading

Fá= Re-action force

Fa= Resultant force

Fa= D - B + z

Ta= l x (D + z - B)

"When the engine is being driven by the dynometer to measure the frictional horsepower the reaction acts in the opposite direction on this case its value is given by:

T_f= 1ft x (Balance Reading-Zero reading-Dead Weight)

See Fig: 2.

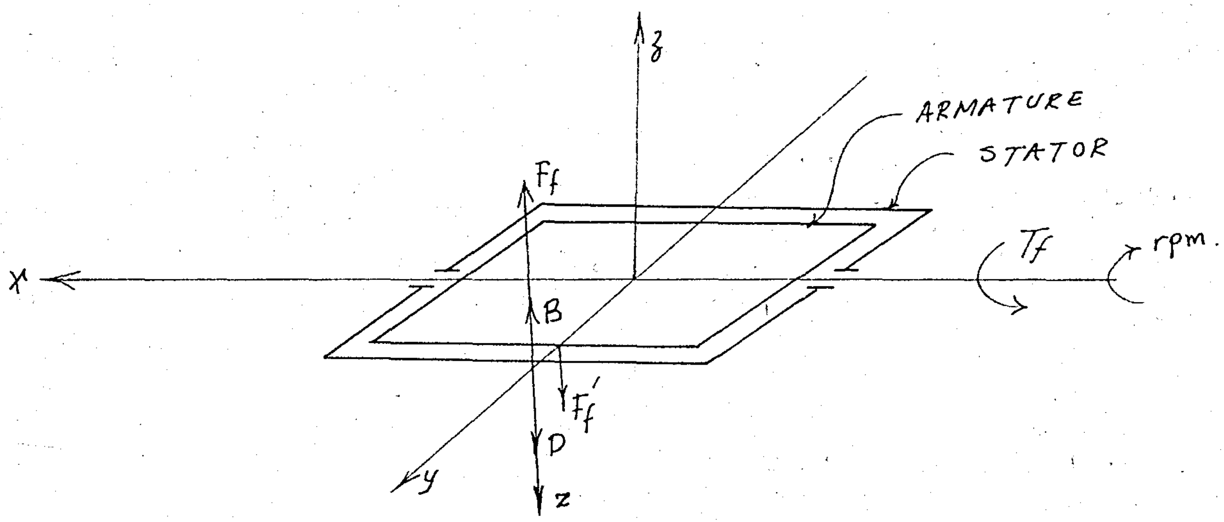


Fig: 2

F_f= Resultant friction or motoring reaction force

T_f= " " " " " torque.

F_f= B - D - z

T_f= 1x (B - D - z)

"The spring balance is suspended from a leveling screw arrangement and is isolated from vibration by rubber Instrumountings. An index mark is provided on the front of the balance support stand on a level with the machine centerline. Before each reading is taken, a painter on the end of the torque arm is brought into line with this mark thereby ensuring that the line of action of the balance is perpendicular to the torque arm. To redue ascilations of the machihe case a simple oil filled dashpot is fitted on a second arm. This consists of a piston formed from two perforated discs in a cylinder filled with oil. The amount of damping obtained from this dashpot can be varied by rotating the perforated piston discs relative to each other."

"The drive from the engine is taken through a Fanner taper-lock flexible coupling. A flexible pin-type coupling is provided at the free end of the dynamometer to derive a Crompton Parkinson tachogenerator."

Electric connection to the dynamometer and tacho-generator are by means of flexible cables arranged on the vertical center-line of the machine so as to Lave as little an effect as possible on the torque measurements." (1)

e) The Basic Rig

"Fig. 3 shows a general view of the basic rig comprising the engine and dynamometer assembled on the bedplate."

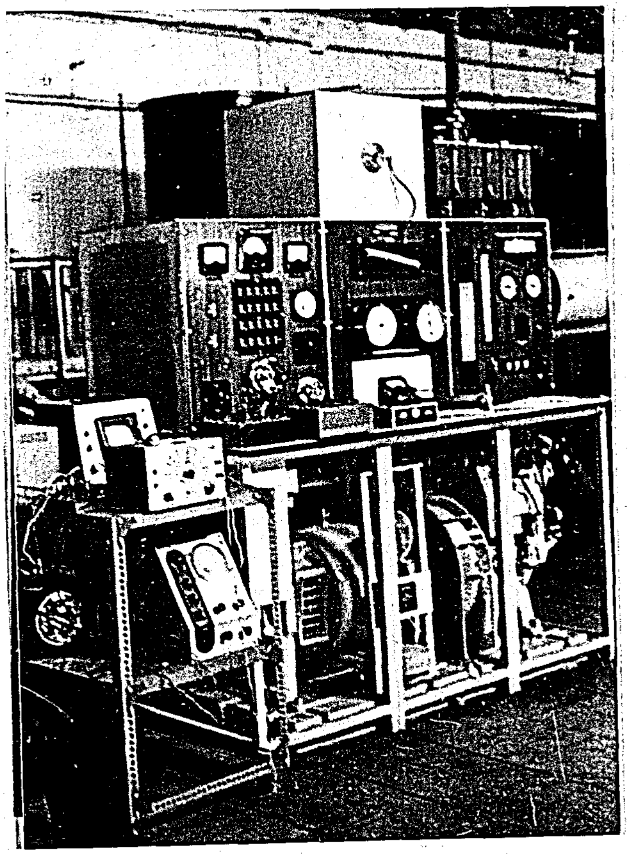


Fig: 3. Basic Rig.

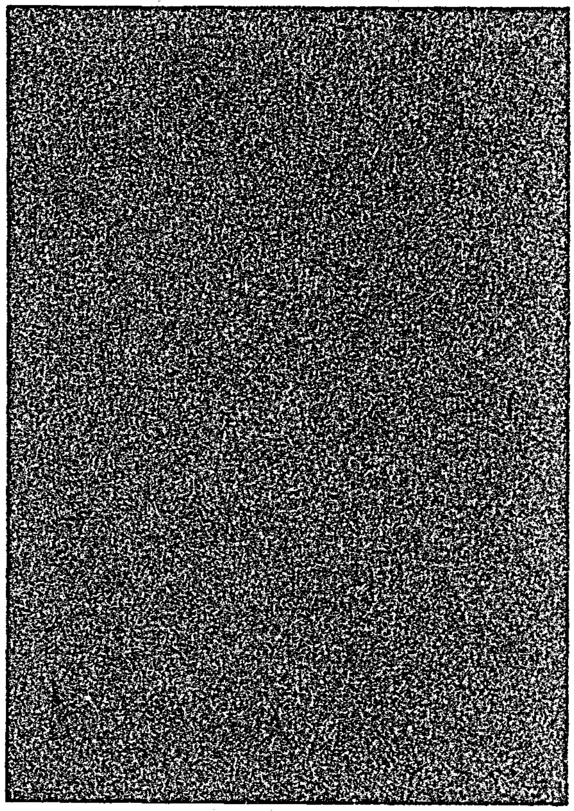


Fig: 4a Electrical Panel.

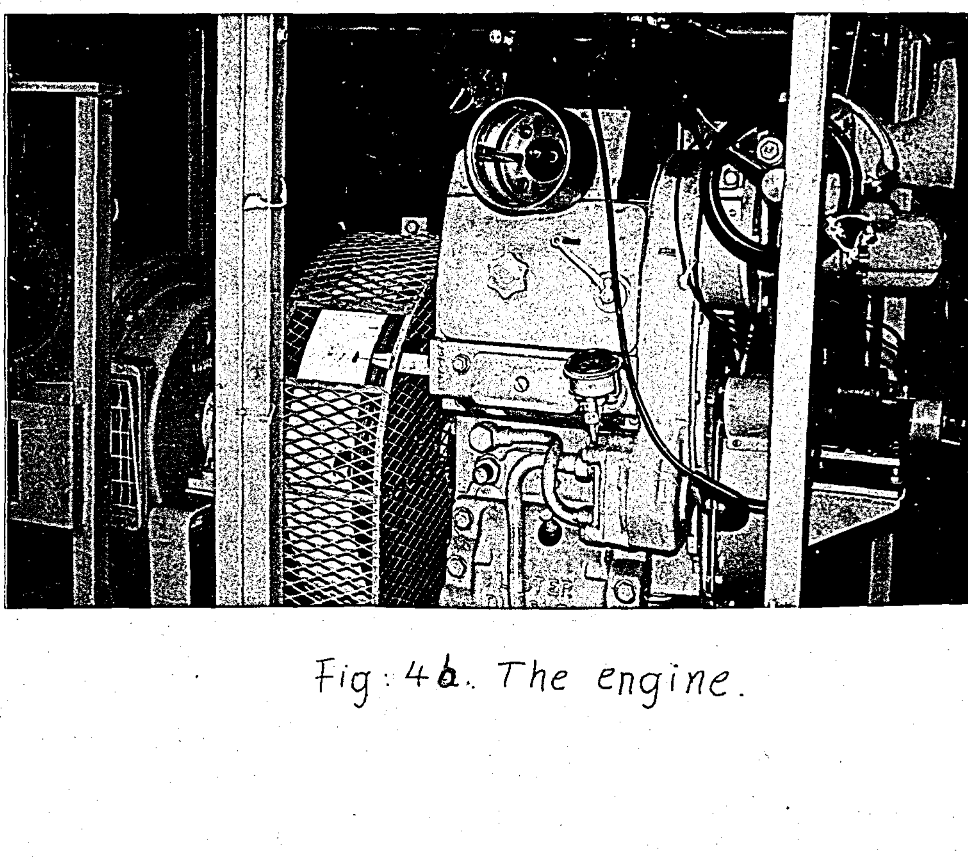


Fig: 4b. The engine.

"The cas-iron bedplate is 5' 0" long, 2' 6" wide and 4" thick with tee slats at 10" centers. The whole of the top face is machined, thus providing with the tee slats, a ready means of mounting any additional equipment which can be fitted."

"The engine and dynamometer are aligned and fixed assembled."

"The rim of the engine flywheel is divided in degrees. 20° either side of the top dead center position and in 10° intervals round the remainder of the circumference."

"Adequate guards are fitted over all rotating parts." (1)

The rig is mounted on the laboratory floor on 3/8 " thick felt pads which are supplied together with a proper adhesive.

f) Instrument Panels

"All instruments are mounted on spale faced plywood panels which are edged with chromium strip. A finish with silicone varnish provides adequate sealing fuel and water. The panels are carried on a framework formed in square section steel tubing."

"This framework is arranged over the engine and dynamometer assembly and is split into three separate units so that if necessary full access can be obtained to the engine for maintenance etc."

"All connections between the engine and the instrument framework are flexible so that vibration of the instruments is reduced to a minimum." (1)

g) Electrical Instrument Panel

"Full controls are provided in the electrical panel to allow the dynamometer to be used first as a motor to start the engine, then as a generator to absorb the engine power and finally as a motor to device the engine (whilst still hot after testing) to measure the frictional hoursepower.

"Completely starting and leading circuits are provided and heavy duty rotary switch is used to change over from motoring to generating through the 'off' position. Load can be applied to the dynamometer by switching into the armature circuit 20 resistance mats arranged in parallel. This gives variation in the torque reaction in steps of up to approximately 2 - lb. ft. Fine adjustment can then be made between successive steps of the armature load by means of a rheostat in the field circuit." See Fig. 4

"Instruments are provided to measure the field and armature voltage and the armature amperage at all stages in the operation of the dynamometer, although these are normally used purely as indicators to ensure that the electrical part of the rig is behaving correctly. In other words no ammeter or voltmeter readings are recorded as part of any engine test but it is sometimes useful to be able to note such things as maximum starting current etc."

"The terminal box for the panel is sited underneath the frame immediately above the dynamometer and flexible cables are fitted between the two so that there is minimum effect on the torque reading at the spring balance."

For convenience the re-wirable type fuses protecting the armature circuit are also housed in the terminal box."

The circuit diagram for the dynamometer control equipment is shown in Drawing No. 2.

"At the end of the rig, in the lower part of the electrical instrument frame is mounted the tools and spares cubboard." (1)

h) Air Box Panel

"To measure the air consumption of the engine the induction pipe is connected by means of a rubber hose to a large leak-proof sheet steel box. When the engine is running air enters the box through a B. S. sharp edged orifice sited in front of the box remote from the induction pipe. The size of the air box is such that there is no noticible fluctuation in the pressure drop accross the orifice as indicated on the 0-3" w. g. inclined manometer."

"As both the atmospheric pressure and temperature are required in the engine air consumption calculations, as well as the orifice plate pressure drop, a barometer to read pressure in ins and rums of mercury and a termometer to read temperature in °C are provided."

"Starting and operating instructions for the rig are printed on a white card and mounted on the air box panel."

i) Fuel and Water Panel

"The third panel, situated at the engine and of the rig, houses the cooling water mixing tank and fuel tanks and carries the flawmeters, thermometers and fuel and water controls."

"The cooling water mixing tank is made from 16 S. W. G. mild steel, measures 24"x12"x12" and has a central weir plate and baffles. The water flows under the baffle in the right hand end of the tank, over the weir plate and under the baffle into the left hand end. From here it passes, via a convoluted rubber hose, to the engine inlet. After circulating through the engine the water is discharged from the outlet pipe, through a convoluted rubber hose and then upwards through a Rotameter flow measuring unit. From there it is fed back into the R. H. end of the mixing tank where it is mixed with a small amount of water from the mains. In order to maintain the quantities of water in the system constant an adjustable overflow pipe is provided in the L. H. end of the tank. Thermometer pockets in stainless steel are fitted at appropriate sections in the engine inlet and outlet cooling water pipes and the pipes are adequately lagged in the region where the temperatures are measured." See fig. 5

"In order that experiments can be carried out using different grades of fuel three seperate fuel tanks are provided. These are mounted on a cross member on top of the instrument frame and piped to the engine, via the control values as shown in fig. 6. The fuel meter consists of a three bulb glass pippette graduated in 1 cn. in and 2 cn. in. volumes (the top bulb is for sighting, not measuring) and connected into a branch from the fuel control value bank.

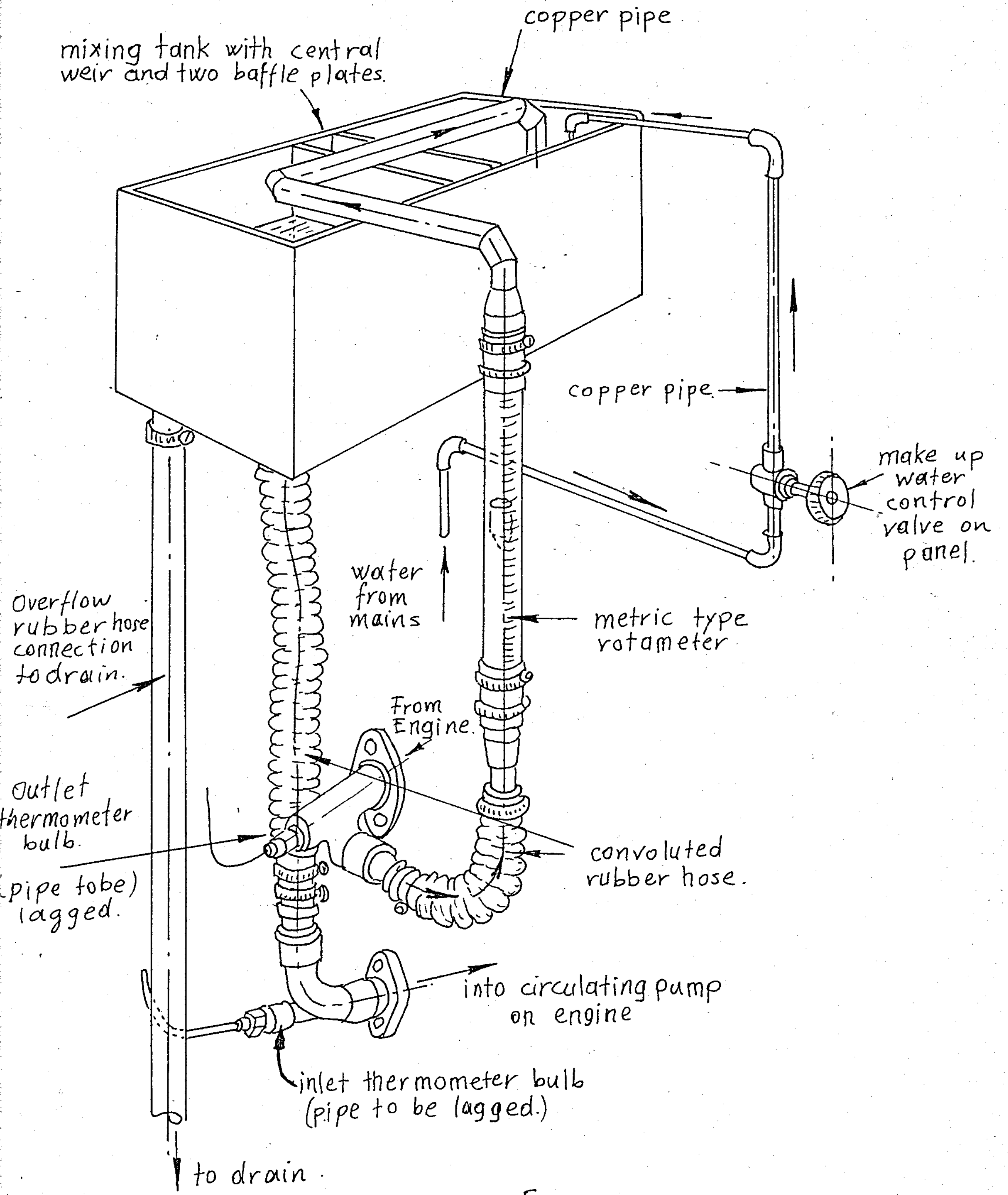


Fig: 5

COOLING WATER CIRCUIT

[Ref: (1)]

Thus, any of the valves are open the fuel passes through to the engine and also back up the branch pipe, through the fuel meter and assumes the same level as the fuel in the tank. To take a fuel consumption reading the fuel valve is turned to the off position and the engine uses the fuel from the pipette, the time being recorded for the consumption of either 1, 2 or 3 cn. ins. of fuel. In addition to the fuel control valves on the panel, shut-off cocks are fitted in the delivery pipe from each tank and it is essential that these are kept shut except when fuel is being used from a particular tank. This ensures that there is no leveling up of fuel from one tank to another."

"Each tank is fitted with a sight gage and a drain plug and is finished in the appropriate color. i. e. Light Brown for diesel fuel and Signal Red for gasoline. Numbered labels are also provided on the tanks to correspond with numbers on the control valves avoiding any confusion in dealing with the fuel supply."

"Mercury in steel dial thermometers (°C) are provided to measure the cooling water inlet and outlet temperatures. An iron-constantan thermocouple and pyrometer (°C and °F) are used to measure the engine exhaust temperature. To ensure that these temperature readings are reasonable accurate all the thermometer pockets are adequately lagged."

"All other controls on this panel are for the petrol version of the test engine. These include a small quadrant throttle

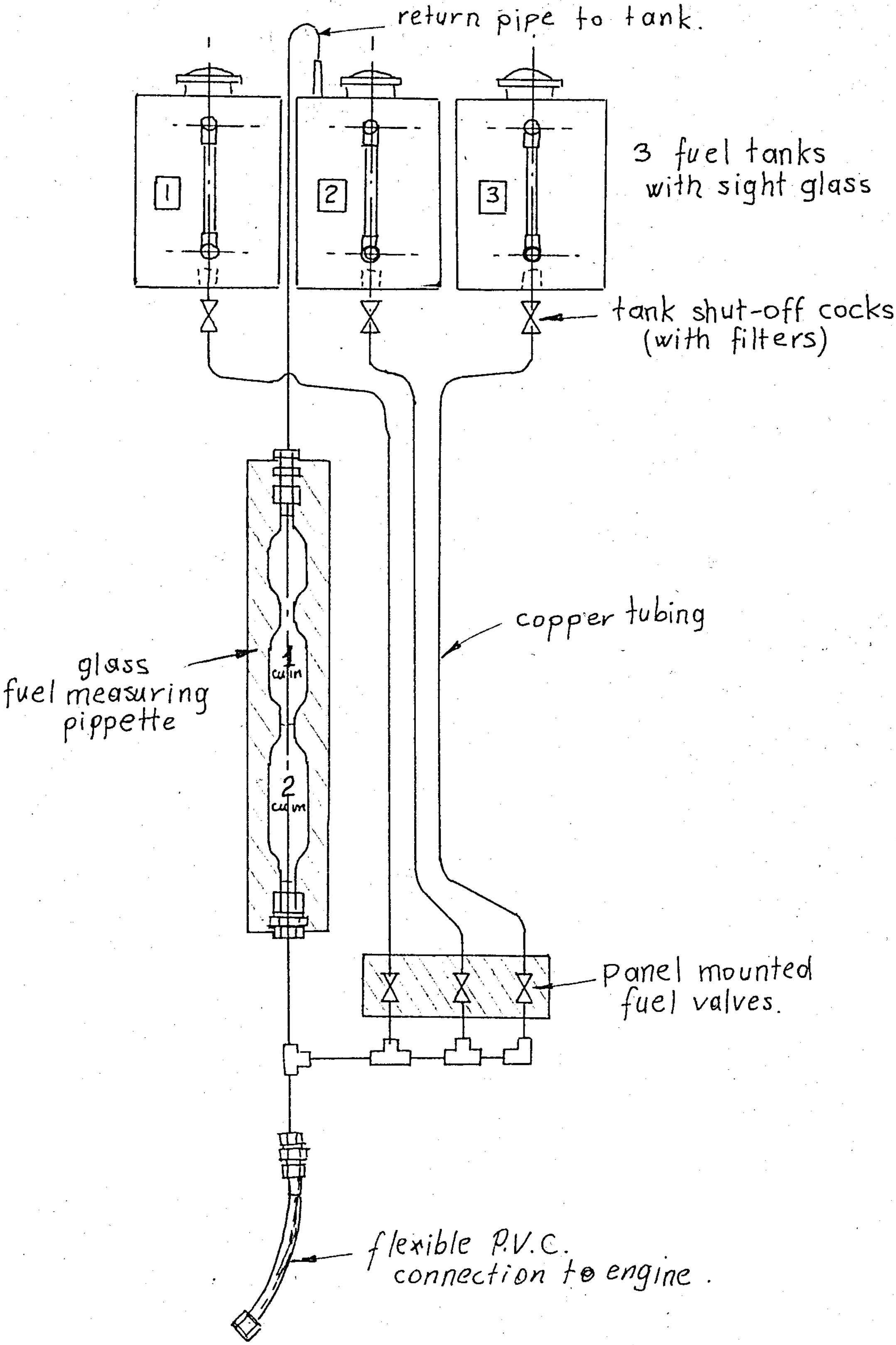


Fig: 6

FUEL CIRCUIT

[Ref: (1)]

control connected to the carburettor throtle, variable mixture strength control connected to the variable needle in the carburettor and the ignition switch." (1)

j) Exhaust system

"The exhaust outlet on the engine is $1\frac{1}{2}$ B. S. Pipe. The piping on the rig has been stepped up to 2" B. S. P."

"Immediately alongside the engine a short lengjt of pipe is provided to house the thermocouple. This is lagged with aspestos rope and composition and a support bracket is fitted to ensure that none of the weight of the exhaust system is thrown onto the engine exhaust flange. To reduce vibration a 4 ft length of flexible metallic tubing is fitted which connects up, by means of screwed unions, the rigid section of the exhaust pipe."

"Exhaust piping includes one socket, a Burgess type silencer and some 2" bare pipes."

"For convenience in carrying out exhaust gas analysis experiments with such apparatus as the Orsat, a gas sampling point is provided in the exhaust pipe and a shut off cock is mounted on the end of the instrument frame." See Fig. 7.

k) Additional Controls:

"For the diesel version a speed control handwheel connected to the pre-loading arrangements on the governor spring, the de-compppressor lever and the stop/start control connected to the fuel pump rack."

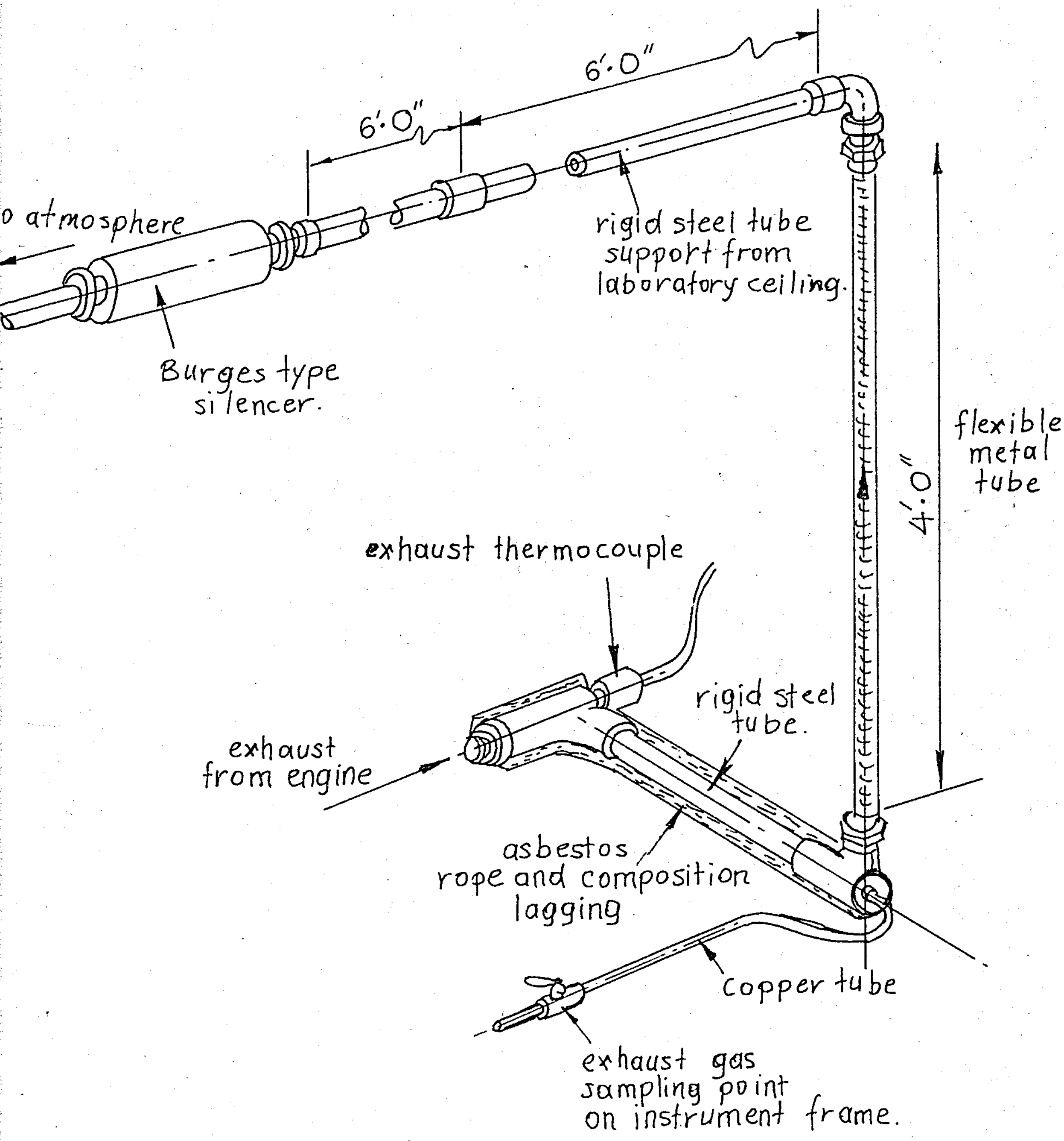


Fig: 7

EXHAUST SYSTEM.

"On the spark ignition version, the manual ignition timing control is mounted on the engine. This is dane for convenience, as the hand-held ignition timing lamp is used to illuminate the degree scale on the flywheel rim whilst the ignition timing is adjusted."

"To protect the petrol engine from overspeed a centrifugally operated switch is driven off the end of the cooling water circulating pump shaft. This is connected to the laboratory 190 volt 50 cycles, single phase A. C. mains supply through a contactor in the law tension circuit of the magnets is earthed and the ignition therefore swiched off. A manual reset button is provided on the contactor so that the engine can be restarted after the fault causing the overspeed has been rectified." (1)

l) Spark Plug fitting:

" A special adopter sleeve is provided to hold the sparking plug. This is fitted in the injector port and held in position with the clamp bar normally used to hold the injector. An interference suppressor is supplied in the sparking plug connecting lead." (1) See Fig. 8.

m) Carburettor:

"The carburettor is the Zenith 26 V M E vertical downdrought unit with a 22 mm diameter chake tube. The construction and functioning of this is described in the following pages."

"For operation with test engine the main jet has been blocket with soft solder and the compansating jet opened out to 0.067" dia.

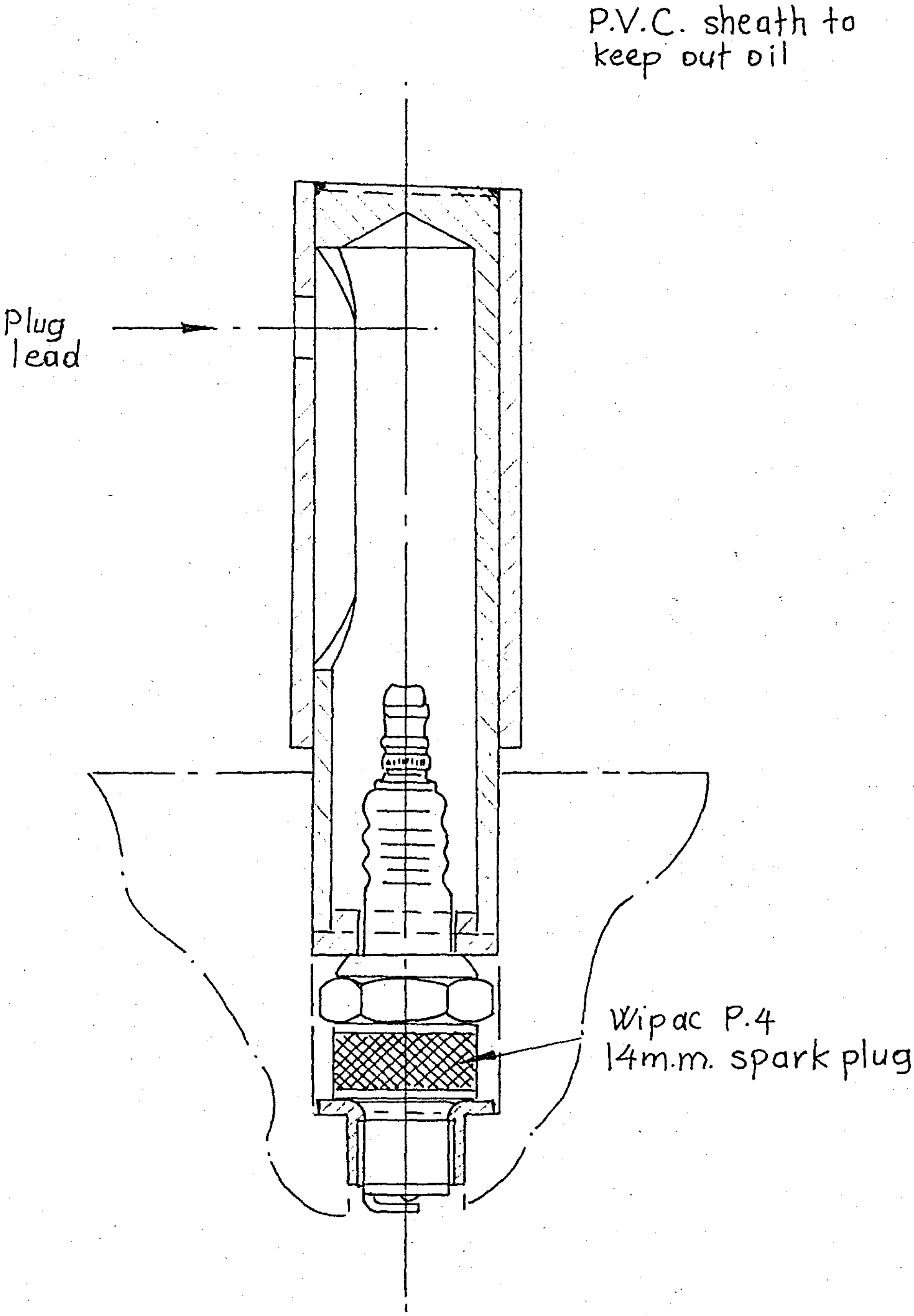


Fig: 8

FITTING FOR SPARK PLUG

[Ref: (1)]

to receive the tapered needle value. The stem of the needle has a 20 T.P.I. thread so that it can be used to manually control the mixture strength to fine degree.

"The carburettor fits neetly into the vertical section of the induction pipe between the engine and the air box replacing a short length of rigid tubing normally fitted when the engine is being run as a diesel."(1)

n) Spark Ignition Version Overspeed Protection Device:

"The diesel version of the engine is fitted with a mechanical variable speed governor control set to allow a maximum speed of 1800 rpm. As this control operates on the injection pump rack it is inoperative when the engine runs as a spark ignition engine."

"An additional electro-mechanical system has therefore been devised to prevent overspeeding of the petrol version of the engine."

"This consists of a centrifugally operated micro-switch in the circuit of the contactor energised from the 230 v, 1ph, 50 cycles electricity supply. This contactor is in the law tension side of the magnets so that any interruption of the A. C. supply, through either the operation of the micro-switch or mains failure will cause the ignition system of the engine to be earthed thereby cuttin off the spark at the plug."

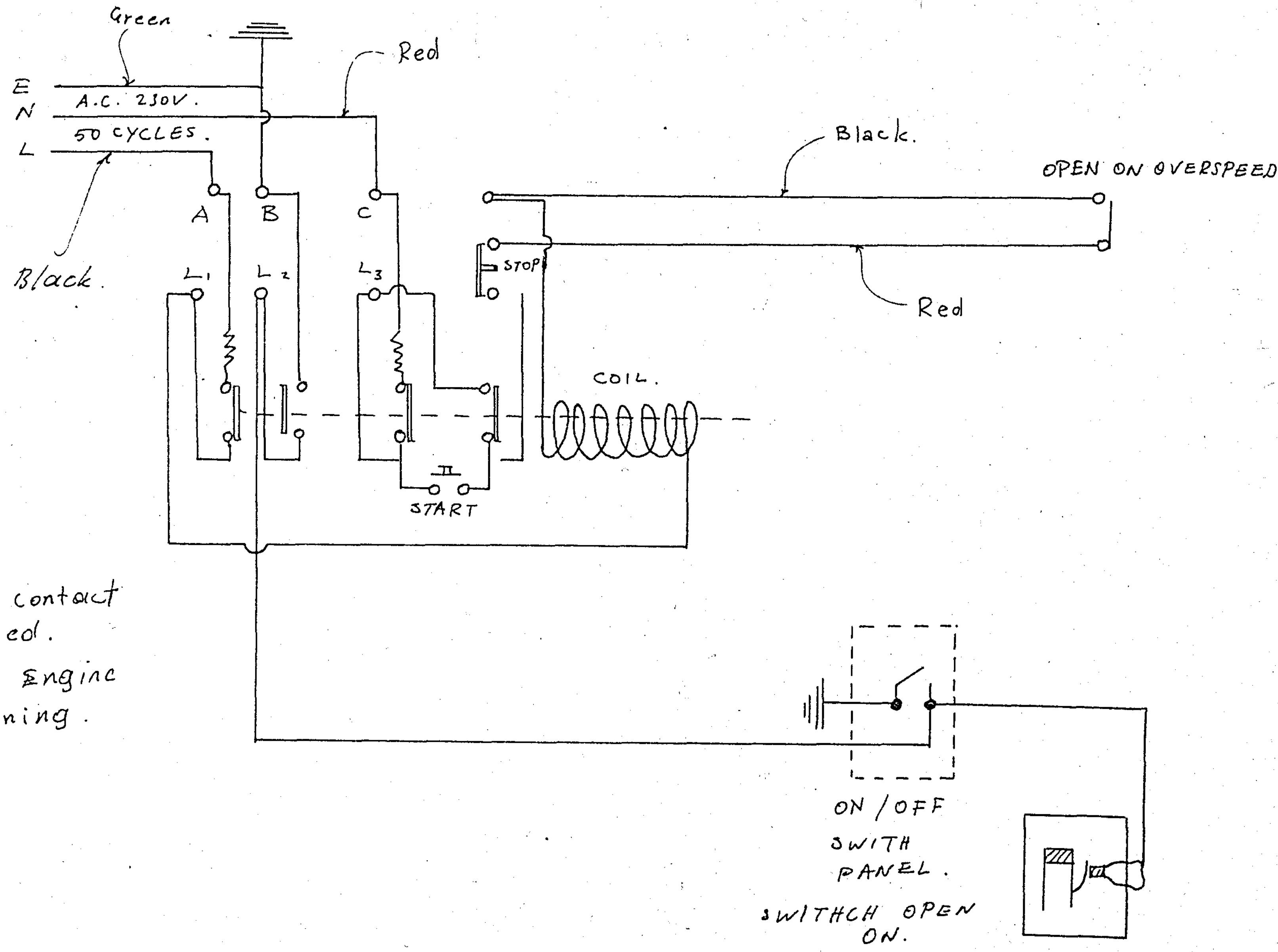
"The centrifugal device which operates the micro-switch is driven off the shaft end of the cooling water circulating pump.

A simple screw arrangement is provided for varying the setting of the trip speed. This is normally set at 1700 rpm before the leaves the works."

"The contactor controlling the device is mounted on the front of the electrical instrument frame on the tool and spares capboard, thus bringing the stop and restart buttons within easly reach of the operator of the rig. (N. B. it is necessary to press the green re-start button after every operation of the contactor whether manual stopping by the red button or automatic stopping on the centrifugal device.) The circuit diagram is shown in Fig. 9." (1).

o) Particulars of the engine:

Basic Engine:	Standard Lister Type FR1 diesel, 9 B. H. P. at 1800 rpm. converted to variable compression ratio; reversed direction of rotation. Vertical single cylinder 4 cycle, water cooled.
Bore:	3.75 ins (95,2 mm)
Stroke:	4.50 ins (114,3 mm)
Swept Valume:	49,74 cu ins (814,9 ccs)
Compression Ratio:	Variable 22,3/1 to 9,5/1 as diesel. Variable 13.6/1 to 7,4/1 as S. I.
Magneto:	Lucas type FV 10 - Model N1; variable timing
Sparking Plug:	Wipac P. 4 14 mm fitted with copper mounting collar - Cap 0,025".
Speed Range:	750 to 1800 rpm.

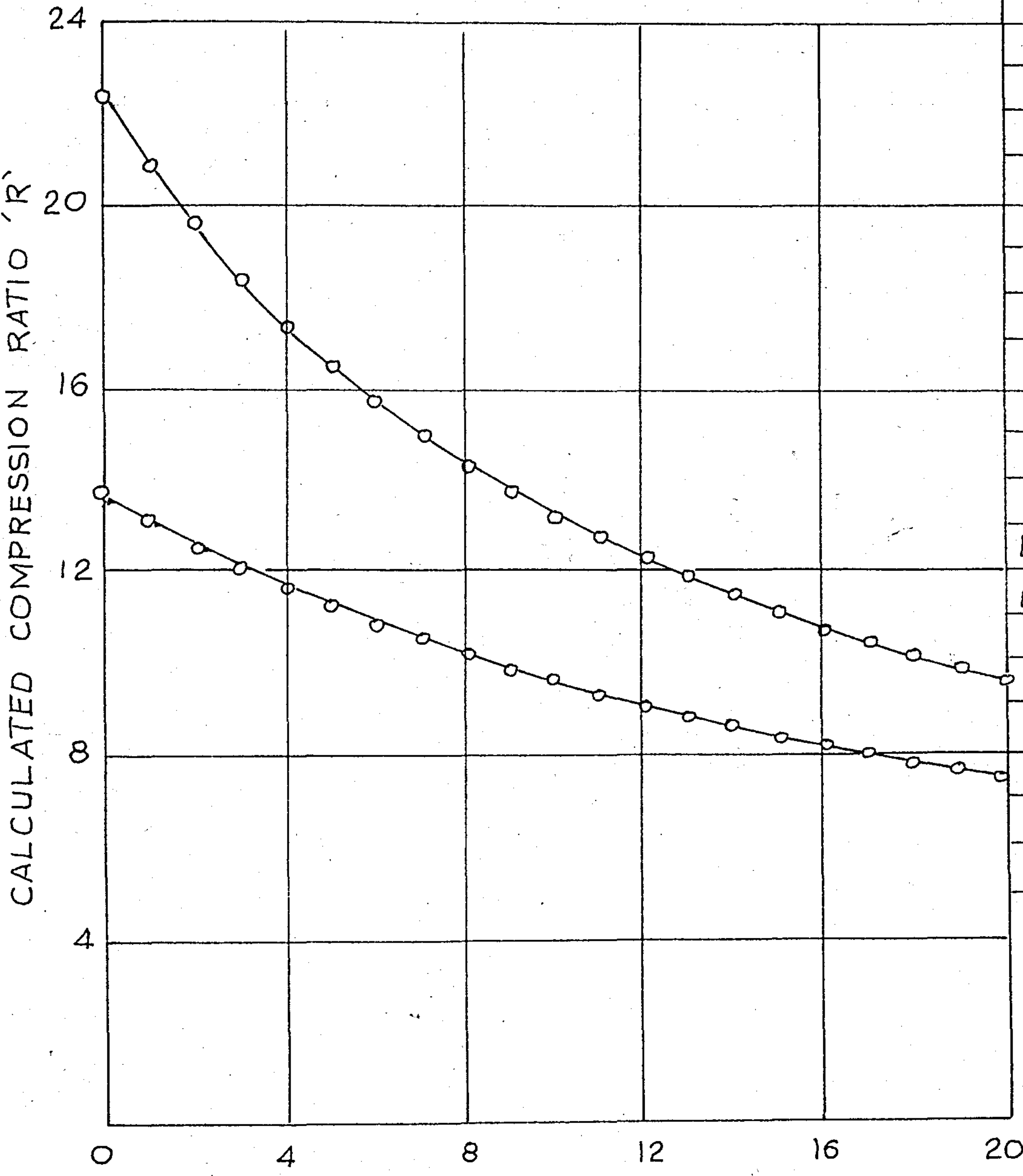


L2 to B contact
Reversed.
AC on, Engine
Running.

Fig: 9. Overspeed protection Device.

Carburettor:	Zenith 26 VME converted to single jet manual mixture control ventury-diameter 22 mm. Main jet blocked, compensating jet reared out to 0.0670" dia. and counter bored 0.125" dia. to give needle shank clearance. Neddle 12° included.
Exhaust temperature:	Typical 350° C as diesel 550° C as S. I.
Cooling Water Temperature:	Control between 50°C and 65° C.
Cooling:	By water, with integral centrifugal circulating pump.
Lubrication:	Pressure fed from gear oil pump.
Gasoline Supply:	By gravity.
Air Supply:	From air box via metering orifice.
Starting loading:	Electric dynamometer (motor/generator)
Ignition Timing:	3.25° advanced. -

CALIBRATION CURVE FOR VARIABLE COMPRESSION UNIT



No. OF TURNS N OF V.C. UNIT

'N'	'R' C.I.	'R' S.I.
0	22.35	13.81
1	20.80	13.2
2	19.58	12.65
3	18.38	12.15
4	17.41	11.70
5	16.48	11.30
6	15.78	10.90
7	14.95	10.52
8	14.32	10.18
9	13.72	9.87
10	13.16	9.58
11	12.70	9.30
12	12.25	9.05
13	11.80	8.80
14	11.45	8.58
15	11.05	8.36
16	10.70	8.29
17	10.38	7.96
18	10.10	7.79
19	9.80	7.61
20	9.55	7.45

Fig : 10 [Ref: (1)]

II. COMPRESSION RATIO CALCULATIONS:

"The valume of the various recesses in the cylinder head are measured by running in praffin from a burette to fill the recesses and noting the level readings in the burette.

The gasket clearance between the cylinder head and the piston crown in the top dead center position is measured by pushing a length of soft lead wire down the injector port and turning the engine over the T. D. C. position.

A typical comprepression ratio is then as follows:

Clearance volume in valve seating (inlet):		= 2,5 cc.
Clearance volume in valve seating (exhaust):		= 3,0 cc.
Volume in cylinder head compression unit		= 25,4 cc.
is screwed in position		= 30,9 cc.
Sum of the above		= 1,8759 cu ins
Gasket clearance	= 11x3.75 ^{2}x 0.443	= 0,475 cu ins
Minimum cylinder head clearance volume:		= 2,3509 cu ins
Average increase in volume per turn of variable compression unit =	2,84 25 c.c. = 0,1734	cu ins
Engine swept volume		= 49.750 cu ins

$$\text{Calculated C. R.} = \frac{49{,}75 + 2{,}3509 + n(0{,}1734)}{2{,}3509 + n(0{,}1734)}$$

or

$$\text{C. R.} = \frac{300.8 + n}{13.55 + n}$$

Where (n) is the number of turns of the variable compression uni

N.B. A calibration chart is supplied specifically for this rig.

III. CHANGEOVER PROCEDURE DIESEL TO SPARK IGNITION ENGINE:

Introduction:

"Before starting to strip down the engine or any part of the rig ample clear bench space should be made available. Care should be taken that parts are kept as clean as possible and free from grit, etc. A few sheets of strong paper will protect the bench from oil and also provide a clean surface on which to place the parts as they are removed from the rig."

"Certain tools are provided with the rig but these should be augmented by tools from the workshop." (1)

Procedure:

a) Dismantling:

1. Completely drain off cooling water from the engine. (Drain cock is sited on the back of the engine immediately under the cooling water circulating pump.)
2. Remove the rocker box cover.
3. Remove the injector nut and clamp bar.
4. Remove the scren at the front of the rocker box.
5. Lift off the rocker box, taking care not to damage the gasket
6. Carefully remove the gasket
7. Unfasten the clips on the air hase connecting the induction pipe to the air box and remove the hase.
8. Unfasten 2 nuts holding the vertical induction pipe to the cylinder head and remove the pipe taking care not to damage the gasket.

9. Remove the cover of the injector pump chamber (at the front of the engine immediately under the variable compression unit.)
10. Disconnect the injector spill back and feed pipes and the lubricating oil feed pipes to the rockers. Remove the pipes upwords from the cylinder head.
11. Remove 4 nuts securing the rocker pillars and lift the pillars and rockers from the head as assembled units. (Take care not to drop any parts into the induction part.)
12. Lift out the injector and copper washer and wrap in greaseproof paper (or plythene bag if available).
13. Lift out the push rods, carefully noting the position. (the inlet push-rod has the spring loaded washer).
14. Remove the remaining 6 nuts which secure the cylinder head, slacking off progressively. (Use box spanner, preferably ractchet type).
15. Remove 2 screws from the cover of the exhaust thermocouple terminal box and disconnect the compansating cable. Replace the cover of the terminal box and tie the cable back to the instrument frame.
16. Disconnect the gas sampling tube from the exhaust pipe end.
17. Tie a rope sling around the exhaust pipe close to the cylinder head flange and suspend from the top of the instrument frame.
18. Remove 2 nuts and 1 balt holding the exhaust pipe on the engine cylinder head.

19. The next stage is to remove the variable compression unit from the cylinder head as follows:

   a) Remove 2 capscrews and take off the black tufnol end cap
   b) Release the clamp from the pressure transducer leads and remove 2 nyloc nuts and spacer tubes from the guide bars.
   c) Screw out the capstan head and draw the piston from the variable compression unit. Take care not to damage the transducer leads. Place the piston, rod and capstan head assembly carefully on the bench.
   d) Remove 4 nuts and locking washers, take off the main barrel and draw out the steel liner and copper sealing washer from the cylinder head.

20. Lift off the cylinder head from the engine, and map up any water from the top of the cylinder block.

21. Remove the crankcase door at the back of the engine and the small inspection cover at the front. (N. B. it may be necessary to slacken off the lubricating oil inlet pipe at the pump end and also completely remove the delevery pipe before the inspection cover can be lifted away from the engine.)

22. Turn the engine to bring the big-end bolts into the most convenient position for working and remove the big-end nuts taking care not to drop anything into the sump. Put a chalk mark on the con-rod to indicate which way round it is fitted.

23. Carefully remove the bottom half of the big-end bearing complete with the shell.

24. Turn the crankshaft up to T. D. C. position, hold the piston and con-rod assembly up and continue to turn the crankshaft so that the crank journal leaves the connecting rod. Take care to ensure that the upper half of the bearing shell does not get damaged or fall into the sump. Remove the bearing shell and draw the piston and con-rod assembly upwards out of the cylinder block.

25. Carefully remove the piston rings from the piston using thin metal shims to prevent the ends of the rings from scoring the piston.

26. Remove the circlips retaining the gudgeon pin and immerse the piston in a bucket of hot water for 3-4 minutes. This should expand the piston and allow the gudgeon pin to be removed auite easily.

27. Check that the shut-off valves on the diesel fuel tanks are closed and then disconnect the fuel pipe at the engine. Drain the fuel from the piping and fuel meter.

28. Unfasten 4 bolts securing the fuel tank mounting plate, disconnect 3 fuel pipes and lift the tanks off the top of the instrument frame as an assembly.

29. Unfasten 2 screws and remove the injector pump. Lift off the end cap from the injector pump tappett. Wrap up the injector pump carefully in greaseproof paper or polythene.

b) Re-assembly:

30. Thoroughly clean the petrol engine piston and immerse in a bucket of hot water for 3-4 minutes. Assemble the piston, gudgeon pin and connecting rod and ensure that when the recess in the piston crown to the front of the engine the chalk mark on the (see 22 above) connecting rod is in the correct position. Fit the circlips securing the gudgeon pin in position. Fit the piston rings using thin metal shims to protect the piston as before.

31. Check that the piston and con-rod assembly is thoroughly clean and dry and then lightly oil all over using the same oil as is used in the engine sump. With the recess in the piston crown to the front of the engine lower the con-rod and piston assembly into the engine cylinder using a piston ring clamp to enter the rings.

32. Replace the upper bearing shell taking care that it registers correctly in the con-rod. Replace the bottom half of the big-end bearing complete with its shell. Refit the nuts and tighten up. Turn the engine by hand to check that the assembly is correct. Replace the crankcase door.

33. Replace the cylinder head gasket (N. B. if the gasket is fully compressed a new one should be used.)

34. Re-assemble the variable compression unit in the petrol cylinder head using the procedure described earlier in this instruction section.

35. Replace the cylinder head and fit and gradually tighten down

6 nuts, working progressively until fully tightened.

36. Put in the push-rods (Check position)

37. Transfer 4 studs from the diesel head and put on 2 rocker pillars and rocker assemblies. Replace 4 nuts and locking washers and tighten down. Check the tappett clearences and adjust to 0,005" inlet and 0,008" exhaust. (see Lister handbook 322/360 page 14)

38. Refit the lubricating oil pipes to rocker gear.

39. Put on gasket and refit the exhaust pipe. Tighten 2 nuts and 1 bolt to secure. Re-connect thermocouple compansating cable at the terminal box. Refix exhaust gas sampling pipe.

40. Put on induction pipe gasket and fit the carburettor. Tighten down the 2 nuts (remaining cylinder head nuts.)

41. Put on rocker box gasket and rocker box and tighten down one screw.

42. Assemble spark plug in the holder complete with lead. Thread over a length of P. V. C. sheathing to completely cover the hole in the side of the plug holder thus providing maximum protection for the plug from oil. Insert plug and holder into the injector port in the cylinder head and secure in position with the clamp bar and nut.

43. Connect up the carburettor controls to the throttle quadrant and the mixture strength control on the instrument panel.

44. Fit the transition piece and elbow on the inlet of the carburettor and effect and air tight seal by means of a

rubber sleeve. Connect the induction pipe to the air box with the rubber hase and secure with clips.

45. Fit the blanking plate over the injector pump mounting and clamp the pump operating rocker by means of the U - bolt.

46. Replace the inspection covers and the cover of the injector pump chamber.

47. Pour ½ pint of lubricating oil over the valve gear and fit the rocker box cover.
Check the oil level in the sump and top up if necessary.
N. B. Use only recommanded oils (see Lister Handbook 322/360 pages 6 and 7.) and do not mix brands of oil.

48. Put on the petrol fuel tanks and secure with 4 bolts. Connect up the three fuel pipes to the tanks. Put a small quantity of gasoline in each tank and flush out each fuel pipe in turn, cathing the waste petrol in a can. When the fuel pipe system has been throughly flushed through connect up to the carburettor. Add more petrol to one of the fuel tanks, prime the fuel system and carburettor and get rid of any air pockets in the piping.

49. Change the air box orifice plate.

50. Screw out the capstan head of the variable compression unit to its full extent to give the minimum compression ratio. (See the calibration curve, Fig 10.) Connect up the cooling air hase to the variable compression unit.

51. Re-fill the cooling system with water, and check for baks. the conversion is them complete and the 190 V, 1 ph,

50 cycle electricity supply switch on the overspeed protection contactor and the mixture strength control at approximately 1,8 , the engine can be started according to the procedure given in the instrument panel. (and also in this instruction section.) (1).

IV. OPERATING INSTRUCTIONS:

Preparation:

1. Check the lubricating oil, fuel and water levels.
2. Open the appropriate fuel valves and ensure that fuel is through to the engine.
3. Turn on the mains water supply to the mixing tank and check that the overflow is running to drain.
4. Turn on the cooling air to the variable compression unit.
5. Turn on the overspeed protection contactor power supply switch on the switch panel.
6. (For spark ignition only) Push the starting button (red one) of the overspeed protection contactor. If it makes noise put off and then re-set the button until the noise stops.
7. Check the transducer circuit and put the necessary eauipment on. (Recorder or osciloscope, amplifier etc.)

Starting:

a) Diesel Version:

1. Move the decompressor lever upwards and set the variable compression unit at about 18/1 compression ratio. (see calibration curve, Fig 10.)
2. Set the speed control wheel at about $\frac{1}{2}$ speed.
3. On the electric panel, check that the mot./gen. switch is in the "off" position.
4. Check that the starting / motoring rheostat and the field rheostat handwheel are rotated fully anti-clockwise.

5. Ensure that the rotary load switch is in the "Full speed Load" position and that all the loading resistors are off.
6. Start the AC - DC motor-generator-set and switch on the supply to the test rig.
7. To start, turn the mot./gen/ switch to the "motoring" position and turn the "starting/motoring", rheostat head-wheel slowly clockwise until the machine begins to rotate.
8. Allow the armature current to fall to a steady value (below 20^A) and then gradually increase speed up to approximately 600 rpm.
9. Move the control lever on the engine to start position and after approximately four seconds drop the compression lever smartly into the horizontal position. Theengine should then fire and run up to half speed (750 rpm) as set on the speed control wheel.
10. Switch over to the "generating" position on the mot./gen. switch, and after a five minutes warming up period during which the speed can be up to the nromal maximum of 1500 rpm, load can be progressively applied to the engine by means of the panel of loading resistor switcher.

b) Spark Ignition Version:

1. Move the decompressor lever upwards and set the variable compression unit to approximately 7.0/1 (See calibration curve, Fig: 10).
2. Set the carburettor needle control approximately 2,9 and the ignition timing to approximately 3^o before T. D. C.

3. The produce with the electrical panel is exactly as described for the diesel version.

4. When the machine is motoring at approximately 600 rpm drop the decompressor lever, open the throtle to about the $\frac{1}{2}$ speed position and switch on the ignition. The engine should then fire and run up to about 750 rpm, at which stage the mot./gen. switch can be put in the "generating" position. After a warming up period of about five minutes load can be applied to the engine exactly as described for the diesel version.

Stopping:

a) Diesel Version:

1. Reduce speed, remove load and move the control lever on the engine into the "stop" position. The engine will then stop and the decompressor lever should be lifted and the fuel shut off.

2. Switch off the D. C. electricity supply and the mains water.

b) Spark Ignition Version:

1. Redue speed, remove load and switch off the ignition. The engine will then stop and the decompressor lever should be lifted and the fuel shut off.

2. Switch off the D. C. electiricity supply and the mains water.

3. Switch off the overspeed contactor switch.

N. B. In either ease DO NOT attempt to stop the engine by lifting the decompressor or shutting off the fuel supply. In all cases after shutting down leave the cooling air supply onto the variable compression unit for a further $\frac{1}{4}$ hour, to ensure that the indicator pick-up unit is not damaged by heat conducted from the mass of the engine cylinder head.

Emergency Stopping:

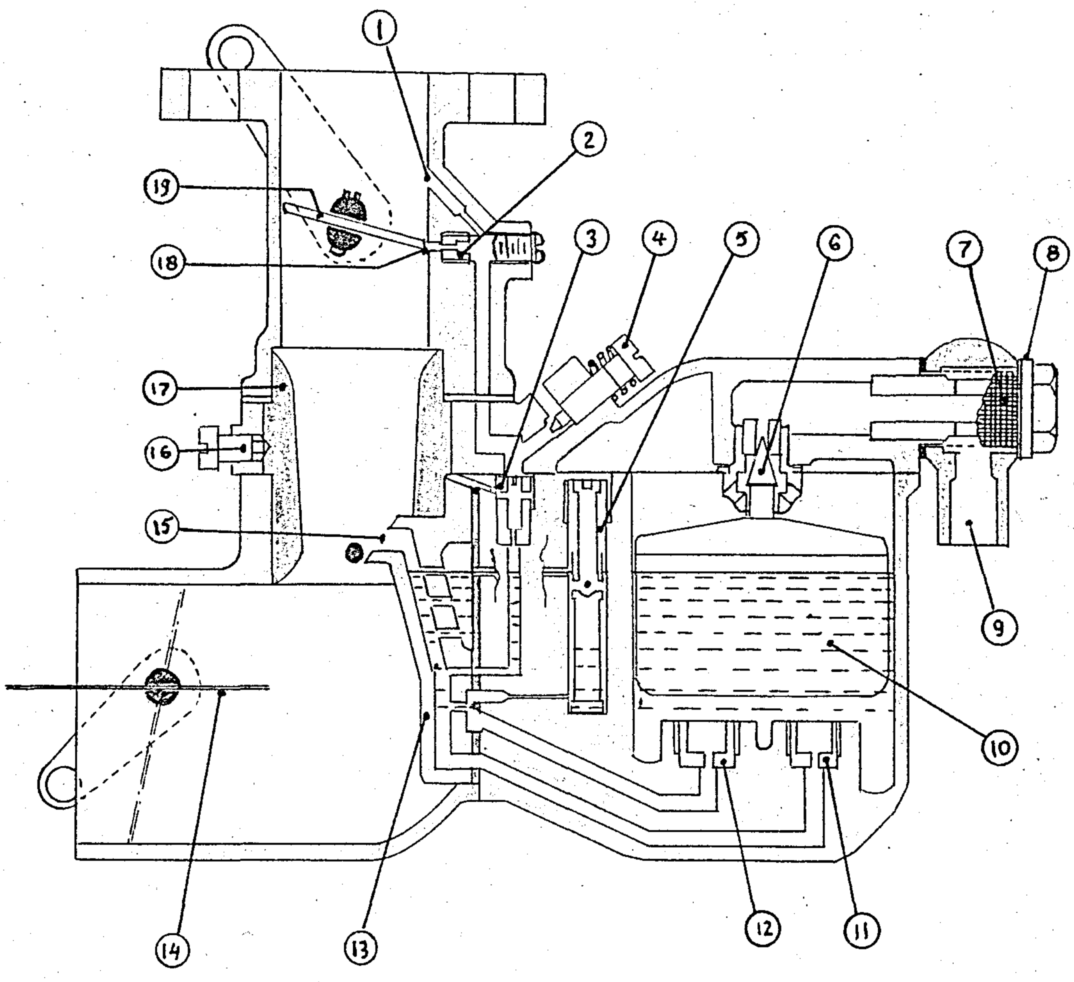
To stop the diesel engine in an emergency move the control lever on the engine to the stop position. In the case of the Spark Ignition Engine switch off the ignition. Before attempting to restart the engine correct the fault which neccessitated the emergency stop, then clear unburnt fuel from the engine by motoring at approximately 600 rpm. with the controls in the "stop" position.

Motoring:

Follow the starting instructions and slowly increase speed by means of the Starting/motoring control and finally the field rheostat. Allow the armature current to fall to a steady value at each step before proceeded.

CARBURETTOR

Fig: 12



1	Depression outlet	11	Main jet orifice
2	Progression jet	12	Compensating jet orifice
3	Slow-running jet orifice	13	Emulsion block
4	Air adjustment screw	14	Strangler flap
5	Capacity tube	15	Beak of emulsion block
6	Seating and needle	16	Screw holding the choke tube
7	Filler	17	Choke tube
8	Washer	18	Outlet for progression jet
9	Fuel supply pipe	19	Throttle
10	Float		

V. WORKING DESCRIPTION OF THE CARBURETTOR:

The Schematic drawing of the carburettor is shown in Fig. 12. This is a typical vertical, V type carburettor, but it also explains horizontal and downdrough instruments for the purpose of following the course of the gasoline, from its entering as a fluid until it leaves the carburettor and is drown into the engine as a correctly proportioned mixture of petrol and air.

"From the tank, gasoline passes through the pipe to the union 9 of the carburettor. The flow continues through the filter 7 and the seating and needle 6 into the float chamber. Passing through the main jet 11 and compansating jet 12, petrol will flow along the passages to a common chanel in the emulsion block 13, and continue to flow until the channels and the float chamber are filled to a predetermined height. The float 10 will then have lifted the needle 6 against its seating, thus preventing further petrol entering and flooding the carburettor. The fuel will occupy the position described all the time the engine is stationary, and there is a supply of gasoline." (2)

STARTING:

Starting description given here applies to a carburettor as it is functioning on a passanger car. Special features relating to the test rig will be indicated at the end of this section.

"Special arrangements for starting are made on the "V" type carburettor. Many models have stranglers fitted, but a type is available with an automatic starting device."

Stranglers:

"To provide the required rich starting mixture some "V" type carburettors have a strangler flap 14 in the air intake. When the control from the dash is operated the flap closes the air intake, and upon the engine being turned over the deppression is directed entirely upon the jets of the carburettors. Consequently a very rich mixture is supplied, and the engine starts readily and continues to run."

"It is often advantages to give the engine one or two turns with the strangler closed and the ignition off. Then switch on and again turn the engine over by starter or handle."

Most stranglers are interconnected with the throttle so that the latter is automatically opened the right amount when the strangler is closed. Since this is not so in our case the throttle is opened slightly by means of the hand control. The correct amount will soon be found by experiment."

Fully-automatic Strangler:

"In this type the strangler flap is free to move on an offset spindle, and held closed by means of a light coil spring only. When extra depression is created after the engine has started, the tension of the spring is overcome, and the flap opens and admits air to give the necessary weakening effect."

"Incidentally, in both types the varying depression causes the diaphram or flap to pulsate and give a buzzing noise, which acts as a warning note that the strangler is in operation."

"Note: It will be appreciated that even with the mixture weakining devices in full operation, the charge is still considerably richer than that normally supplied. Consequently, as the engine worms to its work, the strangler control should be released and dispensed with entirely as soon as conditions permit. Many strangler controls are provided with notches to enable the flap, to be opened in stages."

The mixture strength of the test rig operated manually and there is no need to control the strangler by opening the flap is stages.

Automatic starting device:

This is also a general information about the carburettor and does not apply to our case.

Some models of "V" type carburettors are fitted with a starting device.

"To start the engine from cold the automatic starting device control on the dashboard is operated, resulting in the main valve being drawn off its seating. With the ignition switch on, the engine should now be turned over by means of the starter, ensuring at the same time the accelerator pedal is not depressed. It is essential that the throttle should not be opened beyond the normal idling position for starting purposes. When the engine is rotated with the throttle in this position, all the suction or depression created will be concentrated on the main jet outlet on the engine side of the throttle. This depression will be concentrated at the ventury and in the communication tube which will result in air being drawn through the ventury, and gasoline from the dip tube."

"The gasoline is drawn from the dip tube through the control jet at the top. It then passes across a connection down the communication tube and then to the throat of the ventury. Here it will be met by air entering the ventury, and will be broken up to form a rich starting mixture, which then pass into the induction pipe through a drilling. The sizes of the dip tube, ventury, starting jet and control jet are such that this mixture of gasoline and air is correct to ensure that it will now fire and the engine continue to run."

"This rich mixture is necessary for a short period only. Automatic weakening - off is ensured by air from a hole mixing with the gasoline issuing from the starting jet, as soon as the fuel in the dip tube well and reserve well has been exhausted. Consequently, the mixture is automatically weakened, and the engine will continue to run at a fair speed for a while without "hunting" or showing signs of an unduly rich mixture."

"A very rich mixture is only necessary for the initial firing, after which a more normal mixture is provided, which causes the engine to run at a speed that promotes rapid warming up and circulation of the lubricating oil, thereby minimising cylinder wear.

At no time is neat gasoline entering the engine." (2)

MAIN CARBURETTOR:

"With the starting device valve closed, or strangler opened, and the throttle in the idling position, the engine is now working on the main carburettor only."

"The depression will be concentrated on the outlet 1, (Fig.12), which will in turn be directed on the slow-running jet 3. Consequently gasoline will be drawn from the well beneath the jet, measuring on passing through, and meet air entering at the base of the adjustment screw 4. The amount of fuel issuing from the slow-running jet is controlled by this screw."

"At the throttle edge there is a further outlet 18, which breaks into slow-running channel. Upon the throttle being opened from the idling position, this will give an additional mixture to ensure a progressive getaway from slow-running. This explains the title of (progressive jet) for item, 2."

"Upon the throttle being opened still further, the depression will be concentrated at the beak 15 of the emulsion block, which projects into the narrowest part of the choke tube 17. This will first result in fuel being drawn from the main channel in the emulsion block, the channel beneath the slow-running jet 3, and from the well of capacity tube 5, so that the source of supply is eventually through the main and compansating jets 11 and 12.

It will be observed that the fuel in the well of the capacity tube 5 has been consumed, and as the top of the well is open to the atmosphere, fuel issuing from the compansating jet along the passage beneath is now air-bled from the atmosphere."

"As depression increases, the compansating jet supplies a weaker mixture whilst the main jet delivers more fuel. The fuel issuing from the main jet 11, will meet the emulsified gasoline from the compansating jet 12 in the common chanel. This will tend to break up the fuel from the main jet also, so that when the supply from both sources is eventually drawn from the emulsion block nozzle into the choke tube complete atomization is assured."

"It is essential that this mixture should be distributed completely across the choke tube in all directions. To obtain this even distribution, a small circular bar has been placed accross the choke at right angles to the emulsion block beak. Air drawn from the intake will strike this bar and create a partial vacuum on the sides facing the engine. The fuel/air mixture leaving the emulsion block will also strike this bar and run along it to fill up the vacuum, and then proceed, evenly distributed across the choke, past the throttle valve and into the induction pipe."

"It will be realized that as soon as fuel in the float chamber falls blow the predetermined level the float will fall, permitting the needle 6 to drop, and more fuel will pass into the chamber through the seating."

ADJUSTMENTS:

"Adjustment to the slow-running mixture is the only likely alteration. When trouble is exprienced with the engine, it should not be assumed that it is always due to the carburettor. When the carburettor is free from dirt, other parts, such as sparking plugs, ignition, valves etc. should be investigated." (2)

"The bowl of the carburettor is removed by releasing the fixing bolts. The jets should be removed and throughly cleaned occasionally. One of the fixing bolts is squared at the end to fit into the jets. When this is fitted into the squared recesses, a spanner applied to the head of the bolt will enable the jets to be unscrewed."

"The slow-running jet 3 is provided with a screwdiver slat for its removal. This also applies to the screw holding the capacity tube. Upon removing the screw and inverting the bowl, the capacity tube will fall out."

"The emulsion block is held to the side of the bowl by three screws. To remove the block, first ease the bottom screw, and then completely remove those above. The bottom screw should not be removed completely, but upon turning this in an anti-clockwise direction, it will come away from the bowl, complete with the emulsion block. Particular care should be taken not to damage the gasket beneath the block. Never use shellack or any joining compound on this gasket. Upon replacing the block, locate the bottom screw first, and then tighten the remaining screws evenly."

"The starting jet is removed from the carburettor by means of a screwdiver. This applies also to the progressive jet 2, but in this case the plugging screw must be removed first, and care taken that it is replaced after inspection."

"The slow-running is adjusted by means of the throttle stop screw and the air regulating screw. The stop screw determines the speed of the slow running, i.e. it adjusts the throttle position for idling. To increase the slow-running speed, the stop screw must be turned in a clockwise direction. If unscrewed, a slower tick-over will result."

"The richness of the slow-running mixture is adjusted by the air regulating screw. Should the engine refuse to tick-over for any length of time, or stall on decelaration, the slow-running jet may be choked, and should be cleaned. After examination, reset the slow-running by means of the throttle and air adjustment screws. If the engine is inclined to hunt when running slowly, the mixture is too rich, and must be weakened by turning the air regulating screw in an anti-clockwise direction. The position for the slow-running air screw from the point of view of pick-up is within one turn of the full "home" position. For tapered screws the adjustment is within three turns. A size of the slow-running jet must be decided upon that will permit even tick-over with this setting of the screw, although a slight tendency to richness can often be corrected by setting the idling speed a trifle faster."

"There are other factors quite apart from the carburettor that have considerably influence on the slow-running. These factors include non-airtight joints, worn valve guides, badly seating valves, unequal tapped adjustment, ignition too far advanced, incorrect setting of the spark plug position etc. Such details must always be taken into consideration."

"The fuel filter 7 should be cleaned occasionally. To remove this item, unscrew the plug 8 and slide the filter from it. The gauza can be cleaned thoroughly with gasoline."

"When reassembling the filter, care should be taken to see that the washers on both sides of the fuel pipe connection are correctly replaced."

"The bowl should be cleaned occasionally swilling it with gasoline. It will be seen that the jets are situated well away from the bottom of the bowl, so that any sediment will fall around and not into the jets."

"The accelaration is controlled mainly by the slow-running adjustment and the size of the compensating jet. Bad adjustment will cause a flatspot when opening up the slow-running position, and it is often advantageous to set the slow-running mixture on the rich side to avoid this. If the engine is sluggish in picking up at slow speed, then a different size compensating jet should be tried. When the compansator is too small there is generally a long pause before the engine responds to the opening of the throttle and spitting back may occur. If it is too large the acceleration is heavy."

"The strength of the mixture when the engine working hard at slow speeds is determined by the compensating jet. If the car lacks power on full loads at slow speeds, experiments should be made with the compensating jet until the required power is obtained."

"Care should be taken to make sure that the lack of speed is not due to retarded ignition, an insufficient supply of fuel from the tank or pump, faulty ignition, poor compression, or to some restriction at the carburettor intake. If the loss of speed is definitely is due to the carburettor, different sizes of main jets should be tried, as this jet has most influence at high speeds. If no improvement is effected, no matter what size main jet is fitted, then a size larger choke tube should be employed, and the most suitable main and compensating jets found by trial."

"When the engine gets away badly and popping back occurs in the carburettor when accelerating, the compensating jet is too sa small. If this trouble happens at regular intervals, and the engine has little power and cannot drive the load at a high speed, the main jet is at fault and larger sizes should be tried until the explosions ease. Popping back is very often due to defective sparking plugs or valves not closing properly."

Starting:

"If the starting device is working correctly, i.e. the jet is clean and the main valve opens the full extend when the dash control is operated, no starting difficulty in starting and may be due to a run-down accumulator, an inefficient motor or the crankcase oil being too heavy for the time of year."

"Plugs, too, plays an important part. It should be made sure that they are clean and dry, are the correct type for the engine, and have the specified gap at the points."

"If difficulty in starting is experienced with carburettors fitted with strangler, one should be sure that the strangler flap closes completely when operated from the dash."

"A choked slow-running jet or incorrect adjustment of the air screw will also cause bad starting. This, however, is easily remedied by removing the jet, cleaning and replacing it, and then resetting the screw."

"Care should be taken to see that the bowl is bolted tightly to the float chamber cover of the carburettor."

"Only when all these points have been investigated should the setting of the starting device be altered, if difficult starting persists."

"Trouble some starting can be classified generally as follows:

a) Engine fails to fire

b) Engine fires but fails to run

c) Engine fires and runs, but the mixture is over-rich."

a) Engine fails to fire:

Control jet and starting jets should be adjusted. The control jet measures the fuel flow until the fuel in the well is consumed, and thereafetr affects the depression on the starting jet. First larger starting jets should be tried, but failing improvement resort to increased sizes of control jets.

b) Engine fires but fails to run:

"Over-rapid weakening - off is the fault here, and a larger starting jet should be tried to overcome the fault."

c) Engine fires and runs, but the mixture is over-rich:

"First a smaller jet should be tried, but if this affects initial firing a smaller control jet should be fitted."

"N. B. The concentration of the depression upon the starting device is most essential. Therefore it should be ensured that the throttle is closed to the idling position when the engine is being started."

Excessive fuel consumption:

"The carburettor is frequently blamed for this defect when it is actually caused by the engine being in poor condition, or by the ignition being retarted. There may be a leak in the fuel system or there is a restriction at the carburettor intake."

"If it is certain that the consumption is excessive smaller jets are suggested. First one size smaller main and compansating jets should be tried. If this does not affect the performance then smaller jets should be tried. Since there is no relation between these two it is quite in order to alter the size of one and not the other."

"If the consumption is definitely heavy, then the carburettor must be giving a mixture richer than is necessary. This can always be remedied by fitting smaller jets. If the performance suffers when such jets are used, then it is apparent that the cause of the trouble is not in the carburettor."

"It should be made quite certain that the automatic starting is working freely, and that the main valve is returning completely to its seating. If this is not so the device will remain in action, and consequently will be supplying extra fuel to that given by the main carburettor."

"Care must also be taken to see that the strangler flap, on carburettors to which one is fitted, is returning to the full-open position."

"Heavy consumption may be caused by excessive pressure of the fuel. This is usually indicated by the fact that it is impossible to obtain a smooth tick-over irrespective of the position of the air screw for slow running and also by black smoke from the exhaust."

"This may be overcome by fitting a slightly smaller needle seating to enable the needle to cope with the excessive pressure. If this does not cure the trouble, or the smallest needle seating does not cause restriction at top speed is already fitted, then it will be necessary to regulate fuel pressure." (2)

GENERAL:

"Should the engine be used in very hot climets, or at very high altitude, a slightly weaker seating may be used. Alternatively, in very cold climets larger jets may be necessary. No other adjustments are likely to be necessary under normal conditions."(2)

As it is said before, the above discription of a carburettor applies to car carburettor and the one on the variable compression unit has some alterations as will be explained as follows:

The carburettor used on the test rig is Zenith 26 V M E type. Its main jet is blocked, compensating jet reamed out to 0,0670" diameter and counter bored 0,125" diameter to give needle shank clearance. Needle 12^{o} included. By means of these alterations it possible to control the mixture strength manually. Thus it is necessary to adjust the mixture strength at the start and running conditions seperately if uniform running is required.
The rich starting mixture is provided by turning the mixture strength dial counter clockwise 5 or 6 turns. Normal running condition of the engine is between 1.8 - 2.5 scales of the dial.

VI. PRESSURE TRANSDUCER:

a) Resistance strain gages:

Lord Kelvin is the first one who noticed the electro-dynamic properties of metals. In 1856, among other findings, he reported that the electrical resistance of certain wires varied with the tension to which the wires were subjected. More recently (1823), in America, P. W. Bridgeman confirmed Kelvin's results. Till 1830 no practical application of this knowledge is noticeable. Several attempts were made to apply the phenomenon of strain sensitivity in wires to the actual measurement of strain in other bodies. These attempts were naturally accompanied by the difficulty in developing satisfactory techniques for securing the strain-sensitive wire to the test structure, a search for the best wire with which to build the gage, calibration troubles, and difficulties of manufacturing such a delicate instrument on a mass-production basis.

The original strain gages built by Simmons and Ruge required individual calibration to be dependably accurate. Early strain gages were made by embedding the fine wire in cast thermoplastic-resin coupons which were individually calibrated. These gages were rather bulky compared with the present SR-4 strain gages and did not allow the strain-sensitive wire to be in intimate contact with the surface of the test structure. By the control of manufacturing processes, gages have been made with a uniform resistance and gage factor such that individual calibration was no longer necessary. These developments soon led to the widely used SR-4 strain gage in its present form.

In using electric strain gages, two physical quantities are of particular interest. Change in strain and gage resistance. The dimensionless relationship between these two variables is called the "gage factor" and defined as:

$$F= \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R}{\varepsilon R} .$$

Where R= initial resistance of the gage wire

L= initial length of the gage wire

ΔR and ΔL represent the small changes in resistance and length which occur as the gage is strained along with the surface to which it is bonded. ε is the strain of the gage. The gage factor, as seen, is a measure of the amount of resistance change for a given strain and is thus an index of the strain sensitivity of the gage. The higher the gage factor, the more sensitive the gage and the greater the electrical output for indication or recording purposes, other variables remaining the same. The limiting element in determining in gage factor is the wire material, and all those materials which have demonstrated high gage factors have had other unpleasent charecteristics which made them unsuitable for starin gages.

The ideal strain gage wire would have high resistance, a large change in resistance with strain, and a high elastic limit and would be insensitive to temperature in both its physical and its electrical properties. Furthermore, the gage factor should be constant. In other words, the resistance change must be proportional to or linear function of, the unit strain in the wire. Strain gage wire should be very small in diameter so that the cement in which it is incased will be considerably stronger than the wire. This allows the cement to transmit the strains from the part being tested to the wire. With o.ool-in.-diameter wire, the cement is sufficiently stronger than the wire so that under compressive strains the wire is actually made shorter without buckling, since a 1-in. length wire of o.ool in. diameter has a surface area 4,000 times its cross sectional area. The bonding and supporting effect of the cement on the wire is so great that the cement can control the wire up to strains of 0,03 in. per in. or more in either compression or tension.

If the strain gage wire is to be 1 mil or less in diameter, this imposes another limitation on the physical properties of the wire material; that is, the wire must be capable of withstanding severe drawing operations during processing.

Furthermore, when nickel and some of the other materials are bonded to steel, because of the differences in thermal coefficients of expansion, an addition error is introduced due to apparent strain which occurs with temperature change. There are, however, means to climinate this error. Negative gage factors are just as useful as positive ones, since obtaining the greatest change in resistance for a given strain is the most significent facor, whether the change in resistance is positive or negative is immaterial. (3)

THE SR-4 STARIN GAGE:

Basically, the SR-4 strain gage consists of about 5 in. of 1-mil wire cemented between two pieces of thin paper. The paper serves as a carrier for ease in handling the wire and also acts to insulate the wire from the metal surface on which it is to be bonded. The wire in the gage is in the form of a grid consisting of series of long, parallel loops. In the manufacturing process this grid is fixed on a piece of thin paper with a suitable cement. Larger-diameter leads are then welded or soldered to the two ends of the grid wire, and a second piece of paper is cemented over the wire. A protective layer of felt is usually used to cover the top side of the gage. Smaller strain gages, e.g. 3/8 in. or less in length, are prepared by winding the strain-sensitive wire around a cylindrical paper case in the form of a close-wound helix. This case is then flattened and cemented between layers of paper for purposes of protection and insulation.

Improved techniques and statistical quality-control methods, has resulted in making these strain gages available at a consider=ably lower prices. Unfortunately, the instruments which are necessary to tranlate the strain gage language into numbers usable by the engineer are not so cheap. These instruments are both complex and expensive.

TYPES OF BONDED WIRE STRAIN GAGES:

The gage elements which are varied for special applications are prencipally the cement and the strain-sensitive wire.

For gages which are to be used at temperature below about 180°F, a thermoplastic cement (celluloid dissolved in acetone), is very satisfactory. For higher operating temperatures, up to 300 or 400°F a thermosetting cement (phenol resin) is satisfactoryly employed. Special ceramic cements are generally used for temperatures above 400° F.

For dynamic strains, type C gages are used in order to take advantage of the accompanying higher gage factor.

Strain gages can now be used in almost any place under wide range of conditions applying various protective methods.

The above statements are true also for other types of strain gages. The problems involved are the same for all strain gages which are made of similar types of wire and bonded with similar cements.

A few comments on gage forms developed by the British is necessary. One of the more unusual type is the woven-type strain gage. This is more permiable and thus has very short drying time. These gages are manufactured on a standard weaving machine in the form of a long tape. The tape is made by using a Fortisan warp and a weft of strain sensitive wire. After weaving the tape is cut into proper lengths, and leads are attached. Another type is the self-adhesive strain gage. These are just like postage stamps with a difference that the gages are stuck in place by wetting the back of the gage with acetone.

A recent type is in the form of a metallic foil which is slatted alternately from each end to form a continious grid or series of loops similar in pattern to SR-4 strain gage.

The foil strain gages are mounted in a very thin lacquer having excellent mechanical and electrical properties. This improves the gage performance and stability. Other advantages arise from the rectangular corss-section of the conductor, which increases surface area for a given cross-sectional area. The adhesion between the grid and cement is thus improved and the current carrying capacity to the grid is increased. Foil gages can be manufactured in almost any pattern or configuration with equal ease.

BONDING TECHNIQUES:

The strain gage can perform as better as the bond by which it is attached to the test piece. The surface strains are transmitted to the gage by the bonding cement. This can only be accomplished by a proper bonding job.

The strain gages are classified into two group with respect to the bonding cement:

1. Gages with nitrocellulose.
2. Gages with heat hardening or thermosetting, phenol resin.

Gages of the first type are called "Duco" gages and are bonded with a cellulose cement. Second types are commonly refered to as "bakelite gages" are bonded to the test surface with phenol-resin cement.

Main determining factor for the selection of a proper gage is the temperature the gage is expected to withstand. When the service temperature of the gage is below 150°F, Duco gages are appropriate, since the cementing process for these gages is relatively easy and drying time is short. Between 150°F and 450°F, the bakelit gages are appropriate. Bakelite gages are employed also in long term installations.

DUCO GAGES:

Certain preparation of the surface which the strain gage is to be put is necessary, to ensure a good bond between the gage and and the surface. The surface on which the gage is to be mounted should be smooth but not too highly polished, since this does not promote adhesion. A spot little larger than the gage may be lightly ground off.

Cleaning of the surface is the next step. Carbon tetrachloride or acetone will do admirably for such a job. A clean solvent and clean cloths should be used and the prepared surface and the back of the gage should not be touched. Care should be taken not to dissolve the cement used in the construction of the gage by cleaning liquid acetone. It is good practice, however, to wipe the back of the gage with a cloth slightly dampened with acetone.

After these preparations a fairly liberal layer of cement is spread on both the gage and the prepared surface, and the gage is set in place at once. In the first few seconds after the gage has been applied to the surface it will be possible to slide the gage around slightly in order to orient the gage in the desired direction. Then the gage is pressed or rolled lightly with a fibger to squeeze out most of the excess cement.

A clamping force of about 1-lb is required while the gage is drying. Larger forces are detremental to the gage wire.

The drying time may vary with the temperature, humudity and type of the gage used. A clamping time of one hour or so and drying time of 24 hours at room temperature is practical. The reason for removing the clamp after one hour is to permit free cooperation of the cement solvent. Drying process can be accelerated by beating the strain gage. To heat the metal adjacent to the gage is a good practice. At about 170°F the strain gage will be dry in a few hours. While drying, the resistance of the strain gage increases until it is completely dry.

It is a good practice to tape the soldered bad joints down immediately adjacent to the gage by means of a piece of tape.

A quick check of the resistance of the gage and the resistance between the gage and the metal surface to which the gage is attached may indicate the condition of the gage. A minimum of 50 megahms between the surface and the gage is considered minimum for accurate, stable functioning of the gage.

A final check may be made by ballancing a wheatstone bridge including the strain gage and pressing the strain gage by finger or by any soft material.

If the balance is disturbed the strain is in proper condition. If the balance is disturbed or opposite deflections occur after releasing the pressure there is a problem with the gage. (3)

BAKELITE GAGES:

Bakelite strain gages are used for any one or any combination of the following circumstances:

1. Where temperatures are between 150 and 450°F .
2. Where gage stability is required despite high humidity.
3. Where long-time gage stability or stability under generally adverse conditions is necessary.

Surface preparations are the same as for the Duco gages. A clamping pressure of 100-200 psi is requiréd which should be left applied during the following recommended backing times applied in the order given as:

1. One hour at 140°F
2. Two hours at 175°F
3. Two hours at 250°F
4. One hour at 250°F after the clamp is removed.

Metal surface should be heated not the gage itself.

If the gage is to be exposed to higher temperatures than the highest backing temperature above (250°F) it should be baked one or two hours at the operation temperature once or twice. (3)

b) Pressure transducers:

Transducer is an instrument which is sensible to force, torque, pressure, displacement and other physical quantities. There are several types of transducers to measure the mentioned quantities making use of some physical and mechanical charecteristics of a material.

Since strain is the fundemental quantity measured by a strain gage, all transducers making use of strain gages should consist of one or more strain gages and an elastic body which produces strains proportional to the measured quantity. The measured quantity should not produce strains which exceed the yield point of the elastic member so as to have (stress/strain) ratio, that is, the modulus of elasticity constant.

One of the most convenient features of strain gage transducers is their size. Another advantage of the strain gage transducers is their convenience in measuring quantities at remote distances. Primary disadvantage of the strain gage transducers is their low electrical output, which require considerable amplification.

The most used pressure transducer is a diaphragm-type pressure cells. The strain gages are either directly bonded on the diaphragm displacement. Fig: 13, shows one of the first type. These type of transducers have natural frequencies of about 50 000 cps. and dynamic pressure range of -10 to 2000 psi.

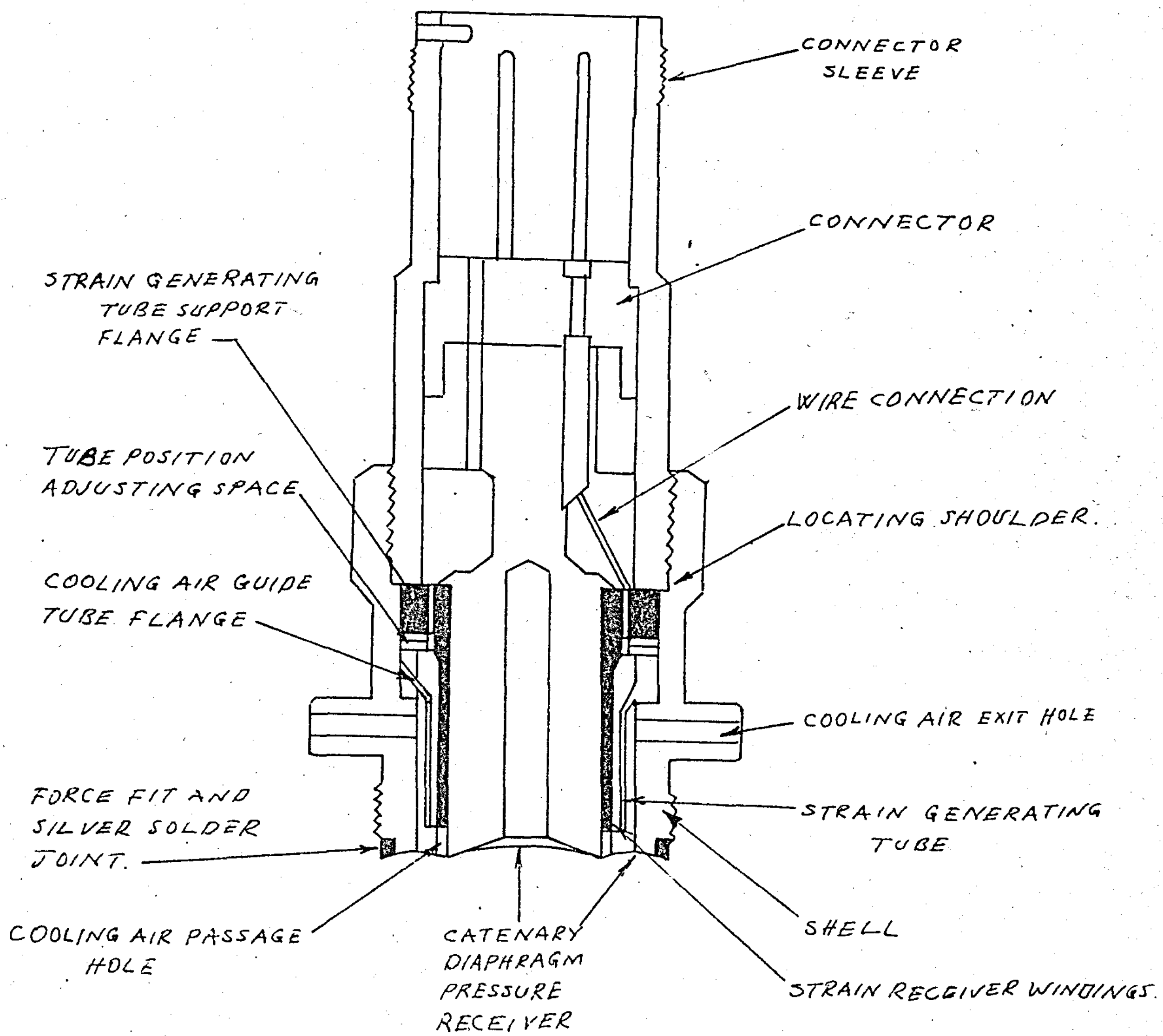


Fig: 13 a.

CATENARY DIAPHRAGM PRESSURE TRANSDUCER
(CONTROL ENGINEERING CORP.)

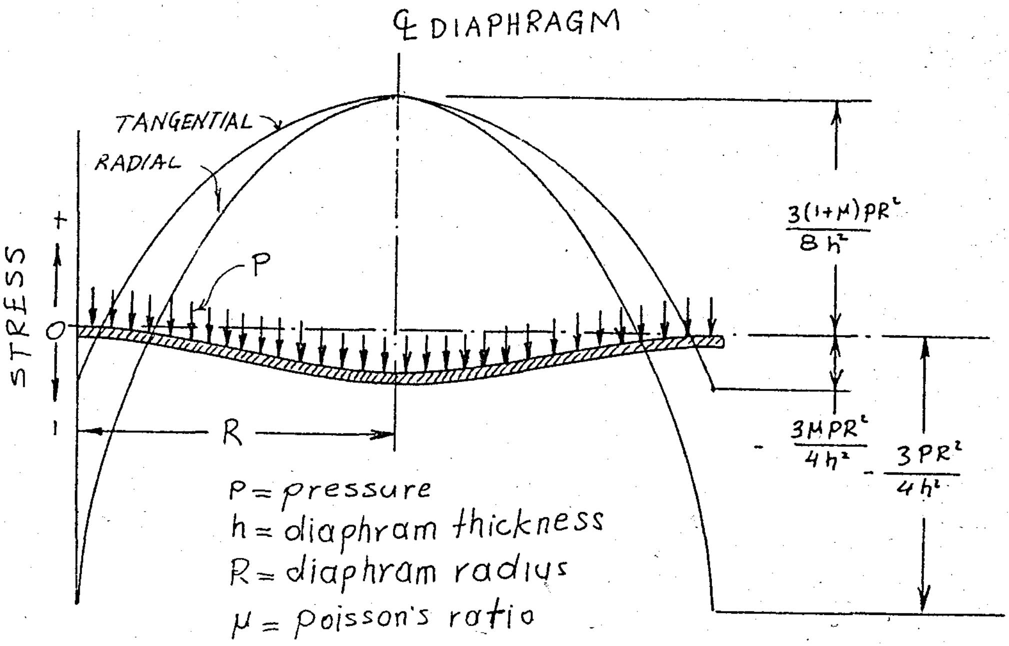


Fig: 13b. Stress distribution in a uniformly loaded diaphragm with clamped edges. (Timoshenko)

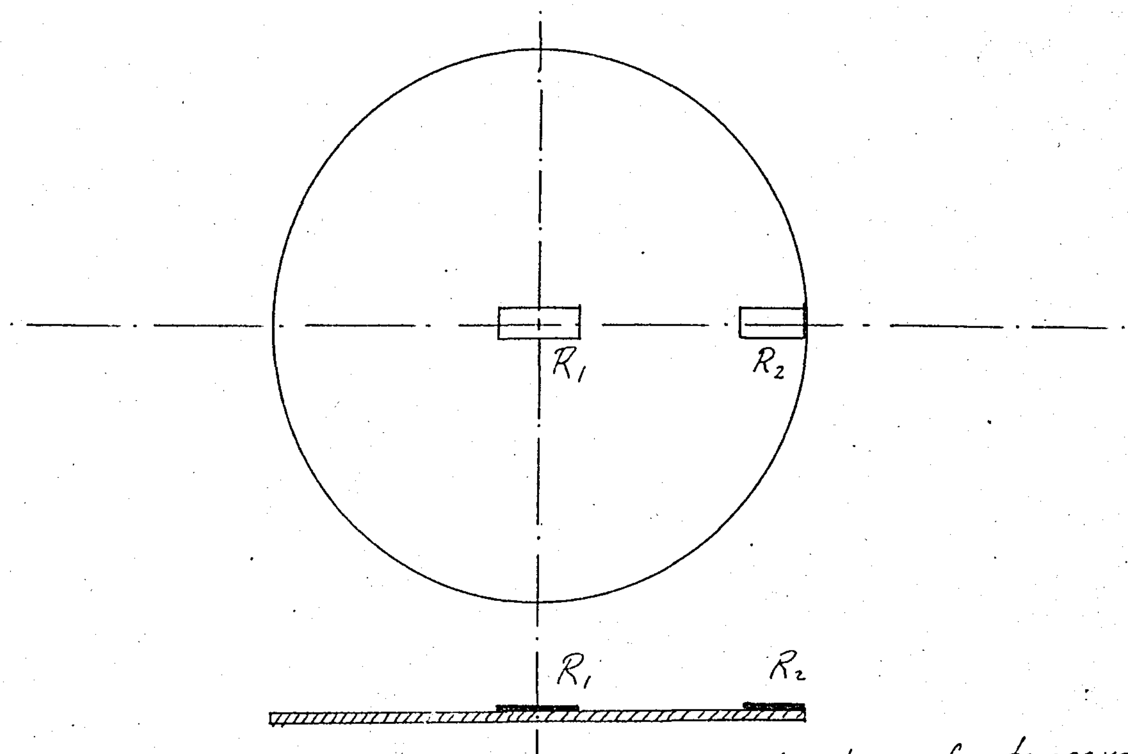


Fig: 13c. Disposition of strain gages on a diaphram for temperature compensation and maximum output (Ref: 3, P: 228)

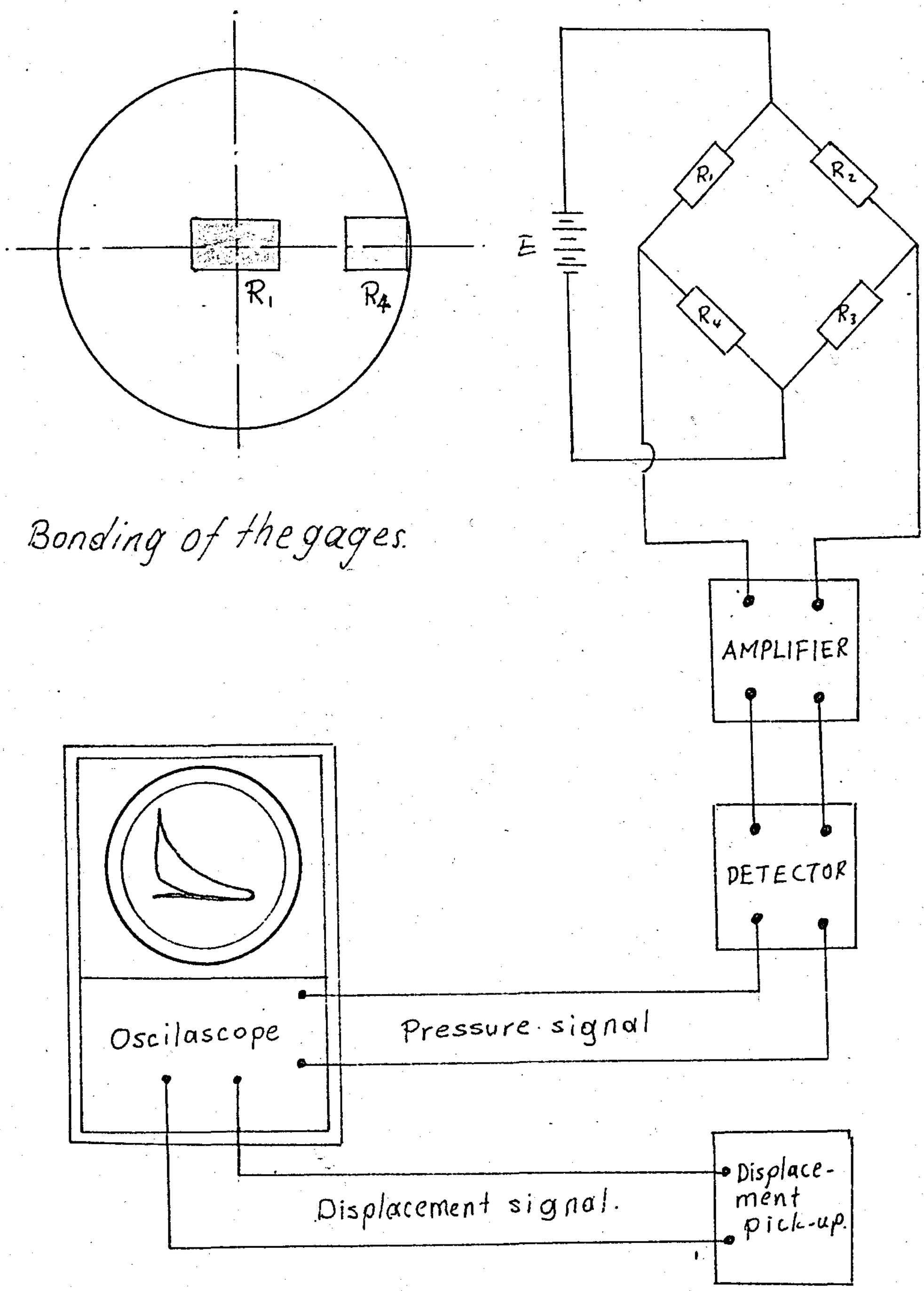


Fig: 13-d

Schematic transducer Circuit.

Usually cooling systems, such as low pressure air cooling is employed in these pick-ups to adopt them for engine indicators.

Mounting the strain gages directly on the diaphragm results in smaller sizes. From theories elasticities it is possible to analyse the strain variations in the diaphragm. It has been proven that there are compressive and tensile strengths in the diaphragm which is suitable for temperature compansation and output maximization as discussed above. The mounting of strain gages is shown in Fig: 13.

See Drawing : 1, for mounting the pressure transducer.

c) Electrical Circuits:

THEORY OF THE UNBALANCED BRIDGE:

Fig; 14 shows the unbalanced Wheatstone bridge circuit. Since the output voltage of the circuit is a function of resistance make-up the circuit and also of the applied voltage we can express the variation of the output voltage in terms of the variations of the resistances. Partial derivative is a useful tool for this purpose.

From the resulting equations we can conclude that:

1. If R_1 and R_4 are the same type of resistance gages and subjected to the same conditions their net effect on the output voltage is zero. Therefore if R_1 is an active resistance gage the temperature compensation can be accomplished by placing a dummy resistance gage, R_4, which will be subjected to the same temperature. Due to temperature both gages will change in resistance but the net effect of the temperature will be zero.

2. Since R_2 and R_3 are outside resistances in a pressure transducer, that is, they are merely used to balance the circuit and not subjected to resistance variations, they are constant. Thus:

$$dR_2 = dR_3 = 0.$$

3. If R_2 and R_4 are bonded to the metalic surface in such a way that their resistances change is in the opposite direction from that of R_1 and R_3 the output voltage of the circuit then will be maximum per unit change of resistances of the strain gages.

4. If R_1, R_2, R_3, R_4 are similar strain gages and have the same resistance and gage factor, bonded on the surface as explained in item 3, and connected to the bridge as shown in Fig:13, then the

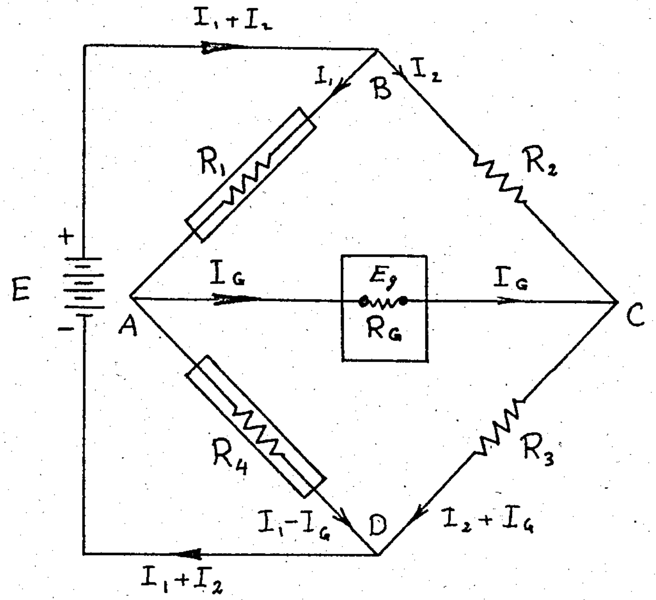


Fig: 14a. Unbalanced Wheatstone - Bridge Circuit.

$E =$ Applied voltage.

$E_g = f(R_1, R_2, R_3, R_4, R_G)$

$$dE_g = \frac{\partial E_g}{\partial R_1} dR_1 + \frac{\partial E_g}{\partial R_2} dR_2 + \frac{\partial E_g}{\partial R_3} dR_3 + \frac{\partial E_g}{\partial R_4} dR_4 \qquad (1)$$

Assuming : $I_G \cong 0$ i.e. the bridge is balanced.

$R_1 I_1 + R_4 I_1 = E$ and $I_2 (R_2 + R_3) = E$.

$R_1 I_1 - R_2 I_2 = E_g$.

$$\therefore \quad I_1 = \frac{E}{R_1 + R_4} \quad , \quad I_2 = \frac{E}{R_2 + R_3}.$$

And $$E_g = E\left(\frac{R_1}{R_1+R_4} - \frac{R_2}{R_2+R_3}\right)$$

$$\frac{\partial E_g}{\partial R_1} = E\frac{R_4}{(R_1+R_4)^2}. \qquad \frac{\partial E_g}{\partial R_2} = -E\frac{R_3}{(R_2+R_3)^2}.$$

$$\frac{\partial E_g}{\partial R_3} = E\frac{R_2}{(R_2+R_3)^2} \qquad \frac{\partial E_g}{\partial R_4} = -E\frac{R_1}{(R_1+R_4)^2}$$

From these equations and eq:(1):

$$dE_g = E\left(\frac{R_4\,dR_1 - R_1\,dR_4}{(R_1+R_4)^2} + \frac{R_2\,dR_3 - R_3\,dR_2}{(R_2+R_3)^2}\right)$$

Since the bridge is balanced

$$I_1R_1 = I_2R_2$$

and $$I_1R_4 = I_2R_3$$

or $$\frac{R_1}{R_4} = \frac{R_2}{R_3}$$

If R_1 and R_4 are the same type of resistance gage and subjected to the same conditions:

$$dR_1 = dR_4$$

Furthermore, if R_2 and R_3 are outside resistances they do not change; and $dR_3 = dR_2 = 0$

$$\therefore \quad dE_g = 0$$

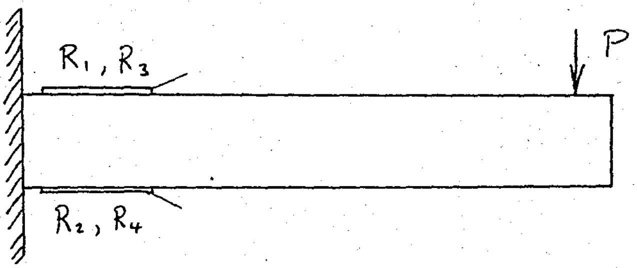
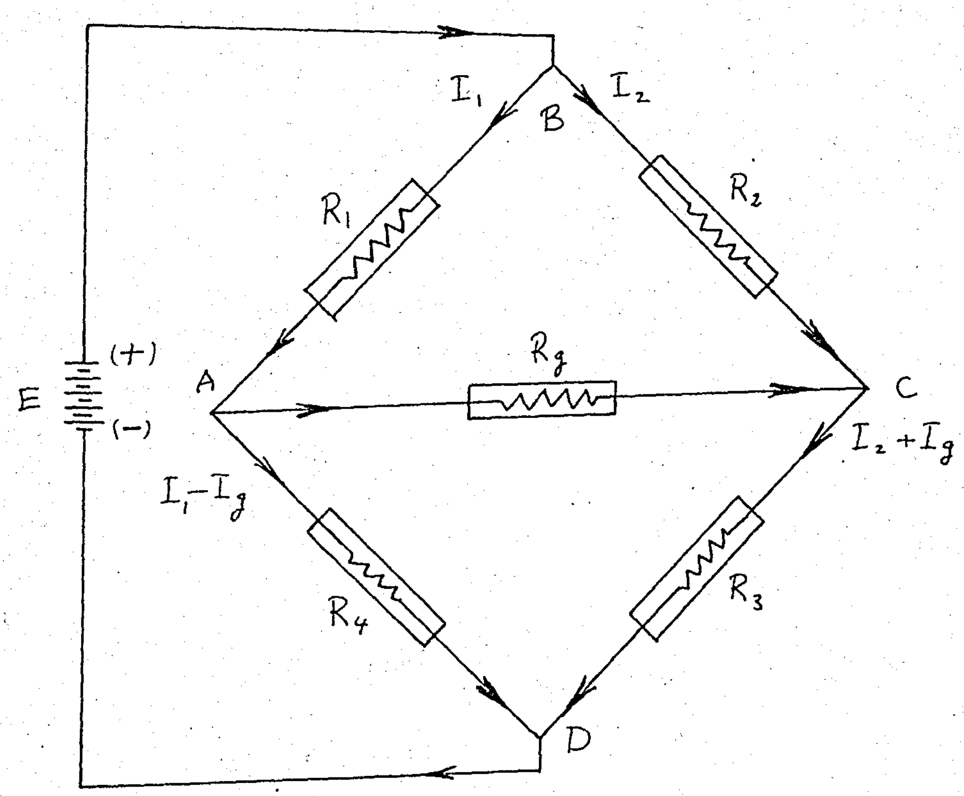


Fig: 14b. Bonding of strain gages to obtain maximum output.



Connection of strain gages in Fig: 14c.

bridge will be

$$dEg = E\frac{4RdR}{(2R)^2} = E\frac{dR}{R}.$$

Since the gage factor, F is defined as:

$$F = \frac{\left(\frac{dR}{R}\right)}{\varepsilon}$$

Therefore: $$\boxed{dEg = EF\varepsilon} \qquad (2).$$

This equation is true only when there is no connection between the points A and C, that is, Ig=0. When these points are connected to an amplifier the resistance Rg is quite large and Ig is very small compared with I_1 and I_2. Therefore output voltage variation of the circuit under the assured conditions can be expressed approximately by the equation (2).

However the output current and voltage, when the resistance between points A and C is not infinitely large, can be calculated as follows:

From Fig: 14;

$$I_1\ (R_1+R_4)-IgR_4=E \qquad (3)$$

$$R_1I_1+RgIg-R_2I_2=0 \qquad (4)$$

$$-R_4I_1+R_3I_2+Ig(Rg+R_3+R_4)=0 \qquad (5)$$

From equations (3), (4), (5):

$$I_g = \frac{\begin{vmatrix} R_1 + R_4 & E & 0 \\ R_1 & 0 & -R_2 \\ -R_4 & 0 & R_3 \end{vmatrix}}{\begin{vmatrix} R_1 + R_4 & -R_4 & 0 \\ R_1 & R_g & -R_2 \\ -R_4 & R_g+R_2+R_4 & R_3 \end{vmatrix}}$$

or

$$I_g = E \frac{(R_1R_3 - R_2R_4)}{R_2(R_1+R_4)(R_g+R_3+R_4)+R_1R_3R_4-R_2R_4^2 + R_gR_3(R_1+R_4)} \qquad (6)$$

If we assume that $R_1 = R_2 = R_3 = R_4 = R$ and strain gages are arranged as in Fig: 14, then:

R_1 ------- $R + \Delta R$

R_2 ------- $R - \Delta R$

R_3 ------- $R + \Delta R$

R_4 ------- $R - \Delta R$.

Putting this values into (6) and neglecting terms containing $(\Delta R)^2$ and $(\Delta R)^3$ and simplifying we obtain:

$$I_g = E \frac{\Delta R}{RR_g + R^2} \qquad (7)$$

Since $I_g = \frac{dE_g}{R_g}$. Then Equation (7) becomes:

$$dE_g = E \frac{\left(\frac{\Delta R}{R}\right)}{1 + \left(\frac{R}{R_g}\right)}$$

By the definition of the gage factor:

$$F = \frac{(R/R)}{\varepsilon}$$

$$dEg = \frac{E\,F\,\varepsilon}{1+(\frac{R}{Rg})} \qquad (8)$$

If $R_g \gg R$ this equation becomes

$$dEg = E\,F\,\varepsilon$$

which is the same as (2), which was derived under the same assumptions.

The simbols are defined in Fig: 14, as before.

Another special case should be considered: In pressure transducer applications only one of the strain gages is active, and others are to be constant. Therefore, if R_1 is the active strain gage and $R_1 = R_2 = R_3 = R_4 = R$

$$R_1 \text{------} \; R + dR$$

$$R_2 = R_2 = R_3 = R$$

Therefore equation (6) can be modified as follows:

$$I_g = E\,\frac{R_1 R - R^2}{R(R_1+R)(R_g+2R) + R_1 R^2 - R^2 + R_g R(R_1+R)}$$

Simplifying:

$$I_g = E\,\frac{R_1 - R}{2R_1R_g + 3R_1R + 2RR_g + R^2}$$

Since $dI_g = \frac{\partial I_g}{\partial R_1} dR_1$

$$\frac{\partial I_g}{\partial R_1} = E\,\frac{2R_1R_g + 3R_1R + 2RR_g + R^2 - (R_1 - R)(2R_g + 3R)}{(2R_1R_g + 3R_1R + 2RR_g + R^2)^2}$$

Since $R_1 \cong R$

$$\frac{\partial I_g}{\partial R_1} = E\,\frac{(2RR_g + 3R^2 + 2RR_g + R^2)}{(2RR_g + 3R^2 + 2RR_g + R^2)^2}$$

or $\frac{\partial I_g}{\partial R_1} = E\,\frac{1}{4R_1R_g + 4R_1^2}$

$$dIg = \frac{\partial I_g}{\partial R_1} dR_1 = E\,\frac{dR_1}{4R_1R_g + 4R_1^2}$$

or $dIg = \frac{E}{4} \cdot \frac{dR_1}{R_1Rg + R_1^2}$

Since $dIg = \frac{dEg}{Rg}$.

$$dEg = \frac{E}{4} \cdot \frac{Rg\ dR}{R_1Rg + R_1^2} = \frac{E}{4} \cdot \frac{\frac{dR_1}{R_1}}{1 + (\frac{R_1}{Rg})}$$

By definition:

$$F = \frac{dR/R_1}{\mathcal{E}}$$

$$dEg = \frac{E}{4} \cdot \frac{\varepsilon F}{1+(\frac{R1}{Rg})} = \frac{1}{4} \times \frac{(E F \varepsilon)}{1+(\frac{R_1}{R_g})} \qquad (9)$$

As it is seen from the last equation (dEg) in this case is ($\frac{1}{4}$) of (dEg) of the first case.

We see that to obtain maximum voltage output from the wheatstone bridge internal resistance of the amplifier should be very high compared with the resistance of the strain gage.

The maximum output of a pressure transducer in which only one of the resistances of the Fig: 14 is active, is:

$$dEg = \frac{1}{4} \cdot (E F \varepsilon)$$

Where

E= Applied voltage, volts

F= Gage factor

ε= Strain due to pressure

TEMPERATURE COMPENSATION:

For balanced bridge, the output voltage is:

$$dEg = E \quad \frac{R_4DR_1 - R_1dR_4}{(R_1+R_4)^2} + \frac{R_2dR_3 - R_3dR_2}{(R_2+R_3)^2}$$

It is clear that if $R_1 = R_4$ and they are similar gages and bonded to the same surface the resistance variation due to temperature in each gage should be the same, that is $dR_1 = dR_4$. Thus the effect of the temperature is eleminated. This reasoning can be applied to R_2 and R_3. Therefore the strain gages in Fig: 13, should be so bounded that R_1 and R_4, or R_2 and R_3 will be subjected to the same temperature and thermal expansion.

INSTRUMENTATION:

A typical strain indicator is composed of an audio-frequency oscilator (from 60 to 4000 C ps) to supply the bridge circuit, an amplifier (several stages for an amplification oh the order of 1000 times), a detection circuit, and a recorder or osciloscope. The detector is composed of a rectifier and a filter. The rectifier first cuts off the bottom halves of the carrier waves. The filter allows only low frequency waves and filter the high frequency carrier waves. The resultant wave form is shown in Fig: 15. The resultant wave is then fed to the osciloscope or recorder.

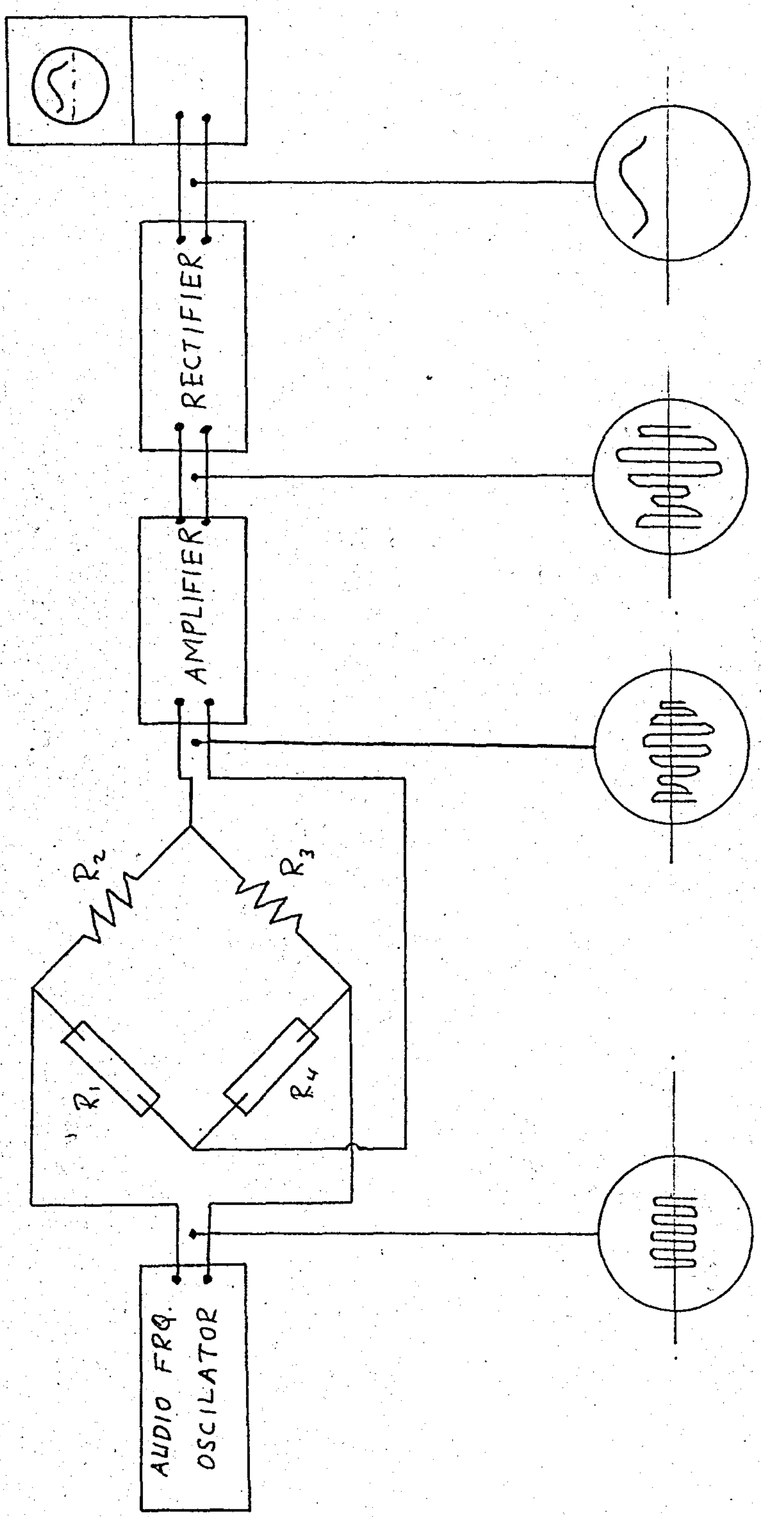


Fig: 15, Waves in the transducer circuit.

DYNAMIC STRAIN MEASUREMENT:

A strain gage is capable of detecting dynamic strains of extremely high frequency, e.g. 50 000 cps. or so.

Since the output of the bridge is quite small, considerable amplification will be required in order to actuate the osciloscope or recorder. Fig: 16 shows a simplified amplification circuit.

The amplifier used should have a constant gain or amplificati factor over the complete frequency range of the strain gage.

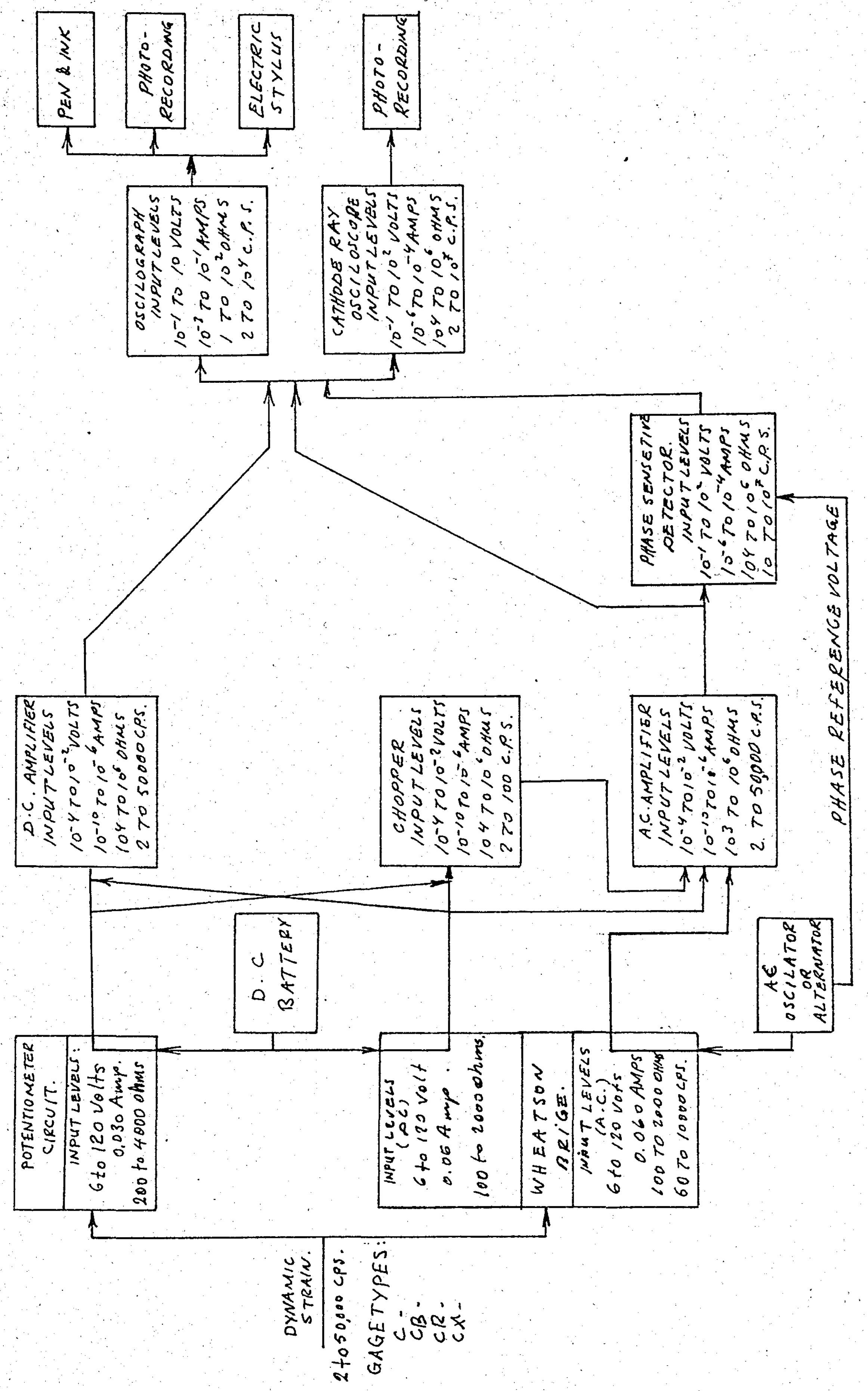
Since the direct-coupled (d.c.) amplifiers are expensive we have to use an oscilator or a chapper in the circuit to make use of the common oudio frequency amplifiers.

The chapper is a device which cutts off the output voltage of the bridge into forms of square waves. An ordinary automative ignition-type circuit breaker can perform as a chapper.

An oscilator supplies carrier waves to the bridge,These waves are modified by the strain gage output. The output voltage from the bridge is a sine wave of oscilator modulated by the signal wave of the active gage. If this output is rectified by a diod circuit before recording a single line trace or the envelope of the carrier wave will be obtained.

If we denote the frequency of the carrier wave by F, and that of signal wave by f, the form of the signal wave by a Cos $2\pi F$, then the modulated oscilator wave is given by:

Fig: 16; INSTRUMENTATION DIAGRAM FOR STRAIN GAGES.



$$y = (A + a \cos 2\pi F) \cos 2\pi F$$

$$= A \cos 2\pi F + \tfrac{1}{2} a \cos 2\pi (F - f) + \tfrac{1}{2} a \cos 2\pi (F + f).$$

The amplifier has to handle frequencies in the range $(F + f)$ down to $(F - f)$. To obtain smooth waves in the osciloscope for photographing it is necessary that

$$F \doteq 10f.$$

RECORDING:

There are two basic types of recording:

1. Pen-and-ink type recorders.
2. Cathod-ray osciloscope and a camera.

In the first method a Brush recording equipment is employed. This instrument is equipped with a variable speed traveling paper and a galvanometer which has a pointer specially arranged to write on the moving paper. The oscilation of the pen on horizontal direction on a curved path indicates the strain or any accompanied quantity the strain gage is designed to measure. In specially designed strain analyzers there is an oscilator for supplying the wheatstone bridge with 2000 cps. current, a high gain amplifier, and provisions for gain control, bridge balancing, and calibration. These are very useful instruments which can be used to analyze any kind of strain.

Cathod-ray osciloscope is useful in another type of recording. A cathod-ray osciloscope is an instrument which is sensetive to voltage variations only.

Thus any quantity to be indicated on an osciloscope should be transformed into voltage. Since strain gage bridge output is in the form of voltage variations, its indication is accomplished easily by an osciloscope. However permanent recording of the indicated quantity from the osciloscope requires photographic means. In general, most satisfactory cathod-ray tube for photographic work is one having a medium or short persistant lightin actinic light output.

For the recording of moderate frequencies the Polaroid Land camera can be employed satisfactorily.

A shutterless motion picture camera is another type of recording instrument used in connection with the cathod-ray-osciloscope.

Time coordinate or the horizontal coordinate of the osciloscope can be accomplished by special arrangements such as crank-angle indicator, piston-motion-indicator which are going to be discussed later.

4. INDICATORS AND INDICATOR DIAGRAMS:

Several kinds of indicators have been developed to get the engine indicator cards and pressure variations in the engine cylinder.

The pressure indicators are generally classified into two groups:

1. Single pressure indicators.
2. Cyclical pressure indicators.

Class (1) includes compression, explosion, and mean-pressure measuring devices, which are usually comperatively simple.

Class (2) includes more elaborate apparatus for actually recording the pressures throughout their cycles of changes.

"The requirements of an efficient single pressure indicator are that it must be strongly made, capable of ready attachment to the engine, by the simple expedient of fitting into a sparking-plug or compression tap hole, must be unaffected by the temperature of the cylinder, and uninfluenced by the rapidity of cyclical pressure variations." (5)

I. SINGLE PRESSURE INDICATORS

This class may be grouped into two:

a) Those that make use of cylinder pressure in recording directly.

b) Those that are using the cylinder pressure to operate an auxiliary part of the recording apparatus.

The piston type indicators belong to the former class, whereas balanced disc type, e.g, "Farn boro" indicators comes into the latter class.

Some of the important types of pressure indicators of this class are listed below:

a)The Okill Indicator.

b)Research Type Okill Indicator.

c)Diesel engine pressure Indicator.

d)The (Dobbie-Mc Inner) "Farn Boro" indicators.

e)The N.A.C.A. disc valve pressure indicator.

f)Bureau of Standards Balanced Diaphragm İndicator.

g)Optical balanced pressure indicator.

h)B.P.C (Bataoian Petrolium Company, Holland) indicator.

i)The Bauer Indicator.

Operations and detailed description of these indicators may be found :

See Fig: 5, pp: 226-283 and

Ref: 6.

II. CYCLICAL PRESSURE INDICATORS:

The purpose of these indicators is to give a pressure variation diagram over the whole part of a working cycle; in some instances consecutive cycle diagrams may be recorded.

For the purpose of obtaining mean indicated pressure and indicated horse power, it is necessary to draw pressure-volume diagrams. For observation purposes these diagrams are useful for noting the changes that occur as a result of varying the engine speed, mixture strength, throttle oppening, ignition advence, etc. The displaced or "out-of-phase" pressure diagrams are very useful. In all cases indicators consist of two priïnciple units:

1. Pressure element.

2. A displacement unit.

The pressure element in the test-rig is a resistance type strai gage transducer. Several forms of the displacement unit which gives the piston stroke for the pressure recorded by the former unit are designed in the following pages.

III. CATHODERAY INDICATORS:

Previously described indicators have proved unsatisfactory, with certain exceptions , at high speeds due to the inertia of the moving parts of the indicators.

The cathode ray indicators, on the other hand, are very satisfactory at high engine speeds.

The principle is entirely different and somewhat complicated and may cause errors in the hands of the uninitiated.

The cathode ray indicator consists of three units:

1. The cathode ray osciloscope.
2. The pressure transducer.
3. The time base or piston position unit.

The cathode ray osciloscope may indicate any quantity which is transformed in to voltage. The horizontal and vertical trace may indicate pressure and time or piston position respectively by applying induced voltages from the second and third units.

The primary disadvantage of this system is the high instrumentation cost.

For the visual observations ordinary zinc-silicate coated tubes which give a yellowish-green spot of light where the electronic stream strikes it, are quite satisfactory.

For the photographic purposes, however, another coating material is necessary. "Calcium Tungstate" coated tubes are suitable for this case. This substance flousesces with a deep blue light, having about 30 times the photographic activity of zinc sulfate.

The horizontal trace plates, usually called "Time Base Plates" connected to the time-base unit, crank-angle, or piston displacement indicator, whatever the requirement may be.

The vertical deflection plates, which are usually called "pressure plates" are connected to the pressure trancducer of the engine.

From the specifications of a cathode ray tube to the order of magnitude of the induced voltages may be calculated. For a specific example is given below:

Filoment current . . . 0.7 - 1.1 amps.

Filoment voltage . . . 0.4 - 1.0 volts.

Anode voltage . . . . 300 - 3,000 volts.

Cathode to anode current 10 - 200 microamps.

Shied voltage . . . . oto (-200), relative to flament.

Screen deflection . . 0.75 mm. per volt across plates.

The pressure element may be one of the following types:

1. Capacity type.
2. Resistance type, strain gages.
3. Inductance type.

Another Classification may be as follows:

1. The moving iron or magnetophone.
2. Resistance Method.
3. Capacitance.
4. Piezo Electric system.

All of the methods have certain advantages and disadvantages. The variable compression unit in our laboratory is equipped with a resistance transducer, which is capable of detecting vibrations of

50,000 cps.

One of the inseperable units of most of the indicators is the amplifier, which may be required to have an amplification of as high as 1,000 times, depending upon the method used. For example, strain gage pressure pick-ups require an amplification in the order of 1,000 times.

Typical Cathode ray indicators include the Standard Sunbury Indicator, The Cassor Indicators. The Dodds Indicators and Photoelectric Cell indicators. For further information see: Ref:5 pp:284-313.

APPLICATIONS OF CATHODERAY INDICATORS:

The Cathode ray indicators may be used, with suitable pick-up units and accessories, for the following purposes:

1. Pressure-time, pressure-crank angle diagrams.
2. Pressure-volume diagrams.
3. Cylinder rate of pressure diagrams.
4. Weak spring diagrams of the suction and exhaust pressures.
5. Weak spring diagrams of inlet pipe pressures.
6. Exhaust pipe pressure diagrams.
7. Compression-ignition fuel injection pressures and rates of pressure diagrams.
8. Fuel injection value lift diagrams.
9. Engine vibration movements on a time base.
10. Cylinder strain diagrams.

SOURCES OF ERROR IN CATHODERAY INDICATORS:

The sources of error in cathode ray osciloscope indicators may be listed as:

1. Inertia effects.
2. Indicator passage effects.
3. Low resonance frequency.
4. Temperature effects.
5. Hysterisis.
6. Electrical errors.

Inertia effects are negligible, indicator passage, if it is longer may distort the indicator diagram, the calibration of the pressure element may change due to temperature, high natural frequency pressure elements are desirable, hysterisis of the deflecting part may cause error, electrical errors are related the circuit of the indicator and can be minimized in the hands of one expert.

IV. INDICATOR DIAGRAMS:

To draw an indicator diagram based on the piston displacement it is necessary to provide means to represent the piston motion in the cylinder. A crank-arm mechanism or a cam may be designed, if we know the crank-arm to connecting-rod ratio, to provide this mechanism.

The phase of this mechanism related to the actual piston motion has a certain effect on the indicator diagram. If the phase of the indicator is in advance of that of the engine then the indicator diagram is enlarged. However if the indicator is behind of that of the engine, the indicator diagram will be smaller.

To adjust the two phases, the spark is retarded and indicator diagrams are taken while adjusting the phase. If the indicator becomes in phase with the engine then the last part of the compression line returns upon itself.
See Fig: 22.

When the indicator diagrams are drawn upon a time or crank-angle base, it is necessary to convert them to piston-motion basis as explained before.

Another method to convert the crank-angle base diagram to piston motion diagram is as follows:

1. Take the crank-angle diagram and draw vertical lines corresponding certain crank-angles. Mark off the intersection points with the curve.
2. Take the length of this diagram and draw this length on a piece of tracing paper and call it 2R.
3. Calculate L= 2.78R (Since crank radius / connecting rod $= 0.378 = \frac{R}{L}$ or,
   $L = \frac{R}{0.378} = 2.78$. This is measured on the engine.
   See Fig: 23
4. Draw $\overline{AO} = L + R = 3.78R$.
5. Draw a circle, center at 0, with a radius R.
6. Divide the circle into angles corresponding to those ones on the indicator diagram.
7. Open the dividers L = 2.78 and mark-off points 1, 2, 3 etc. on the horizantal axis, between A and B.

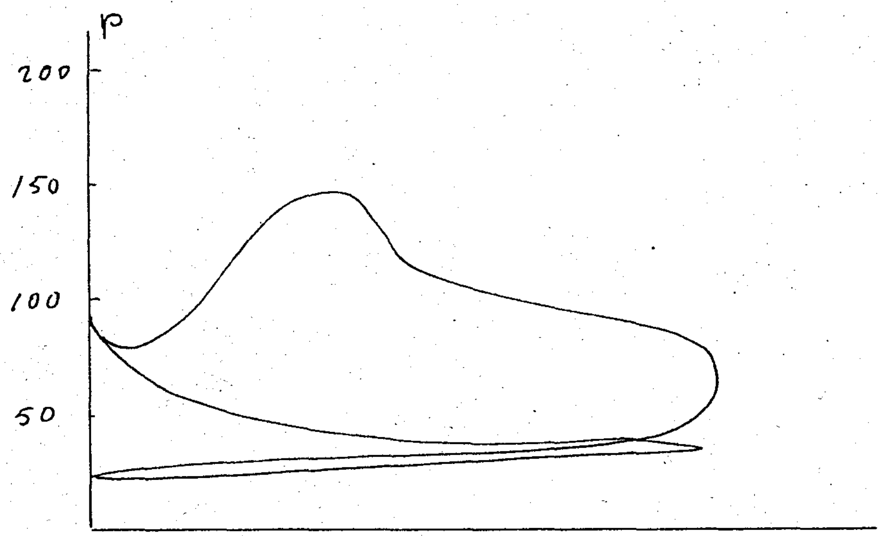


Fig: 22. a

Phase Correction by ignition delay.

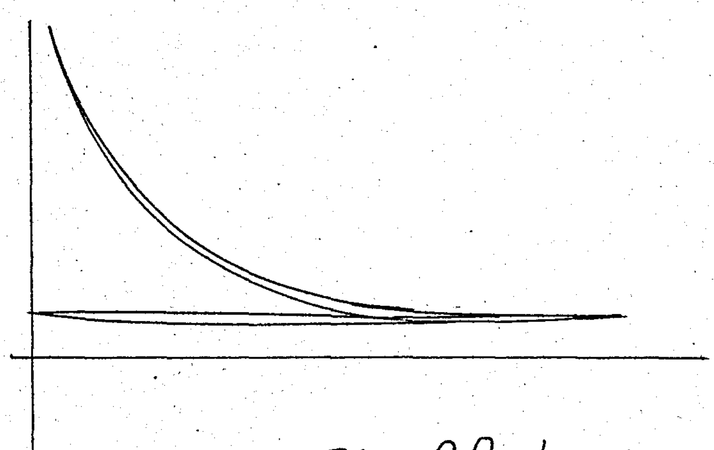


Fig: 22 b.

phase correction by ignition switch-off.

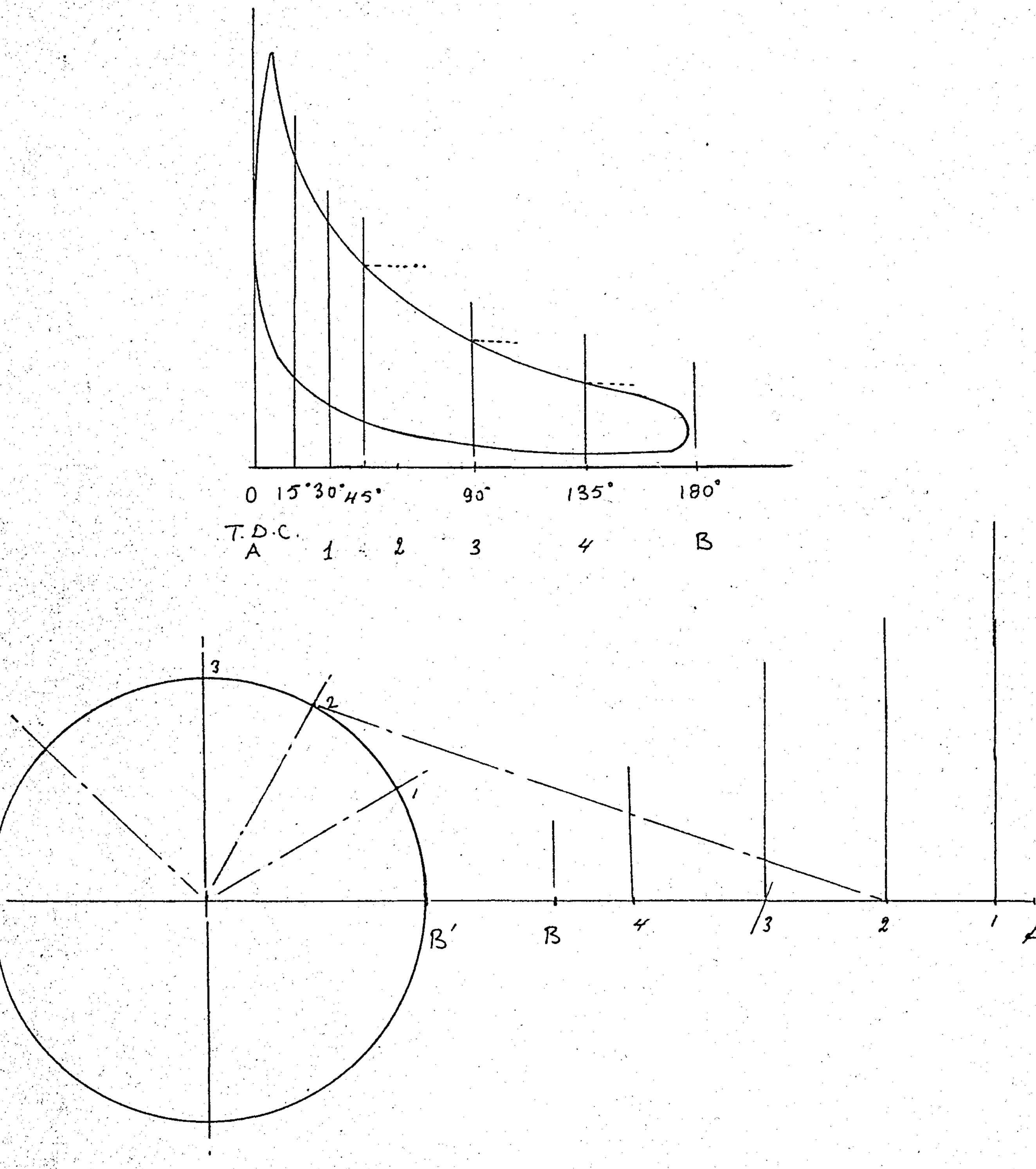


Fig: 23

Conversion of crank-angle indicator diagram.

8. Draw vertical lines through the points 1, 2, 3 atc.
9. Place this tracing paper on the crank-angle base indicator diagram.
10. Draw horizontal lines through intersection point of step (1), to get ordinates on the tracing paper corresponding to respective angles.
11. Draw a smooth curve through these newly found points to get the indicator diagram on piston motion-base, that is P -V diagram.
12. Take a plainimeter and measure the indicator area to calculate the values such as ihp, imep, indicated efficiency etc.

V. APPLICATION OF INDICATOR DIAGRAMS:

"provided it is satisfactorily designed, adjusted and operated, the indicator is a most valuable asset for research and ordinary test purposes." (5)

Indicator is fundamentally a pressure recording instrument, thus, it can be applied to cyclical pressure variation.

In internal combustion engines the pressure variations in the cylinder, in the inlet pipe, exhaust pipe, and in the crank-case, can all be determined.

<u>Displaced Diagrams:</u>

To study the pressure variations during explosion, the most rapidly changing pressure, we use displaced diagrams. In ordinary indicator diagrams the explosion takes place at top dead center where the piston is almost statiinary and the pressure curve has the steep-pest slope. However, if the explosion point is transfered to a point where the piston moves fastest the slope of the pressure curve is reduced and the diagram is spread at this point, so that the pressure varitions during explosion is readily studuied. See Fig: 24.

Measurement of Indicator Diagrams:

The net area of the indicator diagram is proportional to the work done per cycle of the engine, that is, to the indicated hose-power of the engine.

Thus: $$I.M.E.P = M \times \frac{\text{Indicator area } in^2}{\text{Length of Stroke, in.}}$$

Where M = Pressure scale,

$$\left(1 \text{ in.(ordinate)} = \frac{lb}{in^2}\right)$$

Indicator areas are usually measured by plainementers.

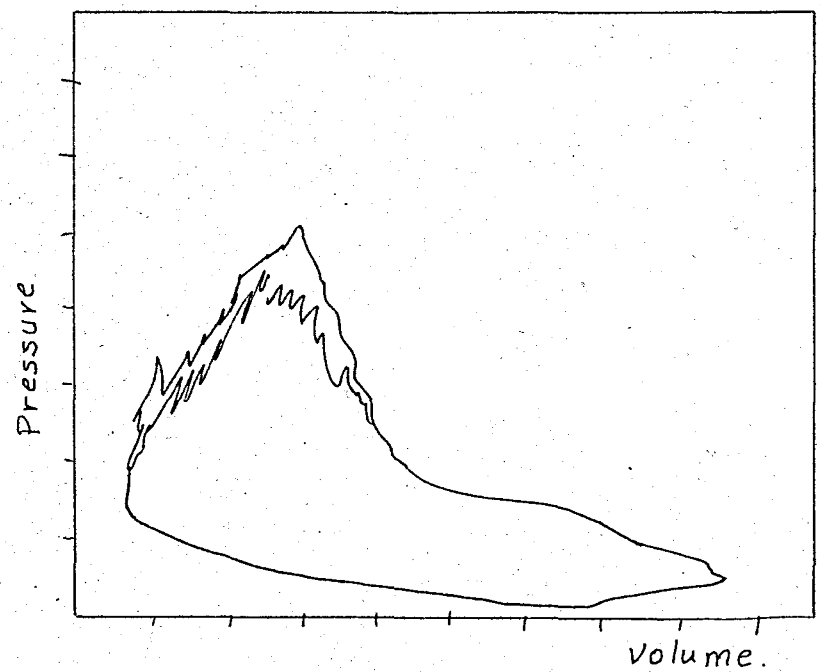


Fig: 24.
Displaced diagram.

5. DESIGN OF A DRUM-TYPE CRANK-ANGLE INDICATOR:

"For the visual observation or records of rapid pressure changes, namely, during the actual combustion period, pressure diagrams on a crank-angle (or time-base) are much better than those on piston-stroke base, although displaced or "out-of-phase" pressure diagrams in the latter case are very useful." (5)

The crank-angle diagrams can be converted into a pressure volume diagrams using a transparent scale, graduated in degrees, and corresponding to the connecting rod/crank radius ratio of the engine under consideration. These are tables calculated for various connecting-rod / crank radius ratios and crank degrees. However there is a simple relation between piston mation and crank-angle:

Referring to Fig: 18,

$$= R + L \; (\overline{OC} + \overline{CA})$$

$$= R + L - R\cos\theta - L\cos\varphi \quad (1)$$

Where (L) and (R) are connecting rod length and crank-radius respectively.

Also $L^2 = \overline{BC}^2 + \overline{CA}^2$

$$= R^2 \sin^2\theta + L^2 \cos\varphi$$

Or $= (L^2 - R^2 \sin^2\theta)^{\frac{1}{2}}$

Therefore (1) becomes: $x = R\left[1 - \cos\theta + \frac{1}{R}\left(1 - \sqrt{L^2 - R^2\sin^2\theta}\right)\right]$

Where x = Piston displacement measured from T.D.C.

θ = Crank-angle $= \omega t$

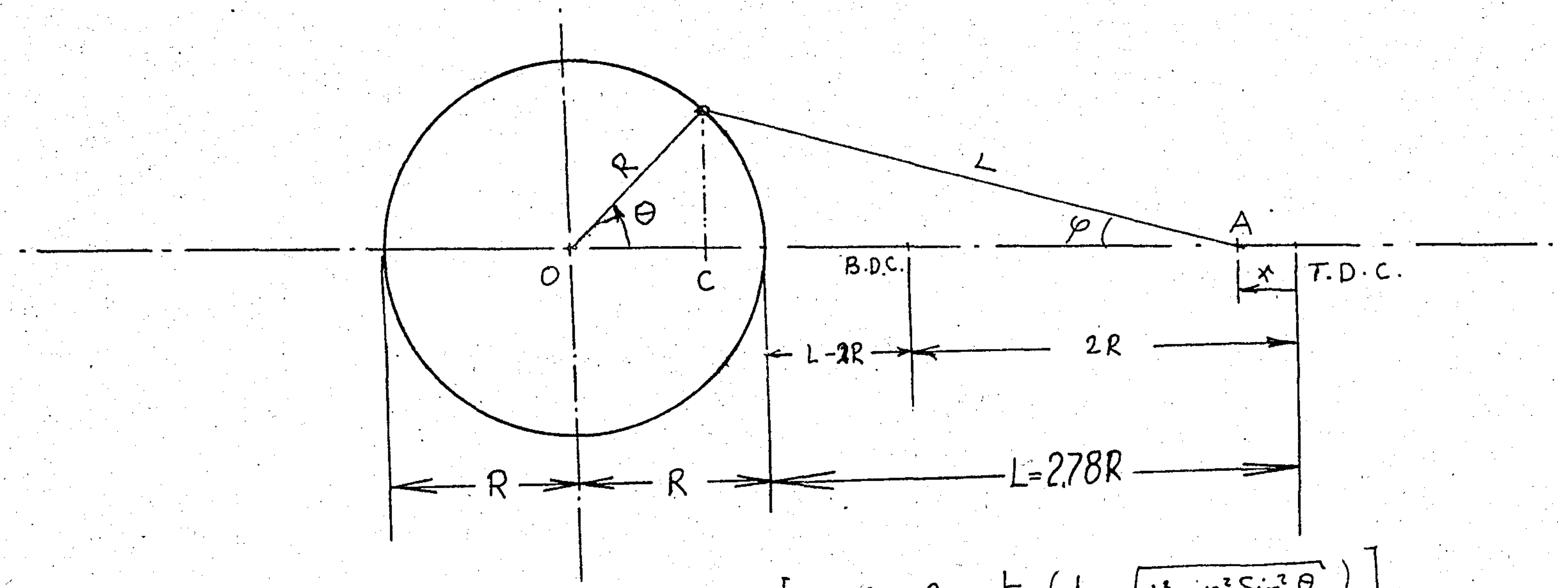
Where: $\omega = \frac{\pi}{30}(RPM)$ t = time, seconds

Expanding the expression under the square-root by the Binomial Theorem and neglecting terms containing second or higher powers of the ratio $\left(\frac{r}{1}\right)$, we obtain a good approximation formula:

$$\frac{R}{L} = \lambda = 0{,}58$$

$$R = 0{,}358L$$

$$L = 2.78R$$



$$x = R\left[1 - \cos\theta + \frac{L}{R}\left(1 - \sqrt{L^2 - r^2 \sin^2\theta}\right)\right]$$

$$\bar{x} \cong R\left[1 - \cos\theta + \frac{R}{2L}\sin^2\theta\right]$$

Fig: 18

Relation of piston to crank angle.

Therefore it is possible to modify the abcissa of the indicator diagram drawn on crank-angle base, by calculating (x) values for each angle so as to derive pressure-volume indicator diagram from the former.

There are two types of pressure - (crank-angle) or pressure-time base indicator diagrams:

1. Building up pressure diagrams.
   Such as in Fig: 19
2. Closed cycle diagrams such as in Fig: 20.

These can be based on crank-angle, or time, and can be converted to pressur cylinder displacement diagrams by the method explained above. The latter diagrams are usually used to calculate the indicated horse power, indicated mean effective pressure, indicated specific fuel consumption, indicated engine efficiency, etc. which make use of the indicated work done by the engine which is proportional to the area of indicator diagram.

Although crank-angle (or time base) diagrams are usually employed for visual observation of the pressure variations due to various factors, these can be converted to pressure-volume diagrams to calculate the indicated quantities as explained above. For quantitative results calibration of the indicator diagram is necessary. The calibration procedure will be explained later. This method has the disadvantages of involving too many conversions which are all sources of error. Despite of this drawback, the apparatus is simple and inexpensive, easily adoptable for various purposes and, under careful conversions, quite reliable.

A simple crank-angle indicator may be designed as follows:

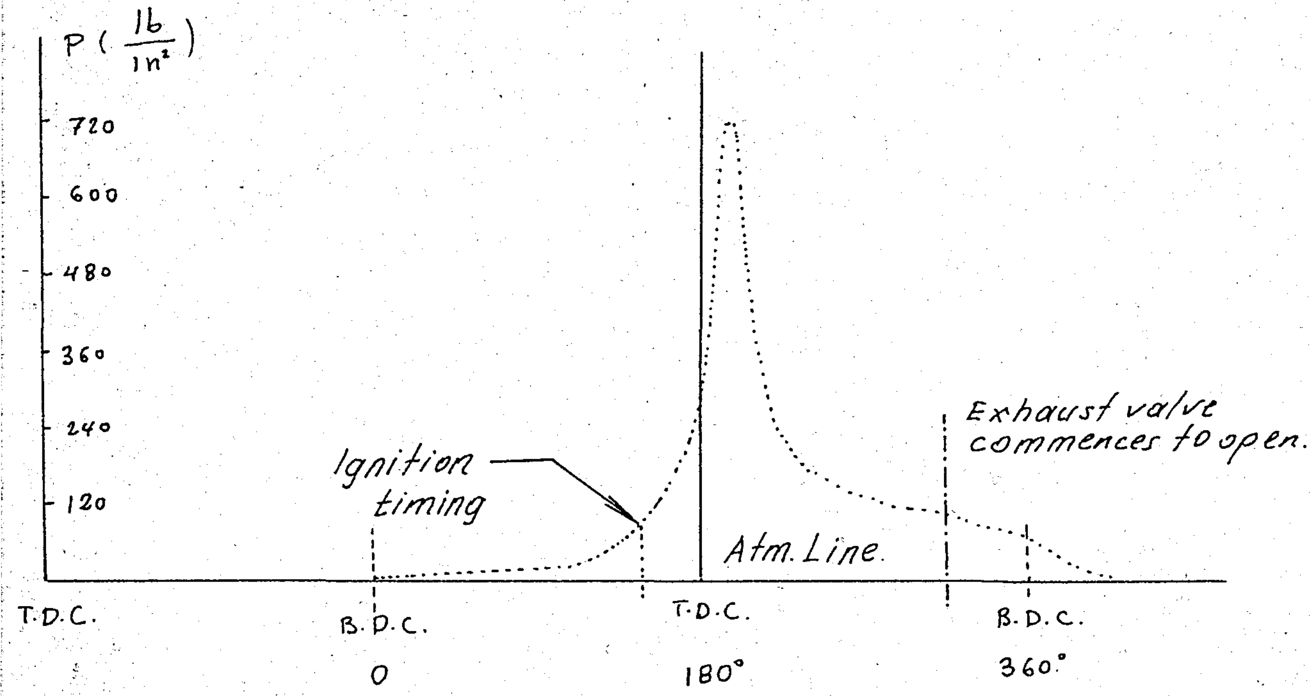


Fig : 19

Pressure build-up diagram on crank-angle-base.

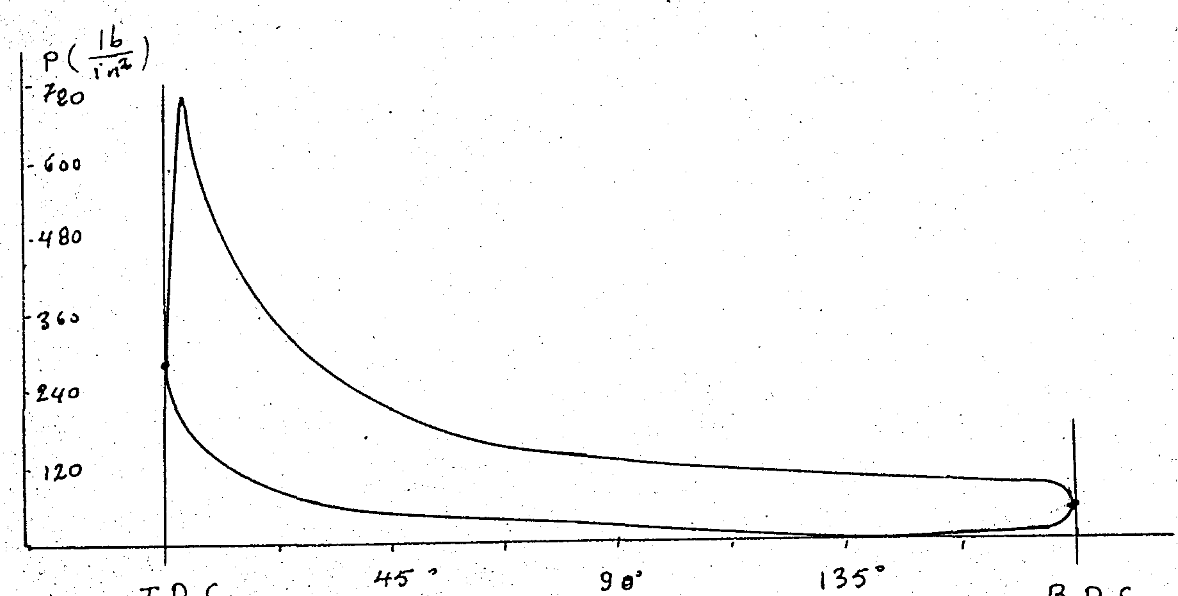


Fig : 20 a.

Closed Cycle indicator diagram, crank-angle base.

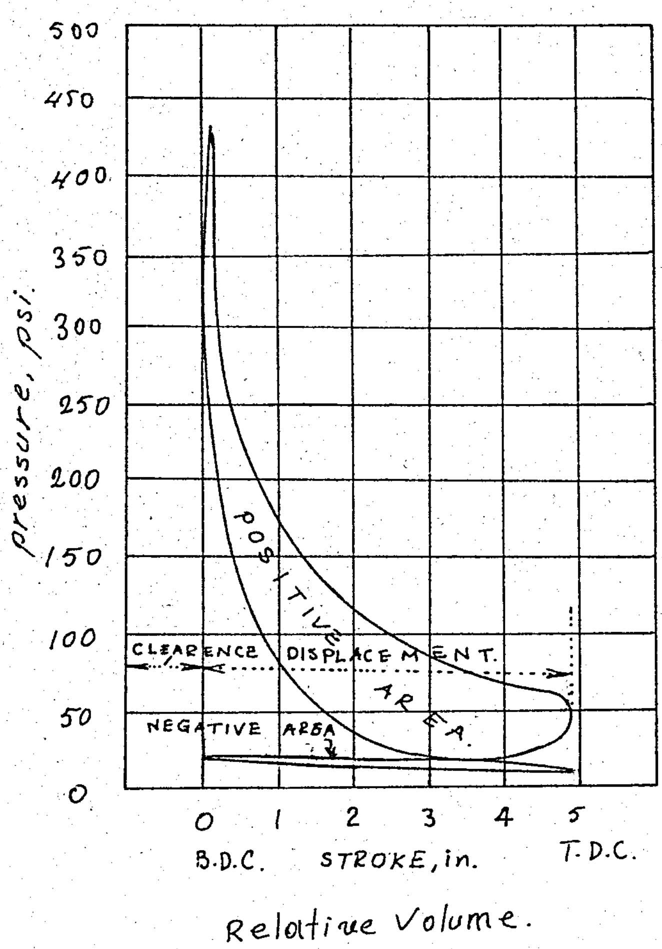


Fig: 20 b.

Indicator Card.

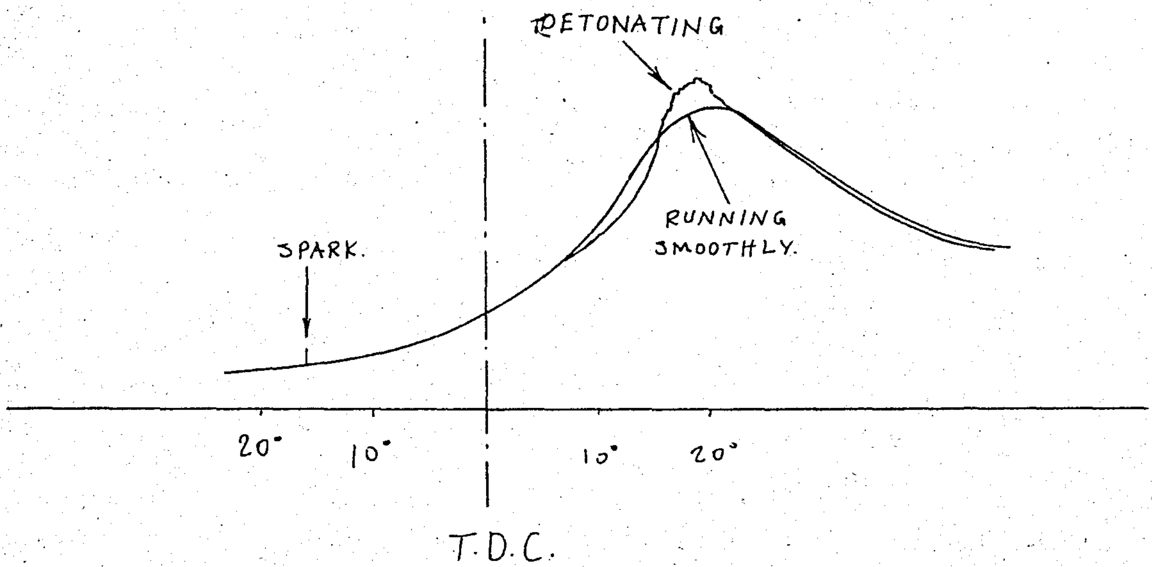


Fig: 21 a.

Spark-Ignition Engine Diagrams

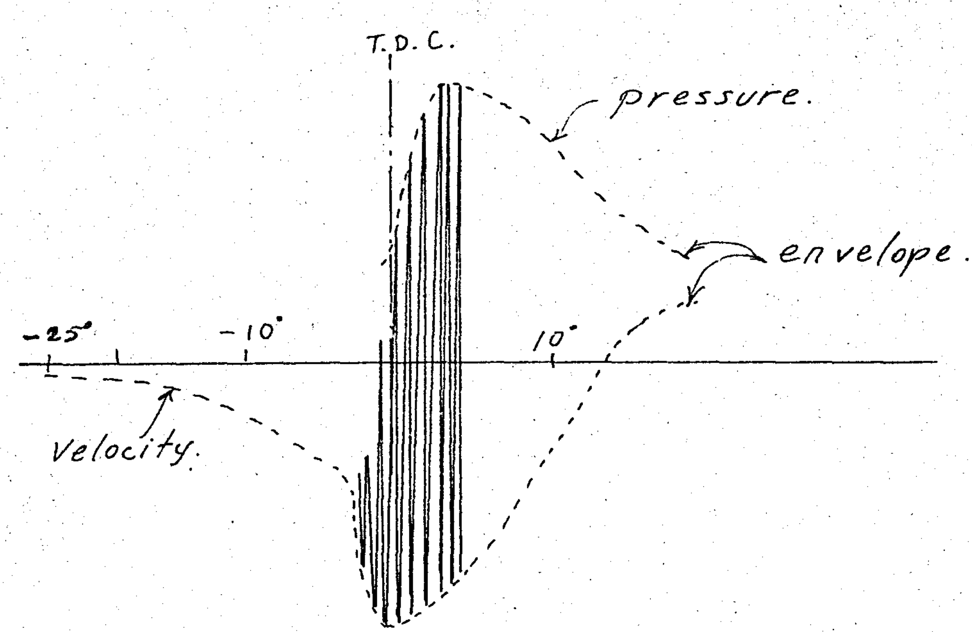


Fig: 21 b.

Detonation Waves.

Take a cylindrical plastic drum of 6-8 cm. diameters as shown in Fig: 25. Drill two small holes at the two ends of a diameter line. Place a piece of 1 mm-diameter silver wire in each hole as shown in the figure. Make a wooden hallow shaft of given dimensions and stick it to back of the drum. Cut a n aluminum or copper tube of 1 in diameter in to two rings of 1 cm. width and slip them into place as shown. Connect each of these rings to one of the wires placed diametrically. Seal the holes with a Duco cement. Take (10) grams of tap water, disolve 2 grams of K_2CO_3 in it and put the solution into the drum up to the level mark predetermined as calculated in the figure. Mount the assembly on to the sleeve shaft. Mount the brush holder and the needle shown in Fig: 26. Interconnect one of the brushes and the needle. Connect a 60 volt battery across the remaining brush and the needle; the negative pole being connected to the needle. Turn the engine and bring the indication into phase as explained before, by turning the needle relative to the drum. The indicator diagram should look like Fig. 22 a, while the ignition is fully retarded Adjust the ignition advance and obtain the correct indication diagram.

The physical principles can be explained as follows:

The water in the drum, due to friction and centrifugal force will split around the periphery of the drum making a layer of uniform thickness, which is stationary after a while, with respect tot he container. Therefore its resistance is constant throughout. By the ordinary potentiometer theory the voltage difference between the needle and the positive pole is proportional to the length of the water layer between the two. But the length of the water layer is $= R\theta$. Since R is constant the voltage difference is directly proportional to the angle θ, which is the crank angle. By turning the drum at the same speed as the crank-shaft of the engine

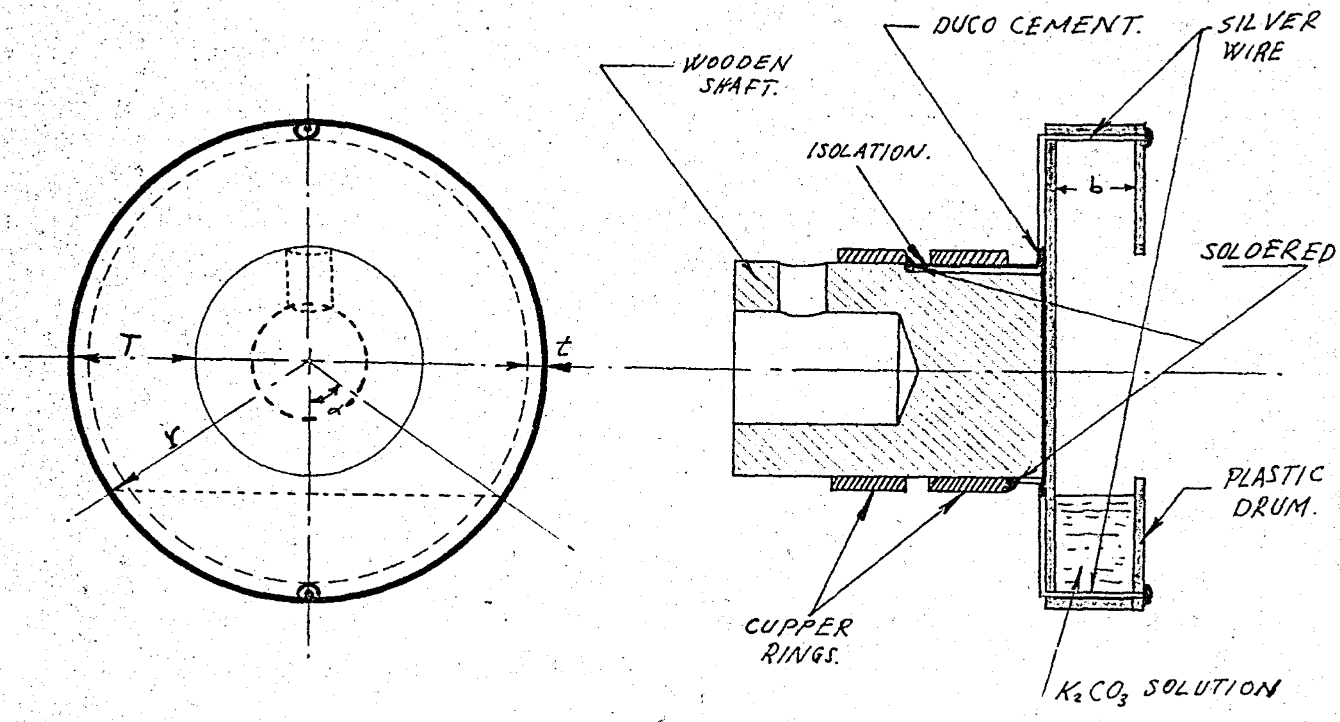


Fig: 25 DRUM.

$$V_1 = r^2\alpha b - 2\cdot\frac{r\cos\alpha\cdot r\sin\alpha}{2}\cdot b = r^2 b(\alpha - \sin\alpha\cos\alpha)$$

$$V_2 = b\pi\left[(r^2)-(r-t)^2\right] = \pi r^2\left[\left(\frac{2t}{r}\right)-\left(\frac{t}{r}\right)^2\right]b$$

$$V_1 = V_2$$

$$\therefore \quad \left(\alpha - \frac{1}{2}\sin 2\alpha\right) = \pi\left(\frac{2t}{r} - \frac{t^2}{r^2}\right)$$

By trial:

$\alpha \leq 52.6^\circ \cong 50^\circ$. $\quad \therefore \alpha = 50^\circ$

$t = 2$ mm. $\quad \frac{t}{r} = \frac{1}{15}$.

$r = 30$ mm. $\quad \frac{T}{r} = \frac{1}{2}$

$\frac{T}{r} = \frac{15}{30} = \frac{1}{2}$. $\quad \frac{T_{min}}{r} = \frac{11}{30}$.

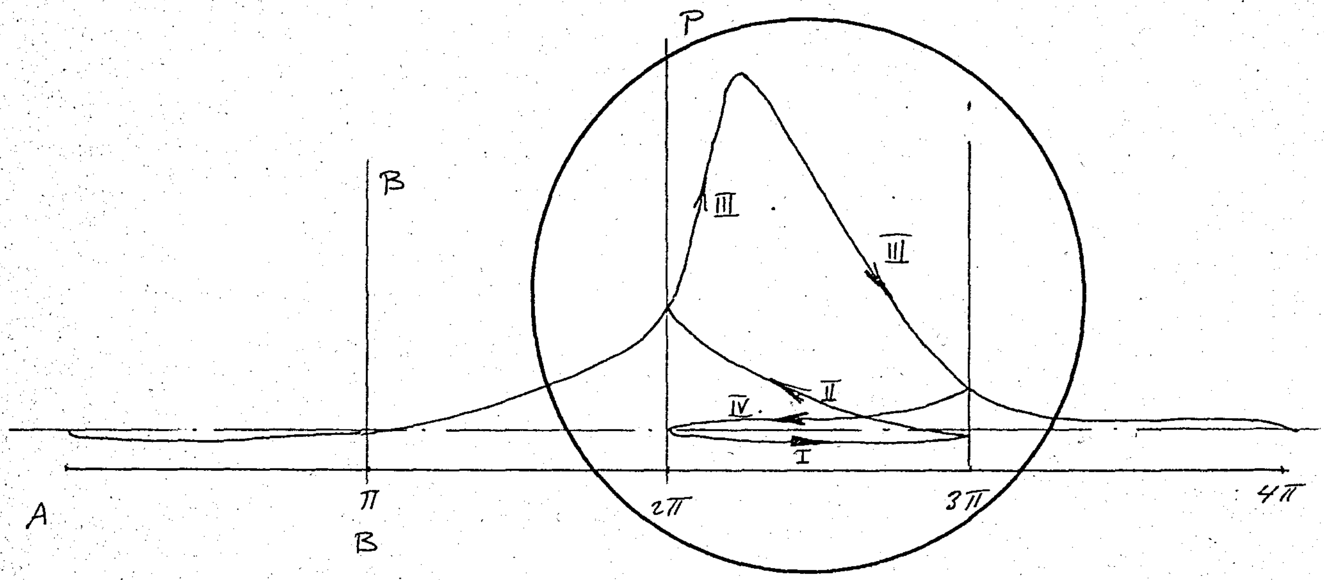


Fig: 26. INDICATOR DIAGRAM BASED ON CRANK ANGLE.

This is the type of the diagram as seen on the osciloscope.

we can obtain a direct relation between the crank-angle and voltage difference between the needle and the positive pole.

Referring to Fig: 26, we see that if the voltage varied from zero to its maximum value while the crank turns 720°, so that one cycle is complete, then the pressure diagram would look like a pressure-build-up diagram. However, since the indicator turns with the same speed as that of the engine, the situation is different.

Assume that the positive pole is just in front of the needle, then the voltage difference between the two is minimum, since the resistance between them is minimum. Now the container turns and the positive pole goes away from the needle making the voltage difference between the two greater and greater. When the drum turns 180°, the voltage difference becomes maximum and the engine completes 1/4 of its cycle. If the indicator is in phase then the first part of the pressure curve is drawn on the osciloscope.

The indicator continues to turn so that the voltage difference starts decreasing which causes the horizontal trace to move backwards so that the second quarter of the pressure-build-up diagram is drawn which is symmetrical around the line B-B. In the third quarter revolution of the indicator, horizontal trace of the osciloscope travels forward and third part of the curve is drawn. In the fourth and the last quarter revolution of the indicator, the cycle is completed while the trace moving backwards.

Therefore we have obtained a close-cyclic indicator diagram of the engine drawn on crank-angle base. This diagram may be converted to p-v diagram as explained before.

ADVANTAGES OF THIS SYSTEM:

1. As it may be seen, the construction is very simple and cheap. There is no amplifier, no rectifier, no filter in the circuit.
2. Displaced diagrams can be obtained very easily by simply turning the needle wrt the indicator drum.
3. Putting the silver wires close to each other, detailed study of the pressure variation of a part of the cycle is possible.
4. The material and the procedure is simpler.

6. DESIGN OF A PISTON-DISPLACEMENT INDICATOR:

In the previous section we have discussed a crank-angle indicator, which has many applications. The P-V diagram of an engine, however, can readily be obtained by a relatively simple instrument. The conversion of crank-angle base diagrams to P-V diagrams have been discussed. The conversion process is not practical for quick calculation of (imep) or other engine characteristics. The piston displacement indicator, on the other hand is a very convenient instrument for this purpose.

I. CAM DESIGN AND CALCULATIONS FOR THE INDICATOR:

Referring to Fig: 27, we want to design such a cam that when it turns around the point O, its intersection with the horizontal axis A, will simulate the piston motion in the cylinder. Its geometric construction is simple; we divide the periphery of the circle into small arcs corresponding to small crank-angle θ. We mark off the points 1, 2, 3, et. on the horizontal axis corresponding to the respective crank-angles. Drawing circles through these points we intersect the radial lines through the center O. The points thus found will naturally cut the horizontal axis at the proper place where the piston would be if it turned through the angle with which the radial line is drawn.

Drawing a smooth curve through the points found as such, we generate the profile of the required cam. The smooth curve in this case turned out to be a circle with radius L and, center at a distance R from the crank circle.

The mathematical proof of this statement is easy:

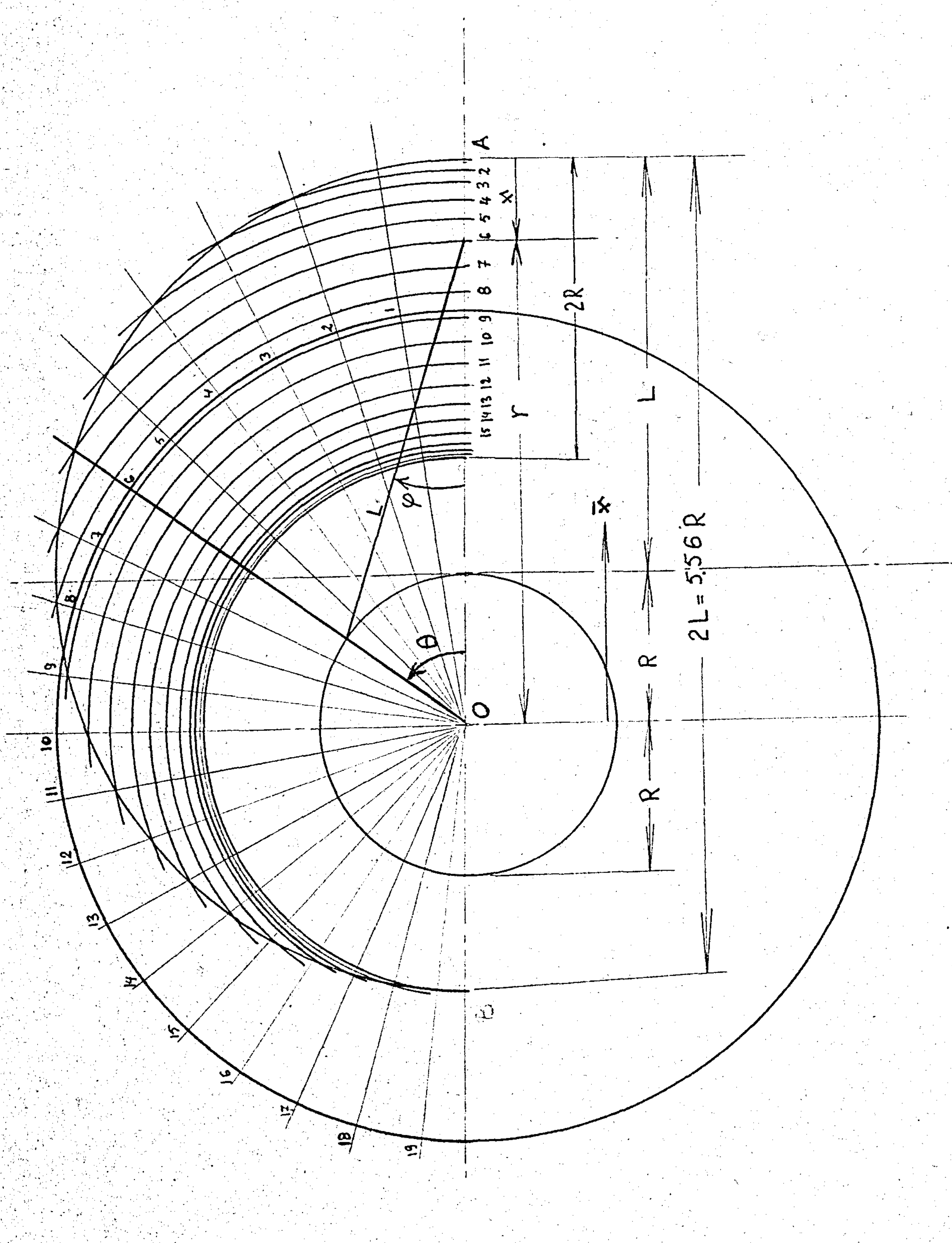


Fig: 27 ; CAM DESIGN

Let r = the distance between the center and the point where the cylinder is.

Referring to Fig: 27:

$$r = R \cos\theta + L \cos\varphi \qquad (1)$$

By the cosine law:

$$R^2 = L^2 \quad r^2 - 2Lr \cos \qquad (2)$$

Or $\cos\theta = \frac{R^2 - L^2 - r^2}{2r}$

Substituting the last expression into (1), we obtain:

$$r^2 = L^2 - R^2 + 2Rr \cos \qquad (3)$$

hich is a circle in polar coordinates. Transferring, this into Cartezien Coordin-tes:

$$u^2 + v^2 = L^2 - R^2 + 2ru$$

Or

$$(u - R)^2 + v^2 = L^2 \qquad (4)$$

here (u) and (v) are coordinates of the point on the required profile of the cam, and neasured from the point O.

Therefore the required profile is a circle with a radius (L) and center at = R.

Since $= \frac{R}{L} = 0.358$ for this engine;

$$L = 2.78R.$$

Cam diameter = 5.56R.

Where R being the radius of a reference circle, representing the crank ra-ius and may have any value according to the requirements.

Therefore, (x), the displacement of the cylinder may be calculated as:

$$x = (R+L) - r = R + L - R\left[\cos\theta + \frac{1}{\lambda}\sqrt{1 - \lambda^2 \sin^2\theta}\right]$$

$$x = L + R\left(1 - \cos\theta - \frac{1}{\lambda}\sqrt{1 - \lambda^2 \sin^2\theta}\right) \qquad (4)$$

Or approximately:

$$x = R\left(1 - \cos\theta - \frac{1}{2\lambda}\sin^2\theta\right) \qquad (5)$$

It is desirable for design purposes to calculate r_{max} and (r_{min}).

Where r_{max} = the distance between the center of rotation and the farthest point of the cam to this point. Whereas r_{min} = the minimum distance between the center of rotation and the nearest point.

From equation (3):

$$r = R\cos\theta + R\sqrt{\frac{L^2}{R^2} - (1 - \cos^2\theta)}$$

Or

$$r = R\left[\cos\theta + \frac{1}{\lambda}\sqrt{1 - \lambda^2\sin^2\theta}\right]$$

$$r_{max} = r_{\theta=0} = R\left[\frac{1}{\lambda} + 1\right] = 3.78\,R.$$

$$r_{min} = r_{\theta=\pi} = R\left[1 - \frac{1}{\lambda}\right] = 1.78\,R.$$

Knowing the profile of the cam we can make use of it in various ways.

As it is stated before R can have any value as long as:

$L = 2.78\,R.$ is a reasonable number.

II. CANTILEVER-TYPE DISPLACEMENT INDICATOR:

The displacement of a piston may be expressed most conventionally by the deflection of a cantilever beam. Since the strains produced by small deflections are proportional to the deflections we can design a cantilever beam subjected to deflections which are produced by a cam whose profile is so designed that it simulates the piston motion.

Referring to Fig: 28, the maximum deflection at the end of a cantilever is given by:

$$y_{max} = \frac{PL^3}{3EI} \qquad (1)$$

Where (P) is the applied load.

This equation is derived from:

$$\frac{\frac{d^2y}{dx^2}}{\left[\left(\frac{dy}{dx}\right)^2 + 1\right]^{3/2}} = \frac{M}{EI} \qquad (2)$$

which is the exact differential equation of the elastic curve, under the assumption that the strains in the fibers are linearly proportional to the distance of the fiber from the neutral axis. Thus, maximum strains are produced in the outermost fibers of a rectangular cross-section beam.

Equation (2) is simplified by assuming that the deflection of the beam is small so that:

$$\frac{dy}{dx} \ll 1 \qquad (3)$$

so that it is negligible, compared with unity. From the strength of materials, it is known that

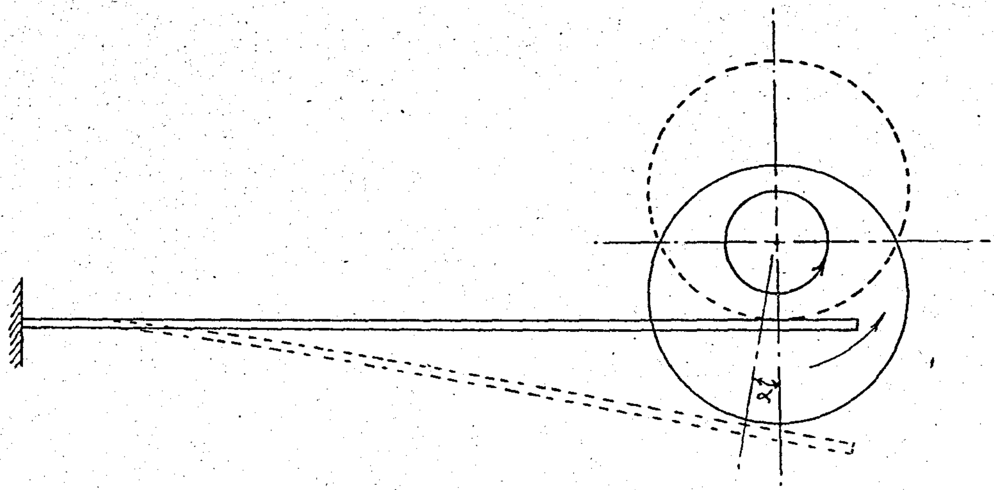


Fig: 28 a. CANTILEVER TYPE PISTON MOTION INDICATOR.

As it is seen, this system causes a phase difference α, which distorts the indicator diagram.

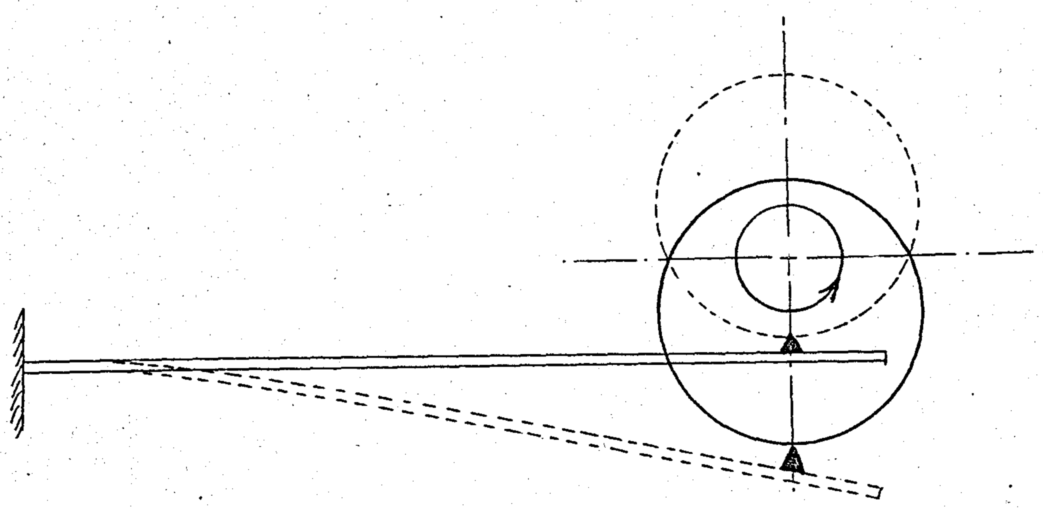


Fig: 28 b. CORRECTION OF THE ERROR.

$$\left.\frac{dy}{dx}\right]_{x_1} = \theta \Big]_{x_1} = \text{Slope of the elastic curve at } x_1. \quad (4)$$

Therefore $\theta \ll 1$ (5)

is the requirement for correct application of the equation (2) in the form of:

$$\frac{d^2y}{dx^2} = \frac{M}{EI} \quad (6)$$

which is the basis for equation (1), above.

We also notice that

$$\frac{dy}{dx} = \tan\theta \quad (7)$$

From (4) and (7)

$$\tan\theta = \theta \quad (8)$$

Therefore it is reasonable to assume that

$$\frac{d^2y}{dx^2} = \frac{M}{EI}$$ is correct as long as $\tan\theta = \theta$.

From mathematical tables:

$$\tan(0.3 \text{ rad}) \cong (0.3 \text{ rad}). \quad (9)$$

That is 0.3rad = 17.2° is the maximum allowable deflection slope of the end of the cantilever beam.

The strains of the beam is measured or deflected most easily by a strain gage. It is common practice to restrict the stresses in the member to obtain correct reading by a strain gage. This restriction is:

$$\sigma_{max} = 0.30\,\sigma_y. \quad (10)$$

where σ_y is the yield strength of the material. This equation may be written in terms of strains as:

$$E_{max} = \frac{0.30\,\sigma_y}{E} \quad (11)$$

Upon these restrictions we can calculate the dimensions of the beam and the

From Fig: 28,

$$M = PL \tag{12}$$

at the end of the beam.

From eq. (1):

$$P = \frac{3(EI)\, y_{max}}{L^3} \tag{13}$$

and from flexural formula:

$$\sigma = \frac{M_c}{I} = \frac{M\frac{h}{2}}{I} \tag{14}$$

or

$$\sigma = \frac{M h}{2(EI)} = \frac{PLh}{2(EI)} \tag{15}$$

From (13) and (15)

$$\mathcal{E}_{max} = \frac{3}{2} \cdot \frac{y_{max}}{L} \cdot \frac{h}{L} \tag{16}$$

By the definition of gage factor:

$$F = \frac{R/R}{\mathcal{E}} \tag{17}$$

$\Delta R = \mathcal{E} FR$, where R = resistance of the gage.

Multiplying by (I allow) through the gage:

$$V_{max} = {}_{max} F V_g \tag{18}$$

where V_g = the voltage accross the gage, having a resistance of (R) ohms.

Therefore from (16) and (18):

$$V_{max} = \frac{3}{2} \circ \frac{y_{max}}{L} \cdot \frac{h}{L} \cdot FV_g \tag{19}$$

Since y_{max} is produced by the cam and can be expressed in terms of the crank angle θ, as:

$$y_{max} = R\left[1 - \cos\theta - \frac{\lambda}{2}\sin^2\theta\right] \qquad (20)$$

the equation (19) becomes:

$$V_{max} = K\,y_{max} \qquad (21)$$

where (K) is a constant including all the symbols in equation (19).

Equation (21) states that the output voltage of the gage is directly proportional to piston displacement.

From the strain gage calculations page ( ), eq.: 2, if the gages are arranged as in Fig: 28:

$$(dEg)_{max} = EF\,\mathcal{E}$$

But $\mathcal{E} = \frac{3}{2} \cdot \frac{y_{max}h}{L^2}$

Therefore $(dEg)_{max} = \frac{3}{2}\,EF(y_{max})\frac{h}{L^2}$

To obtain a minimum bridge output of say $(dEg) = 10^{-4}$ volts, when the applied voltage E = 30 volts, using strain gages with a strain factor F = 2, to defect deflections of $y_{max} = 10^{-2}$ mm $= 10^{-3}$ cm,

$$\frac{h}{L^2} = \frac{2}{3} \cdot \frac{dE_g}{EFy_{max}} = \frac{1}{(3o)^2}$$

Therefore if L = 15 cm. h should be:

$$h \geqslant 2.5 \text{ mm.}$$

But the load on the cam limits the deflection of the cantilever beam:

$$P_{max} = \frac{y_{max}\,3EI}{L^3}$$

For: L = 15 cm.

h = 0.25 cm.

$b = 2$ cm.

$E = 21 \times 10^5$ Kg/cm^2

$I = \frac{bh^3}{12} = 2.6 \times 10^{-3}$ cm^4

$P_{max} = 16.3 y_{max}$

y_{max} can vary from zero to 2R, where 2R is the state of the piston displacement simulator cam. Allowing a 25.0 Kg. force on the cam bearings:

$y_{max} = 2 \times 1.54$ cm.

Therefore $2R = 2 \times 1.54$ cm.

$R = 1.54$ cm.

Diameter of the cam: $L = 2.78 R = 4.30$ cm.

Therefore a cantilever of the following dimensions is appropriate:

Length = 15 cm.

Tickness = 0.25 cm.

Width = 2 cm.

From a material of:

$E = 33$ ksi

And a cam diameter of:

$L = 4.3$ cm.

with an excentricity of:

$R = 1.54$ cm.

See the arrangement in Fig: 29.

We see that if the cam and the cantilever are arranged as in Fig: 29 a, ther is an error as indicated in the figure. To eliminate this error, the arrangement should be as in Fig: 29 (b).

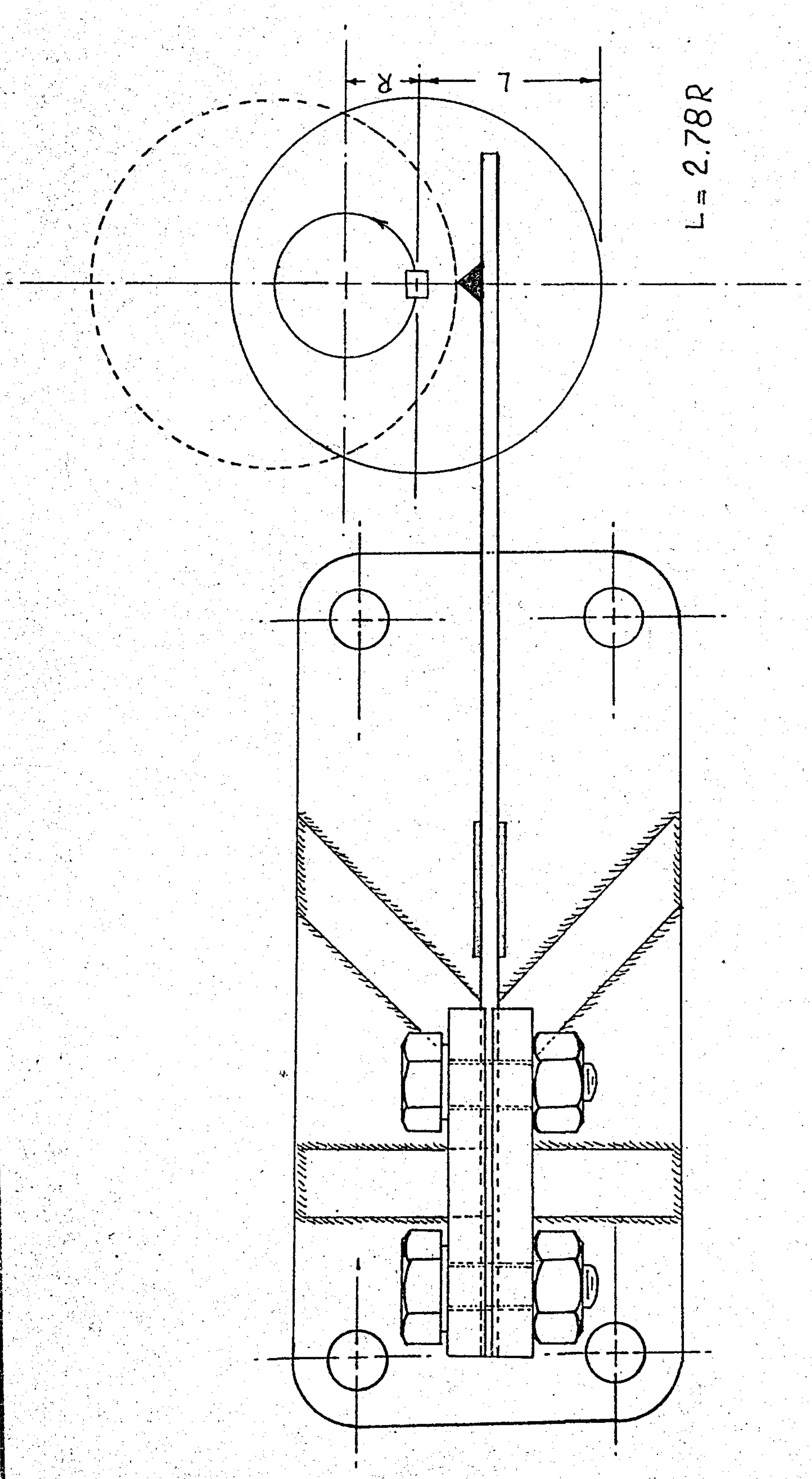


Fig: 29. CANTILEVER AND CAM ASSEMBLY.

The electrical arrangements are similar to that of the pressure transducer. This system may enable us to obtain the P - V indicator cords directly, but it requires and amplifier and wheatstone bridge circuit which add expenses to the highly elaborate cam arrangements making the overall expenses too high for our present purposes.

III. LIQUID-RESISTANCE-TYPE PISTON MOTION SIMULATOR:

In the previous sections we have discussed crank-angle indicator and a cantilever-type piston motion indicator. In this section a similar device to indicate piston motion by making use of the conductance of a liquid will be considered.

Referring to Fig: 30, we see that the voltage difference between the needle ar one of the electrodes is proportional to the distance between them. Therefore if the needle is connected to mechanism which simulates the piston motion in the cylinder we can obtain voltages proportional to the piston displacement. By applying sufficiently high voltages we can stimulate the horizontal beam of the esciloscope so as to indicate the piston motion. Combination of this signal with that of the pressure transducer will result in an indicator diagram. The primary advantage of this system is its high voltage output so that there is no need for an amplifier. However a rectifier circuit is required which is essential for all the other arrangements.

Therefore the cheapest arrangement to get engine indicator directly, is this method; however, it has a vibration isolation problem.

7. THE BRUSH RECORDER:

The brush recorder is a very sensitive recording instrument which can be used to get pressure build-up indicator diagrams on time bases. There are two channels which can be used simultaneously, while one of them recording the pressure variations the other may indicate piston position.

The amplitude of each channel is 40 mm., and the sensitivity of the instrument is 0.01 volts/chart line. Therefore a 0.4-volt potential difference is sufficient to obtain full defflection of the recorder point.

The speed of the recording paper may be set at the following magnitudes:

$V_1 = 1$ mm/second

$V_2 = 5$ mm/second

$V_3 = 25$ mm/second

$V_4 = 125$ mm/second

The length of one complete cycle on the paper for a given RPM can be calculated as follows:

$$\text{No. of cycles/sec.} = \frac{RPM}{60} \cdot \frac{1}{2} \cdot \frac{\text{cycle}}{\text{sec.}}$$

Since the engine is a four stroke-engine and there are two revolutions per cycle:

If Δ_i = The length of one cycle on the paper wrt V_i

$$\therefore \quad \Delta_i = \frac{V_1}{\frac{(RPM)}{120}} = \frac{120\, V_1}{(RPM)} \quad \text{mm/cycle.}$$

$$\Delta_1 = \frac{120}{RPM} \quad \text{mm/cycle}$$

$$\Delta_2 = \frac{600}{RPM}$$

$$\Delta = \frac{3000}{}$$

$$\Delta_4 = \frac{15000}{RPM}$$

For example, if the engine is running at a speed of 600 rpm.

$$\Delta_2 = 1 \text{ mm/cycle}$$

$$\Delta_3 = 5 \text{ mm/cycle}$$

$$\Delta_4 = 25 \text{ mm/cycle.}$$

The maximum length of the cycle corresponding to the maximum engine speed (1800 RPM) and chart speed is:

$$(\Delta_4)_{max} = \frac{15000}{1800} = \frac{25}{3} \text{ mm.}$$

or 1/3 of an inch which is too small for detailed study of pressure variations. Besides the vibration sensitivity of the recorder is not suitable for detonation waves which have quite high frequencies. See Fig: 21. The recorder can be used, however, to analyze the pressure variations qualitatively. Using slower chart speeds it is possible to compare the peak pressures at uniform running conditions. This procedure may indicate how smoothly the engine is running under uniform conditions. If any variation occurs in the cylinder pressure even in a fraction of a second, it is noticible. Thus the cause of abnormal pressure variation may be detected.

At slower engine speeds time-base indicator diagram is quite instructive.

Another application of the recorder is the calculation of engine speed precisely by counting the cycles and measuring the cycle length in a certain period. And

$$RPM = \frac{120\ V_i}{\Delta_i}$$

Where V_i = chart speed

Δ_i = length of a cycle, mm.

8. SUMMARY ON INDICATORS:

The cheapest and most practical way of getting an indicator cord of the engine with a pressure transducer we suggest to use:

I. Brush-recorder arrangement for time-base pressure variations. (See section 7: Brush Recorder.)

II. Drum-type crank-angle indicator for crank-angle base indicator diagrams. (See section 5: Drum-type crank-angle indicator.)

III. Liquid resistance type piston motion simulator. (See section 6.)

. TEST OUTLINES FOR THE VARIABLE COMPRESSION ENGINE:

A. PROCEDURE:

I. Tests with the Brush-Recorder:

1. Set-up of the apparatus and test procedure.

a. Follow the instructions given in the sections "1-IV: Operations Instructions" for preliminary preparation.

b. Connect the transducer to form a Wheatstone Bridge as shown in Fig: 11, where R_1 is the active gage, R_4 is the dummy gage. Connect an oscilator in place of the battery in the figure.

c. Connect the Bridge outputs to an audio frequency amplifier.

d. Connect the emplifier output to a rectifier circuit.

e. Connect the rectifier outputs to the brush recorder.

f. Run the engine, regulate the speed at 900 rpm.

g. Operate the Brush recorder at various speeds and obtain pressure build-up diagrams for about 5 seconds at 125 mm/sec. chart speed.

h. Change the speed and repeat the step (g) at higher and lower speeds.

i) Change the compression ratio from 7.5 to 9.5 then to 13.5 and set the speed at 9000 rpm each time. (See calibration curve for compression ratio setting.) Do not change the setting of the electronic instrument during these procedures.

j) Change the fuel-air ratio and set the speed at 900 each time.

k) Load the engine at a constant speed that is at 900 rpm.

l) Change the ignition timing at constant speed, i.e. at 900 rpm.

2. Calculations:

a. Count the number of cycles for each case and calculate the engine speed. Compare the result with engine speed read by the tachometer.

b. Convert the time scale to crank-angle scale.

c. Convert pressure build-up diagrams to closed cycle diagrams based on crank-angle.

d. Convert the diagrams of step (c) to piston displacement-pressure diagrams.

e. Measure the net area of each diagram by a planimeter.

f. Calculate indicated characteristics of the engine using the indicator areas and calibration of the transducer.

3. Results:

a. Compare the results of step l-g, h, i, j, k, l.

b. Compare the indicated characteristics of each step.

II. Tests with Drum-crank-angle indicator:

a. Fallow instructions given in the section "1-IV: Operations Instructions"

b. Connect the transducer to form a Wheatstone Bridge as shown in Fig. 11, where R_1 is the active gage, R_4 is the dummy gage. Connect an oscilator in place of the battery in the circuit. Adjust at 2000 cps.

c. Connect the drum indicator to a 12 volt D-C battery.

d. Run the engine and follow the instructions given for the Brush-

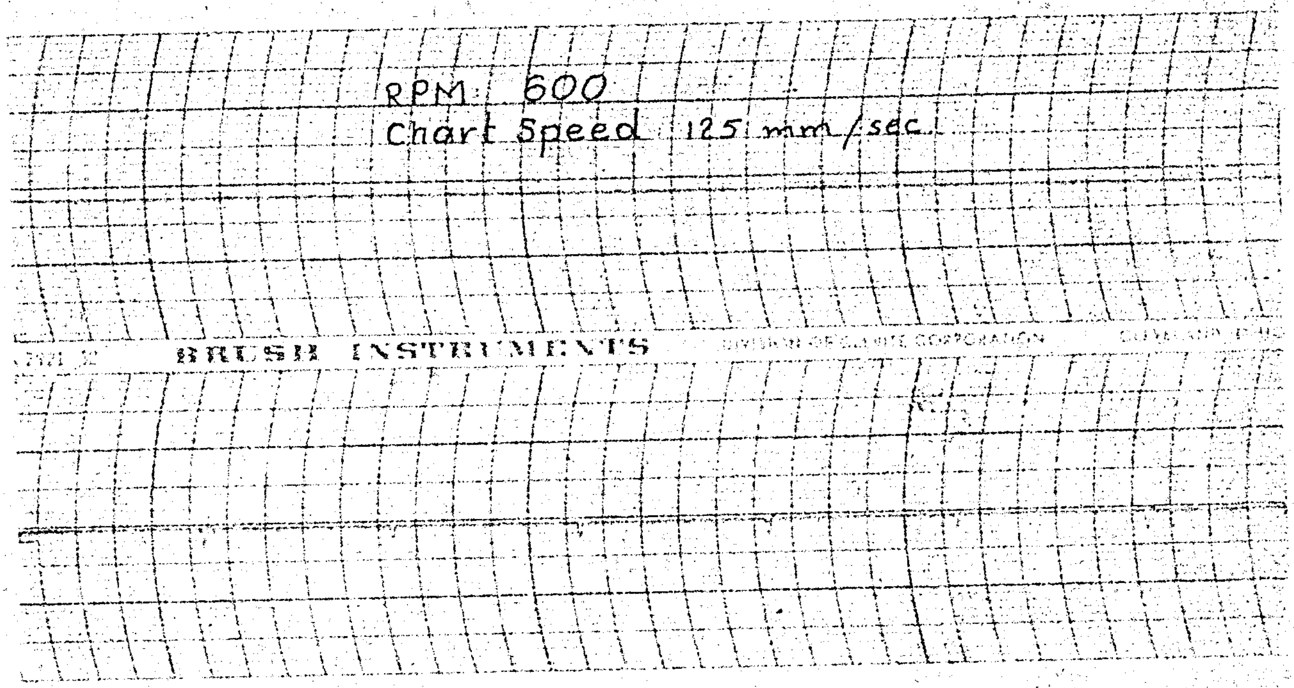


Fig 31-a

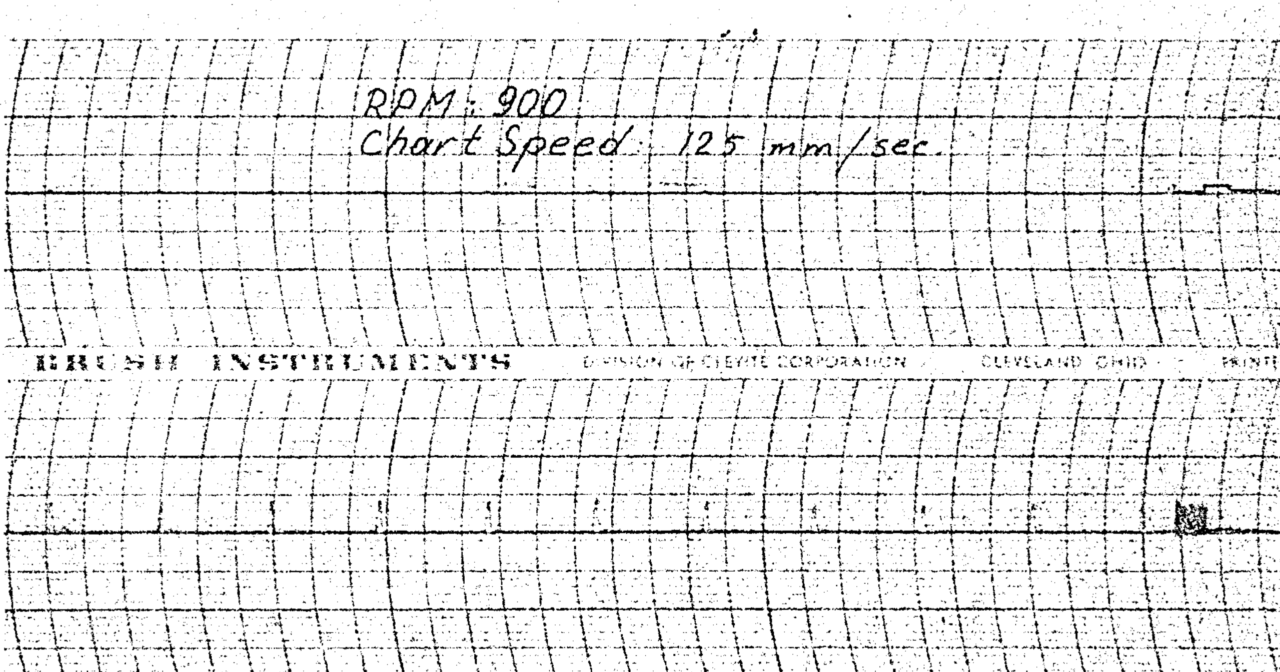


Fig 31-b

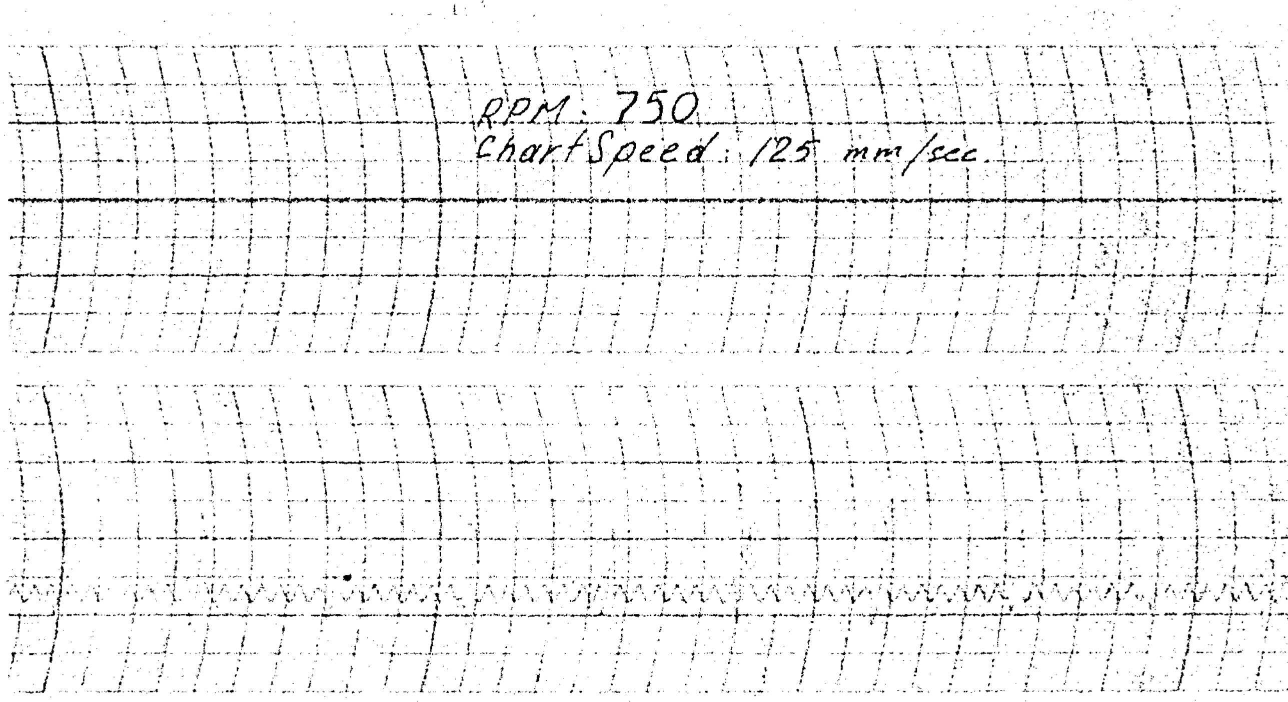


Fig: 31-c

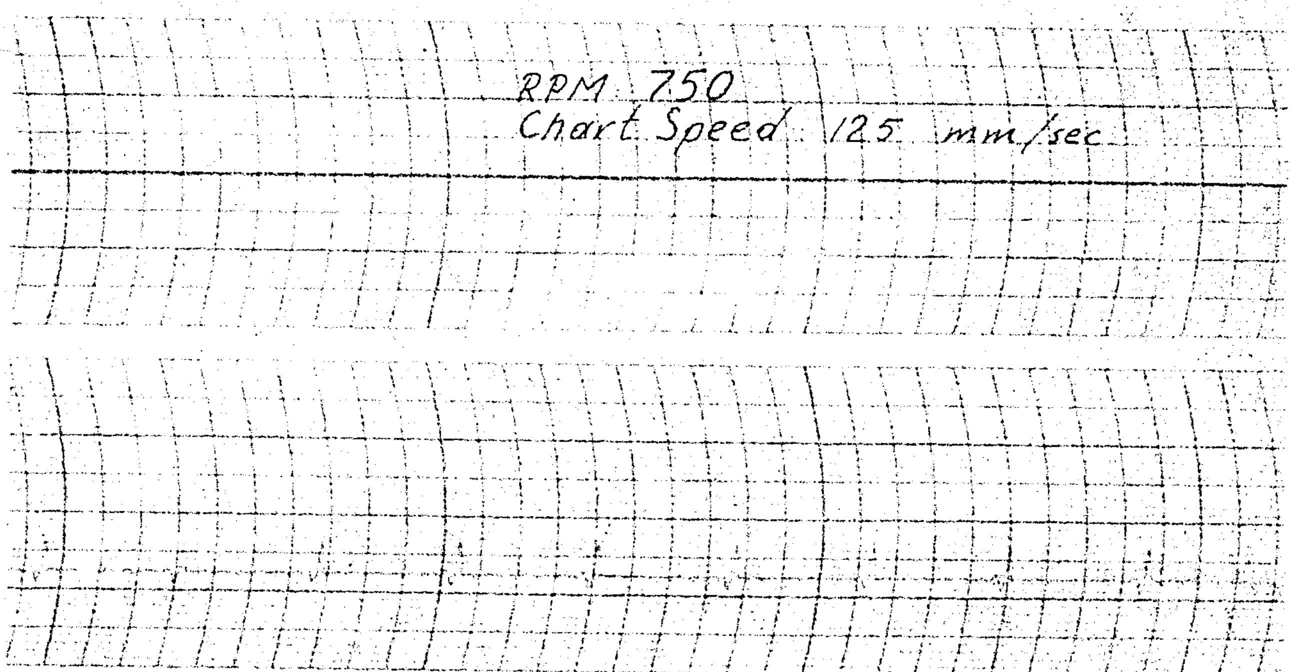


Fig: 31-d.

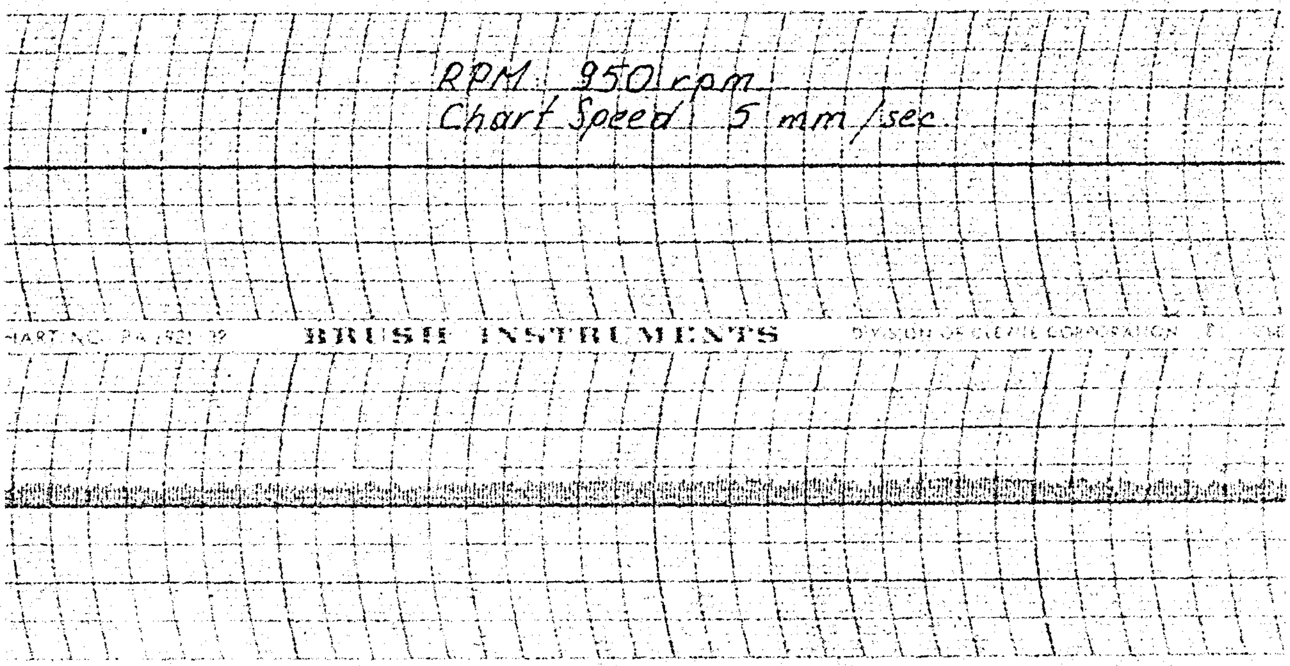


Fig: 31-e

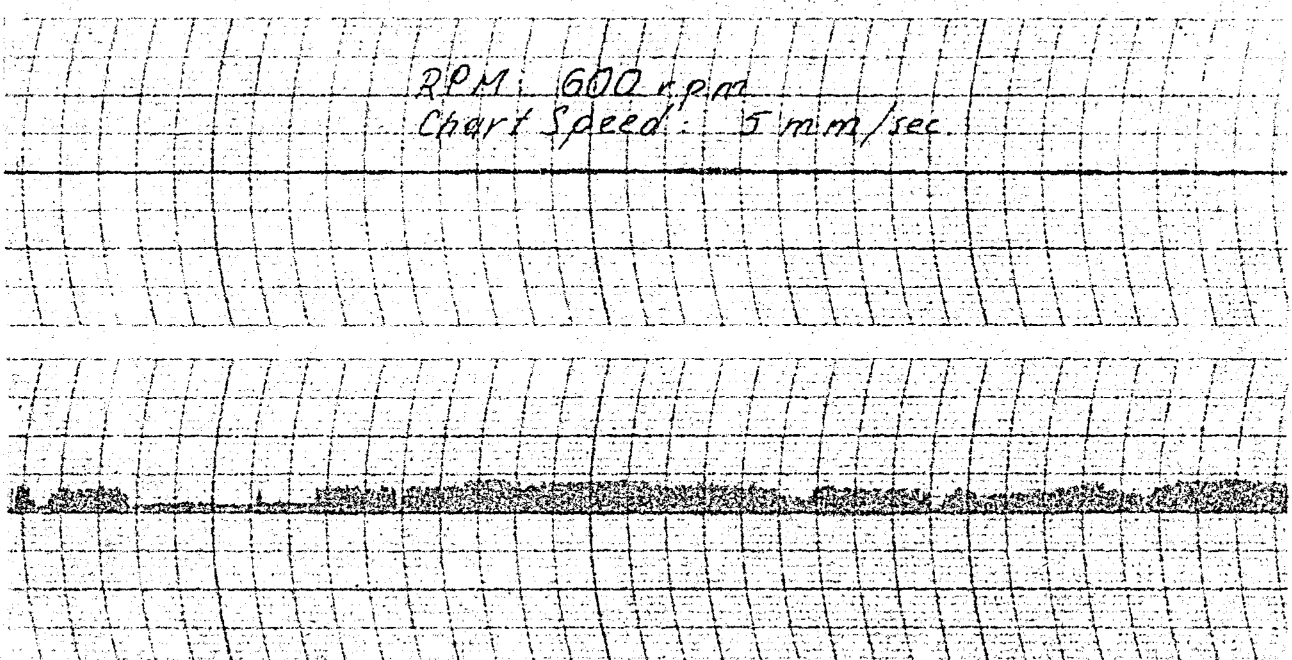


Fig: 31-f

III. Tests with piston motion simulat or:

a. Follow instructions given for the drum-crank-angle indicator.

Skip the steps 2-c and 2-d of the Brush recorder tests.

IV. General Comparisons:

Compare the results of the previously described experiments. Draw the conclusions about the test results.

B. TEST RESULTS:

Fig: 31, a, b, c, d, e, f shows the results of the procedure explained in the previous section.

In Fig: 31, a, we see some small peaks with regular intervals. If we amplify these peaks the *shapes* in Fig. 31-b, c, d, are obtained. Fig. 31-e and 31-f are the same peaks taken at a lower chart speed.

C. DISCUSSION OF THE RESULTS:

We see that the curves in the Fig: 31, do not resemble the expected presssure-build-up curves. The smaller peaks were obtained without amplification. The set-up of the engine completing the electric connections, exhaust and water circuits and over-speed protection device circulates too much time. Besides, the engine was not balanced and vibration of the engine at somewhat higher speeds was terrible. W have noticed that the engine was not lined properly with the dinometer. Due to thes complications actual test of the transducer was not possible. After completion of th above items, tests are performed and Fig: 31-a and 31-b were obtained.

Since the peaks were regularly appearing we thought that they were actual pres sure variations of unsufficient intensity to induce the recorder. We changed the

the form that we expected. Thus we looked for a mistake and after several trials, we observed that the peaks on the chart were actually due to magnetic waves caused by the high tension sparks between the spark plug gaps. To make certain, the transducer was disconnected and the engine run. The result was a proof of our suspicion. Therefore the transducer was not functioning. We checked the transducer by the methods explained to check a strain gage. The result showed that the strain gage might be unbounded to the diaphragm. Meanwhile letters had been written to the Tecquipment Company for information. There had not been any answer.

We tried to open and see the gages whether there were any damage caused due to temperature or other factors. It was impossible to open the assembly that contained the strain gages.

The mentioned effect of the spark plug is then studied by the recorder. Fig: 31-d and 31-e shows the results. In these figures it is clear that:

1. Either the spark is not functioning uniformly
2. Or magnetic waves are not transferred to the recorder properly so as to have uniform peaks on the chart.

The second case is more likely to be true since the waves travel in the air and they may be changed by the surrounding objects. However improper ignition of the plug is also possible.

. SUMMARY AND CONCLUSION:

We have discussed various forms of indicators and their application to our case, esigning the most suitable ones for our purpose and comparing the expected results. is clear that the most useful indicator from the point of view of investigation of ressure variations throughout the cycle is the drum-type crank-angle indicator. his type is also the cheapest one.

To calculate the indicated engine characteristics, Liquid-resistance type piston-iotion simulator is the most suitable one. This instrument is entirely our design nd no reference is consulted for its design and construction. This is a conribution investigations in this field and the requirements of a thesis are fulfilled.

I. RECOMMENDATIONS:

A. INSTRUMENTATION

I. Full advantages of the Variable Compression Engine Test Rig can not be obtained unless the following instruments are supplied:

1. A Cossor Type Indicator Osciloscope suitable for photographic investigations.
2. Suitable D-C supply, i.e. 110 volts, 75 Amps.
3. An Oscilator.
4. A Poloroid Camera to take pictures from the osciloscope.

II. If arrangements are to be made by using the available standard instrument, the following instruments should be supplied:

1. An osciloscope with calcium tungstate coated tube or similar arrange-

2. An oscilator to supply voltages of known frequency and magnitude.

3. An audio frequency amplifier capable of amplifying 1000 times or sc

4. A rectifier

5. Two resistance boxes sensetive up to 4 digits.

6. Two variable reistances sensetive up to 4 digits.

7. A poloroid camera.

III. If the Brush-recorder is to be utilized the following instruments should be supplied.

1. A strain analizer

2. Sufficient chart paper for the recorder.

IV. No additional instrument is required for the drum-type crank-angle indicat or liquid resistance-type piston motion simulator, except the ones necessa for the transducer circuit, i.e. the instrument recommended in items II an III.

V. If a cantilever piston motion indicator is to be used:

1. Two rectifiers

2. Two audio frequency amplifiers

3. One osciloscope

4. One poloroid camera are the required instruments.

B. TESTS AND PROCEDURES:

I. The measurable variables and engine characteristics of the Test-Rig.

1. R.P.M.

2. Load

3. Fuel-air ratio i.e. mixture strength

5. Ignition timing
6. Indicated horse-power
7. Break horse-power
8. Pressure variations in the cylinder
9. Compression ratio
10. Friction horse-power
11. Inlet water temperature
12. Outlet water temperature
13. Amount of coolant
14. Amount of heat loss to the coolant
15. Exhaust temperature
16. Combustion gas products
17. Inlet and exhaust presssu res.
18. Amount of oil used and its pressure.

II. Engine characteristics against the variables.

The following characteristics of the engine can be plotted against engine speed:

1. The compression ratio is constant

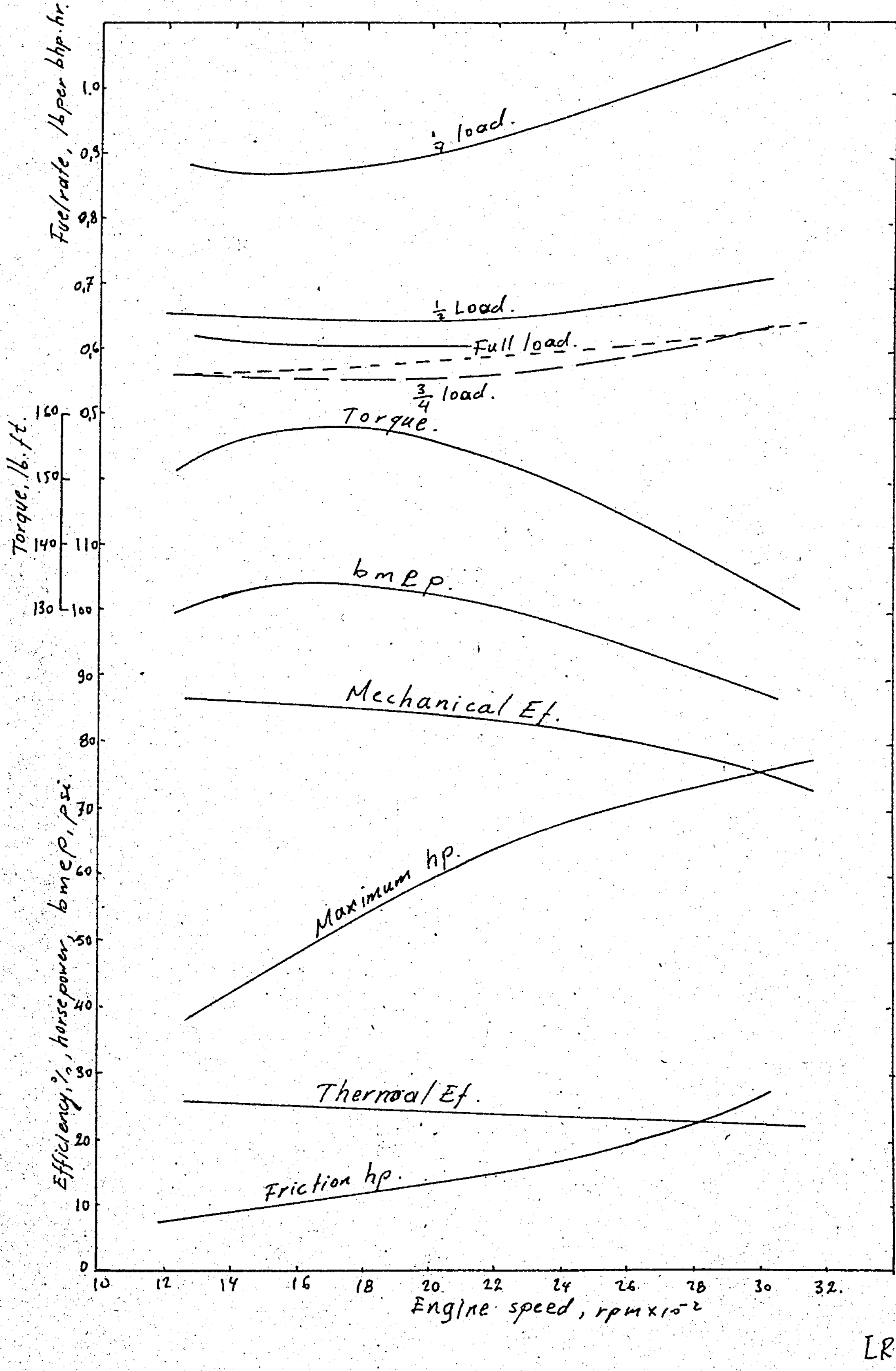
   a. Fuel rate, load as parameter
   b. Torque and Brake mean effective pressure
   c. Indicated mean effective pressure
   d. Mechanical and thermal efficiency
   e. Maximum brake horse-power
   f. Frictional horse-power.

Steps from 1 to 6 can be repeated for different compression ratios. (See Fig:

for graphical representation of the engine characteristics.)

2. Engine characteristics against compression ratio variation

In addition to the characteristics given above, engine speed may also be plotted against compression ratio. (See Fig: 33; Data Sheet.)



[Ref: 7]

Fig: 32. Typical Charecteristic Curves of an internal combustion engine

Fig: 33. EXPERIMENT SHEET.

Name:	Fuel ... Btu/lb ... sp.gr. ... at ... °F
Model: No: Cycles:	Dynamometer: Area: ft
Bore: In Stroke: In Disp: cu in	Humidity: %
Laboratory: Date:	Oil grade; ... Cold Test ... °F
Observers:	Sybolt viscosity at 130°F ... at 212°F.

BRAKE HORSE-POWER AND FUEL CONSUMPTION.

RUN NUMBER	SYMBOL	FORMULA	1	2	3	4	5	6	7	8	9	10.
TIME STARTED	-											
DURATION	t											
COUNTER START	C_o											
COUNTER FINISH.	C_t											
TOTAL REV	r	$C_t - C_o$										
AVERAGE RPM.	N	r/t										
PYROMETRY												
CORRECTION FAC.	C.F.	$\frac{P_o}{P_s} \times \sqrt{\frac{T_s}{T_o}}$										
BRAK LOAD	P	"										
BRAKE LOAD CORRECTED.	P_o	$CF \times P$										
TORQUE lb×ft.	T	$P \times R$.										
BRAKE mep.	n_p	$\frac{150.8T}{D}$										
BRAKE HP.	B.HP.	PRN/5251										
FRICTION HP.	B.HP.	F.H.P. curve.										
INDICATED HP	I.H.P.	B.HP + F.HP.										
MECHAN EFF.	ME	BHP/IHP										
COOLANT AT												
COOLANT AT.												
OIL TEMP.												
OIL PRESSURE												
TEMP. AIR TO CARB.												
WT. FUEL START	W_o											
WT. FUEL FINISH	W_1											
lb. FUEL USED.	W	$W_o - W_1$										
S.F.C.	u	$\frac{60W}{t \times BHP}$										
THERMAL EF.	TE.	2545/F×Btu										

FRICTION HP.

TIME STARTED												
DURATION, min.												
Average R.P.M.												
BRAKE LOAD												
F. HP.	FHP	PRN/5252.1										
MEAN COOLANT TEMP.												

LIST OF REFERENCES

1. Tecquipment/Lister Variable Compression Engine Test Rig. Instruction booklet, Tecquipment Ltd. Research and Developing Engineers, Clinton Hous 24 Sherwood rise, Nottingham.

2. 'Zenith Carburettor Service Bulletin'.

3. The Strain Gage Primer, C.C. Perry and H.R. Lissner, 1955, Mc.Graw-Hill Book Co. Inc., New York, Toronto, London.

4. Electric Resistance Strain Gauges, W.B. Dobie and P.C.G. Isaac, English Universities Press Limited, St, Paul's House, Warwick Square, London, E. 4, Reprinted 1959.

5. The Testing of High Speed Internal Combustion Engines, Arthur W. Judge, Third Edition, Chapman and Hall Ltd., 1943, London.

6. The Engine Indicator, K.J. Juhasz, New York, Instruments Publishing.

7. Mechanical Engineering Laboratory, Messersmith, Warner, Olsen, 2nd editii J.W.

8. 'The Influence of various Fuels on the Performance of Internal Combustion Engines,' Part VII. "Automobile Engineer," August, No. 1321, Ricardo.

9. Handbook of Experimental Stress Analysis, p. 238, 'Electric Induction Gages, John Wiley and Sons Inc., New York, 1950.

10. The Internal Combustion Engine, C. Fayette Taylor and Edward S. Taylor, Revised Edition, International Textbook Co., Soranton, Pennsylvania, 1948.

11. The Internal Combustion Engine in Theory and Practice, Charles Fayette Taylor, Vol. I. 'Thermodynamics Fluid Flow Performance,' The Massachus setts Institute of Technology and John Wiley and Sons Inc., New York and London, 1961

12. The Internal Combustion Engine, D.R. Rye, Vol. I., 2nd Ed., Oxford Univ Press, London, Humphrey Millford, Reprinted 1941.

13. 'New High-Performance Engine Indicator of Strain-Gage Type,' Draper, C.S. and Y.T. Li, J. Aeronaut. Sci., Vol. 16, pp. 593-610, October, 1949.

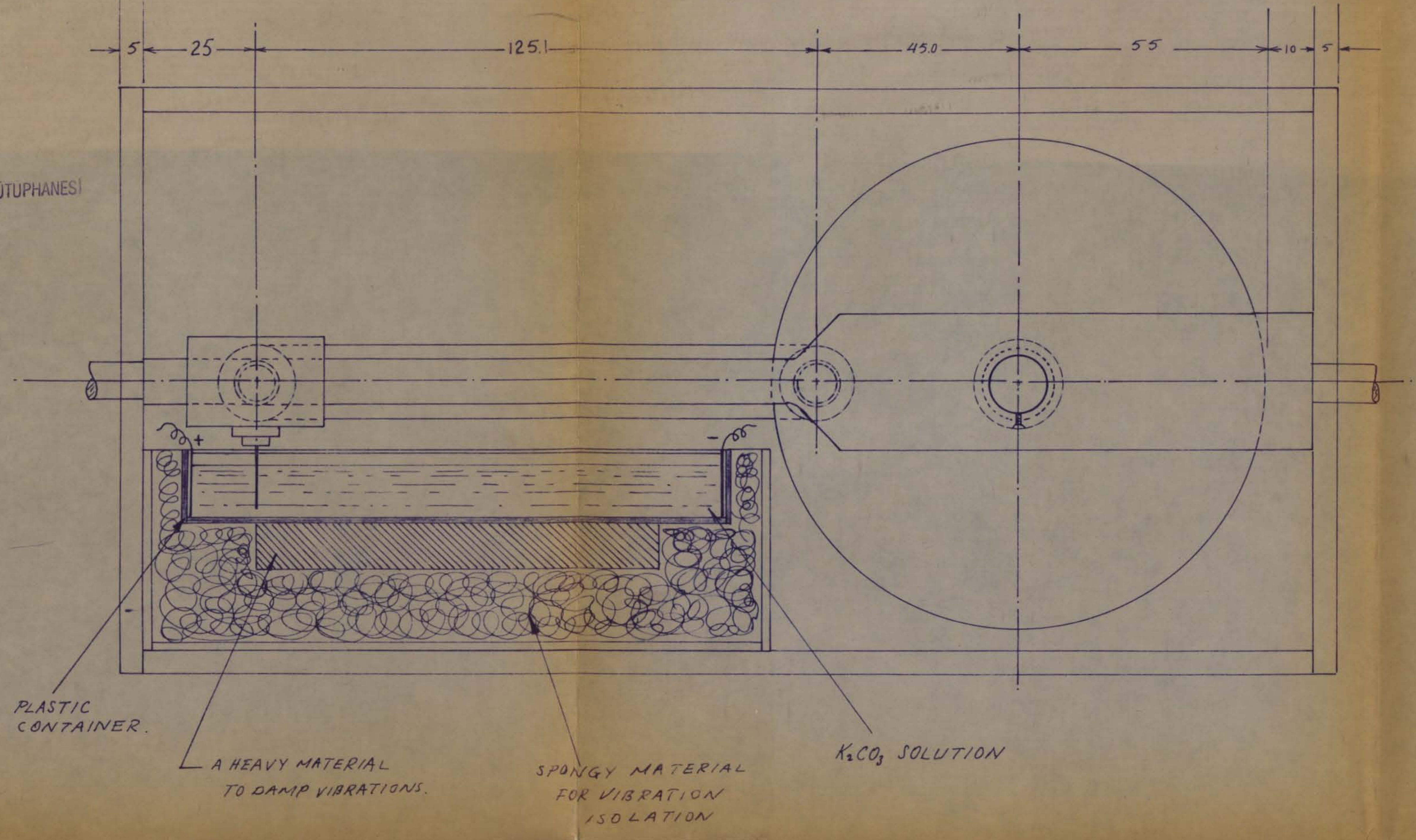
14. 'A Gage for Indicating Pressure Transients in a Combustion Chamber,' Warshaw, H.D., Rev. Dxi. Inst. (264), Vol. 23, No. 9, pp. 493-496 September, 1952.

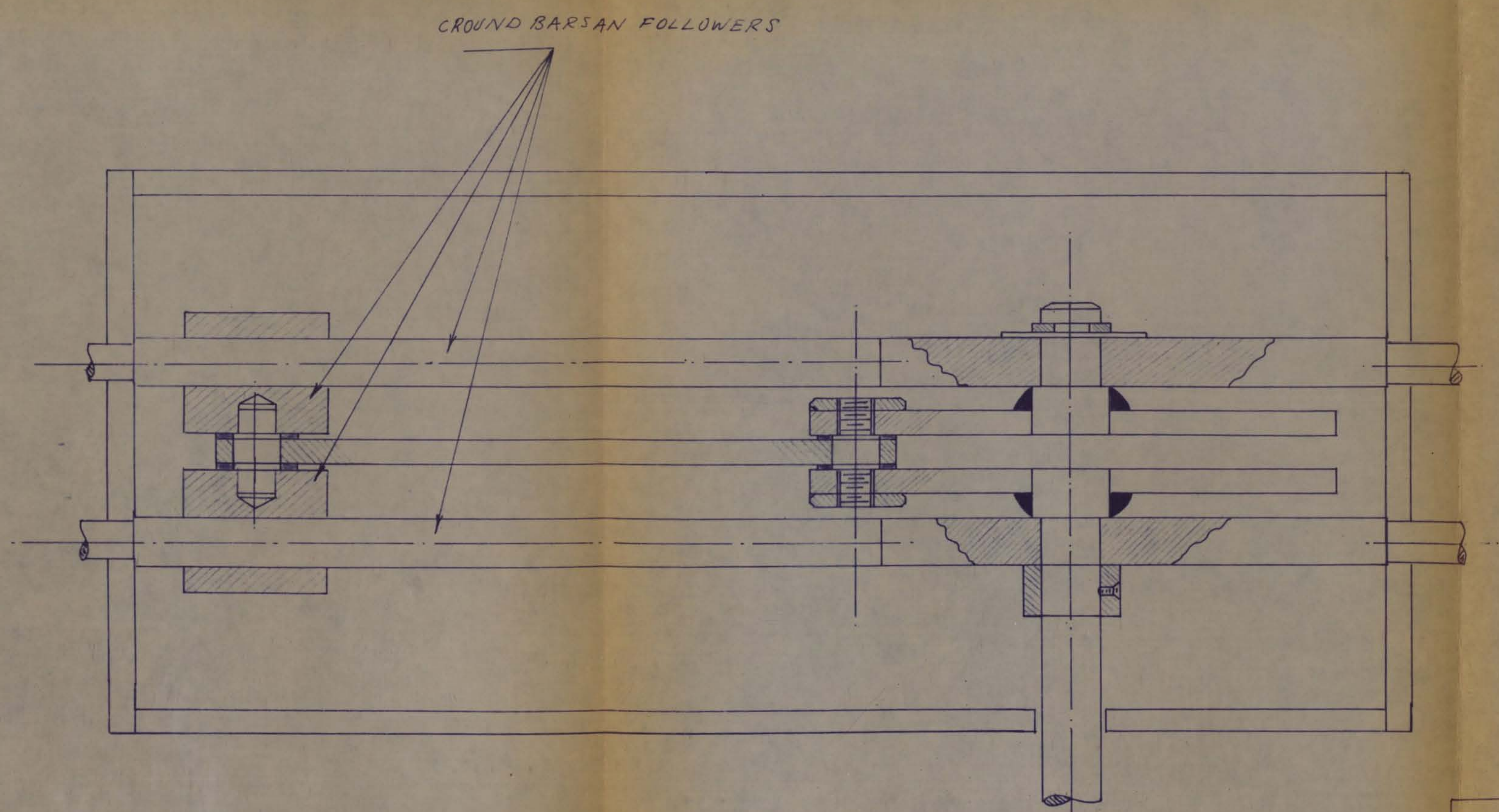
15. 'Oscillograph Strain Gage Recording,' Kaufman, A.B., Radio-Electronic En Vol. 15, No. 3, pp. 15A-18A, 27A.

16. Techniques of Photo-Recording, H.P. Mansberg, 'Oscillographer', April-June, 1950, Du Mont (house publication).

17. Transducers - A Review of the Design and Application of Transducers for Oscillography, Berkley, Carl, 'The Oscillographer,' Vol. 12, pp. 9-24, January-March, 1950.

18. Theories of Engineering Experimentation, Hilbert Schenck, Jr. McGraw-Hil Book Company, Inc., 1961.

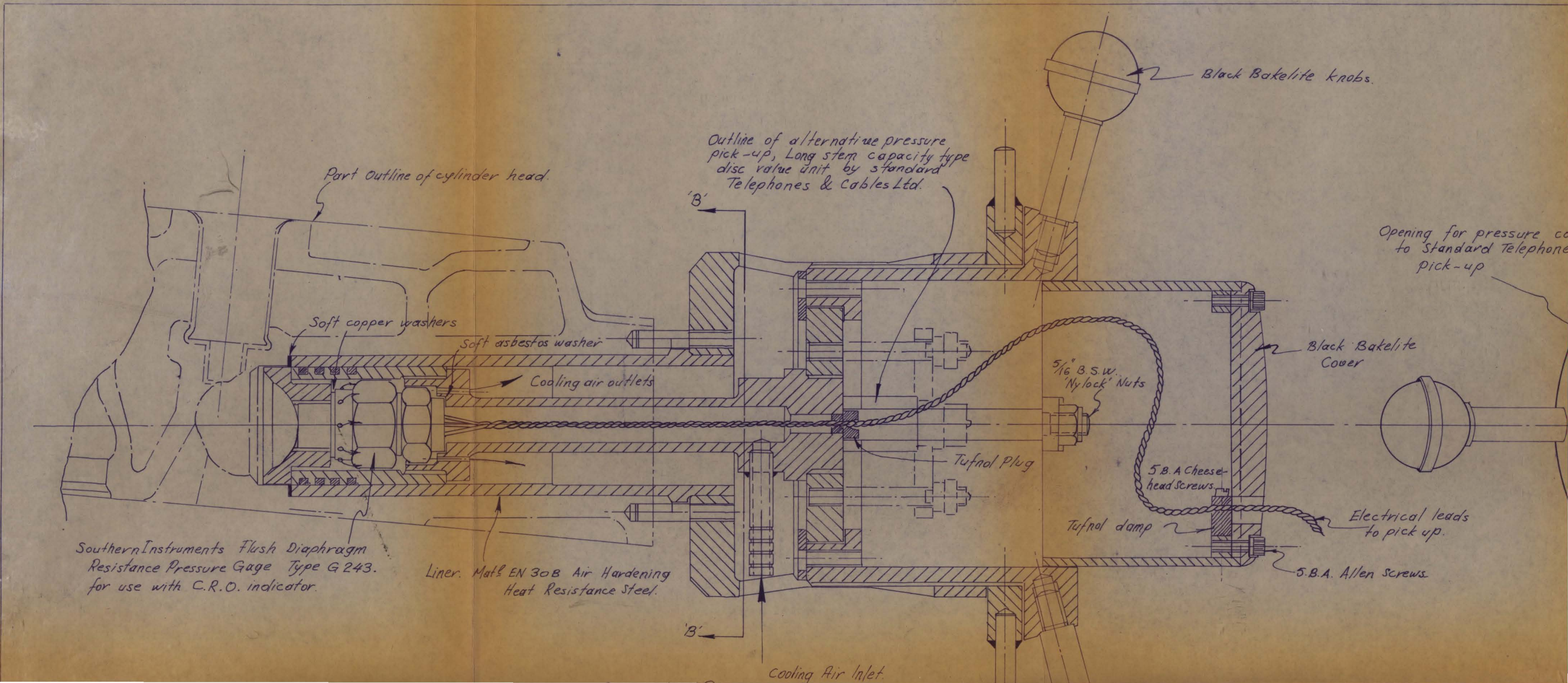




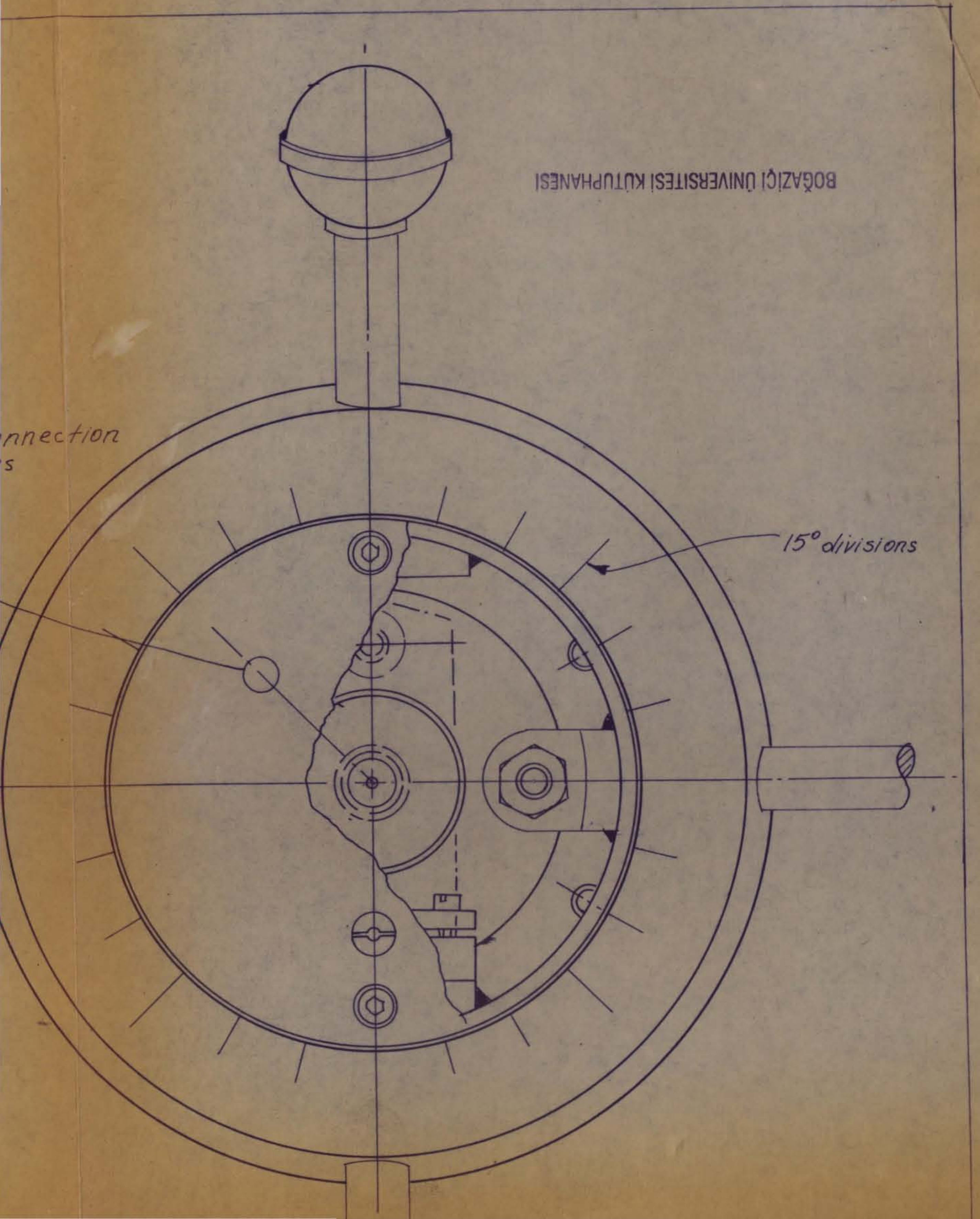
BOĞAZİÇİ ÜNİVERSİTESİ KÜTÜPHANESİ

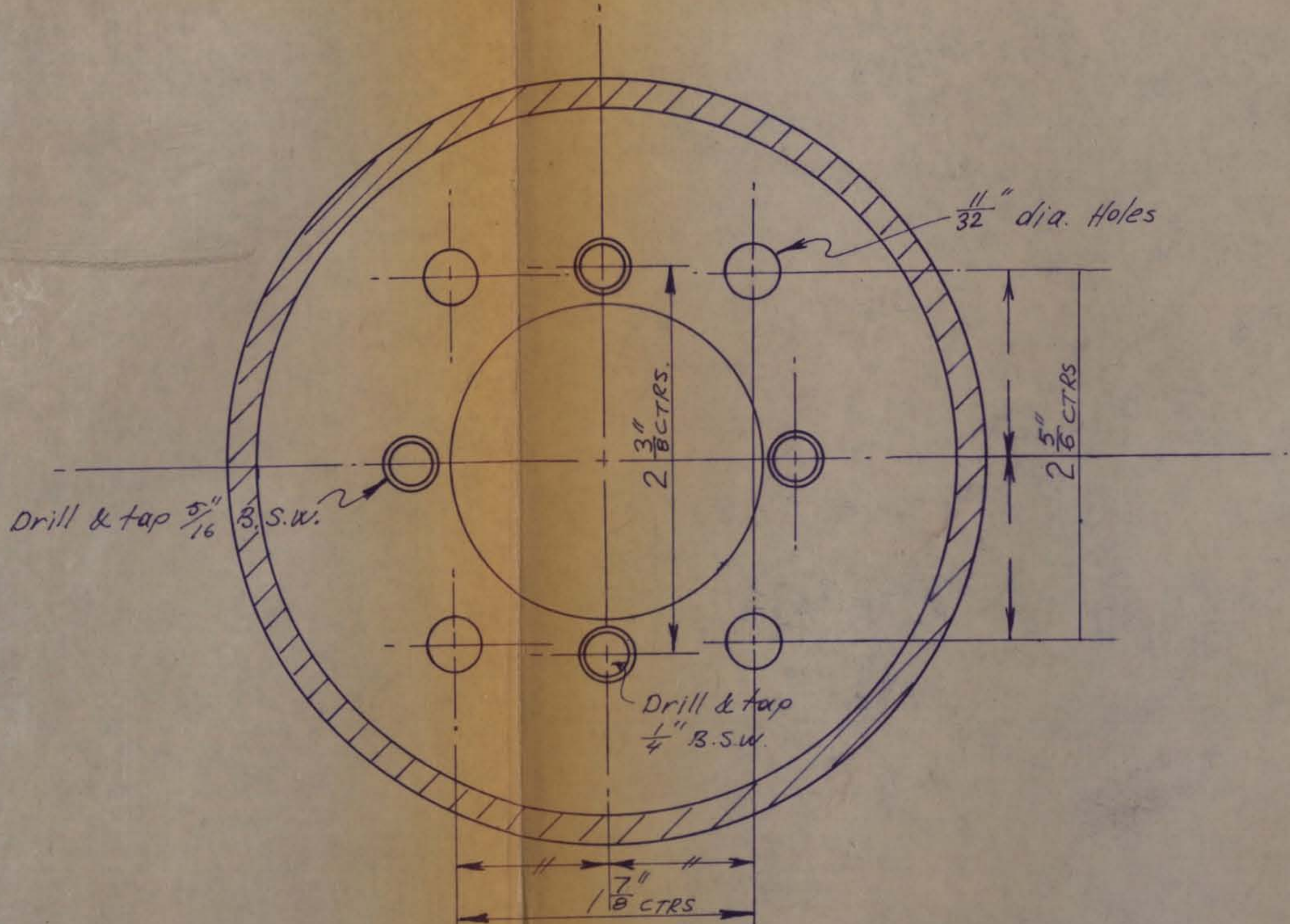
LIQUID RESISTANCE TYPE PISTON MOTION SIMULATOR.

DRN BY	FG.	SCALE : 1/1
DATE :	JUNE 15, 1964	
SUBJECT	THESIS.	



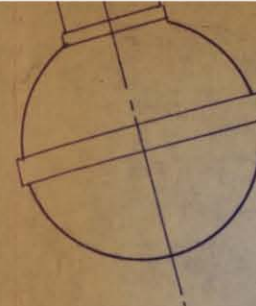
Black Bakelite knobs.
Outline of alternative pressure pick-up, Long stem capacity type disc valve unit by standard Telephones & Cables Ltd.
Part outline of cylinder head.
'B'
Opening for pressure co
to Standard Telephone
pick-up
Soft copper washers
Soft asbestos washer
Cooling air outlets
Black Bakelite Cover
5/16" B.S.W. 'Nylock' Nuts
Tufnol Plug
5.B.A Cheese-head Screws.
Electrical leads to pick up.
Tufnol clamp
5.B.A. Allen screws.
Southern Instruments Flush Diaphragm Resistance Pressure Gage Type G 243. for use with C.R.O. indicator.
Liner. Matl EN 30B Air Hardening Heat Resistance Steel.
'B'
Cooling Air Inlet.

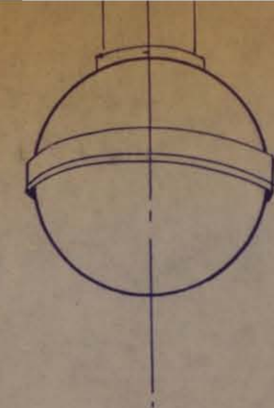

15° divisions



11/32" dia. Holes
2 3/8" CTRS.
2 5/16" CTRS
Drill & tap 5/16" B.S.W.
Drill & tap
1/4" B.S.W.
1 7/8" CTRS

SECTION 'BB'





END VIEW (IN DIRECTION OF ARROW "A")

TECQUIPMENT LTD. RESEARCH AND DEVELOPMENT ENGINEERS NOTTINGHAM				DRG NO
ASSEMBLY OF MODIFIED COMPRESSION VARYING VALVE FOR LISTER FR.1 DIESEL ENGINE.	DRN	JOB N	SCALE: Full Size	TH/01/2
	CHD	DATE	RE-PRODUCED BY: FG	