1965

Instrumentation of a diesel engine for measuring cylinder head temperature, and pressure at various crank angles

Raman A. Patel

Department:

Recommended Citation

Patel, Raman A., "Instrumentation of a diesel engine for measuring cylinder head temperature, and pressure at various crank angles" (1965). *Masters Theses*. 6951.
https://scholarsmine.mst.edu/masters_theses/6951

INSTRUMENTATION OF A DIESEL ENGINE FOR MEASURING CYLINDER HEAD TEMPERATURE, AND PRESSURE AT VARIOUS CRANK ANGLES

BY

RAMAN A. PATEL, 1938

43p

A

THESIS

submitted to the faculty of the

UNIVERSITY OF MISSOURI AT ROLLA

in partial fulfillment of the requirements for the

Degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

Rolla, Missouri

1965

Approved by

Adolph Feingold (Advisor) Charles L. Edwards

Edward J. Bechemeyer John A. Nelson

ABSTRACT

In this investigation, an attempt has been made to measure the instantaneous pressures in the cylinder and the transient temperatures of cylinder head versus crank angle in a Diesel engine.

A strain-gage pressure transducer and a sensitive surface thermocouple were used. The pressure transducer was practically free from temperature influence and strain effects caused by installation. It had a greatly reduced sensitivity to vibrations compared with other available types of pressure transducers. The thermocouple had a very short response time. A device enabling very accurate measurement of crank-angle was constructed. Appropriate quantities were displayed on the screen of an oscilloscope and the readings were recorded on a continuously rotating film by means of a drum camera which was especially constructed for this purpose.

Results obtained were satisfactory.

ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Dr. Adolph Feingold for his continuous advice, encouragement, and guidance throughout this investigation.

Special thanks is also given to Dr. Aaron J. Miles, Chairman of the Mechanical Engineering Department for supporting this project.

Professor George McPherson of the Electrical Engineering Department and Professor Robert F. Bruzewski of the Mining Engineering Department have given valuable assistance in solving various difficulties encountered in the fields of electronics and photography, respectively.

The author is indebted to Mr. Lee N. Anderson of the Machine Shop and to Mr. Richard D. Smith, Mechanical Engineering Laboratory Technician who devoted much of their time and skill, showing patience and understanding without which this project could not have been completed in time. Mr. Arthur R. Hemme, Laboratory Technician, did part of the necessary machining.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

At present, almost everyone is aware of the importance of internal combustion engines. These can be divided into reciprocating engines, gas turbines, rockets, etc. A Diesel engine is a reciprocating internal combustion engine in which the fuel is ignited by the heat of compression. Thus, Diesel engines are also known as compression-ignition (C.I.) engines. The engine is named for its inventor, Dr. Rudolf Diesel of Germany, who, in 1892 (1), established the first patent on an internal combustion engine using powdered coal as fuel. The first commercial Diesel engines in the world used liquid fuel, which was injected into the cylinder by a blast of high pressure air. These were manufactured in 1895 by the Maschinenfabrik Augsburg Nurnberg (M.A.N.) company of Germany.

The large demand for modern high-speed Diesel engines is based mainly on the fact that the Diesel engine has the highest thermal efficiency of all heat engines which are in practical use today. Gas turbines and free piston engines, by virtue of their simplicity, are the most recent competitors of Diesel engines. Therefore, it is now more important then ever, to improve the thermal efficiency of the Diesel engine without basic changes in its operation and design.

Analytically and through experimental methods, there has been a considerable amount of research concerning thermodynamics and heat transfer in diesels. Unfortunately, most of it is either questionable or inconclusive because of inadequate or inexact measurements. Thus, many questions remain largely unanswered.

The recent development of optical and electronic techniques opens the door to better experimental work and it is the purpose of this thesis to make a modest contribution to the understanding of the problems of instrumentation involved.

It is expected that such new investigations will result in information that will lead to a still more scientific design of internal combustion engines in the future.

REVIEW OF LITERATURE

The comparatively high standard of efficiency and reliability of the modern high speed internal combustion engine is due very largely to the study of the information gathered from research. In order to obtain the greatest thermal efficiency and power output from an engine, it is necessary that the temperature of the cylinder walls and combustion head should be maintained at a certain minimum value (2).

No direct means have been generally available for measuring the temperature of the cylinder gases, particularly in the period prior to combustion. Conditions during compression have a strong influence on the character of the whole cycle, and especially on the combustion process. Several methods had been developed to measure the gas temperatures (3, 4, and 5). As the gas temperature varies during the cycle, cylinder-walls and combustion-head temperatures vary with it.

In the early 1900's, Negal (6) made a heat transfer study in reciprocating engines. From this, and through experimental results, Eichelberg (7) concluded that variation of temperature during the cycle decreases with the distance from the inner surface.

Recently, high response thermocouples have been developed for measurements of transient surface temperatures (8). However, there is some doubt about the ability of any thermocouple to measure the very rapid variations of surface temperatures in high speed diesel engines.

The balanced-diaphragm remote plotter for recording the cylinder pressure versus the crank-angle of an internal combustion engine has recently been developed at the General Motors Research Laboratories (9). This method has the following advantages:

1. smaller number of man-hours required
2. data are recorded in continuous analog form
3. curves plotted are truly representative of many engine cycles.

The disadvantages of this apparatus are that it is very complicated and expensive.

In industry, extensive research has been carried out in the field of heat transfer in internal combustion engines. Because of the extreme competition existing in this field, information with regard to engineering design or performance characteristics rarely appears in technical journals. Descriptions of existing equipment are generally found only in patents.

PRESSURE MEASUREMENT

Pressure indicators are commonly used for several purposes:

1. calculation of indicated horsepower
2. study of particular parts of the engine cycle
3. detection of malfunction.

Such indicators may be mechanical, strain-gage type, piezometric, etc. For fast revolving engines the mechanical indicator is excluded because of its inertia effects.

Another way to classify the indicators is to differentiate between the ones yielding curves of each complete engine cycle and those which yield a composite curve representative of many such cycles. In this connection, it must be understood that the pressure versus crank-angle relationship within a cylinder does not repeat itself precisely. There are even some small observable differences between two consecutive cycles.

Our purpose was to study the pressure changes, particularly in the neighborhood of the top dead center (T.D.C.). These pressure variations are especially important because of their influence on engine performance. For greater accuracy, crank-angle was selected as the horizontal coordinate rather than volume or piston displacement.

The strain-gage and the piezometric pressure transducers are generally provided with a water-cooled adaptor. These types are sensitive to ambient temperature changes. The type chosen, was water-cooled internally, and thus retained its normal high-frequency response despite ambient temperature changes. The selected strain-gage was also less sensitive to vibration than the flat-diaphragm type of pressure transducer.

The pressure transducer acquired was a Norwood model 110 bonded strain-gage type. It was water-cooled and provided with a low noise cable. It supplied an electrical output proportional to the pressure in the cylinder. The following table gives the specifications for this transducer:

Manufactured By: American-Standard
Model No: 110-2-5000-34-10-61
Sensitivity: 3.909 MV/V
Input Resistance: 350.0 Ohms
Mounting Torque: 35 Ft. lbs.
Serial No: 7325
Excitation: 10 V
Pressure Range: 0-5000 psig.
Coolant Inlet Pressure: 30 psig. water

This type of pressure transducer consists of a high-flexibility catenary-type stainless steel diaphragm and a strain-generating tube covered by circumferential and longitudinal strain gage windings, and temperature compensating windings. It carries a complete four-arm bridge circuit with fixed resistances permanently bonded to the strain tube. The entire body is cooled through large-area liquid passages. The cooling water is introduced and removed from the body by two hose connections at the connector end of the pressure transducer. Applied pressure causes a minute deflection of the diaphragm and compression of the strain tube, resulting in an unbalanced bridge circuit. This provides an electrical output from the bridge which is proportional to the pressure. The pressure transducer is shown in Figure 1.

A calibration chart, up to full scale range of 5000 psig., was provided for this transducer by the manufacturer. Since the test engine was not supercharged the maximum pressure to be measured was below 1000 psig. Therefore, to ensure maximum accuracy the pressure transducer was recalibrated on a dead weight gage tester, as shown in Figure 2. The manufacturer's recommended excitation to the bridge circuit was 10 V DC or AC. At first a constant excitation was provided from a variable DC rectifier. It was discovered however that the oscilloscope was so sensitive that it picked up 60 cycle interference from the rectifier and the electrical noise was thus introduced into the transducer output signal. A dry battery was substituted for the

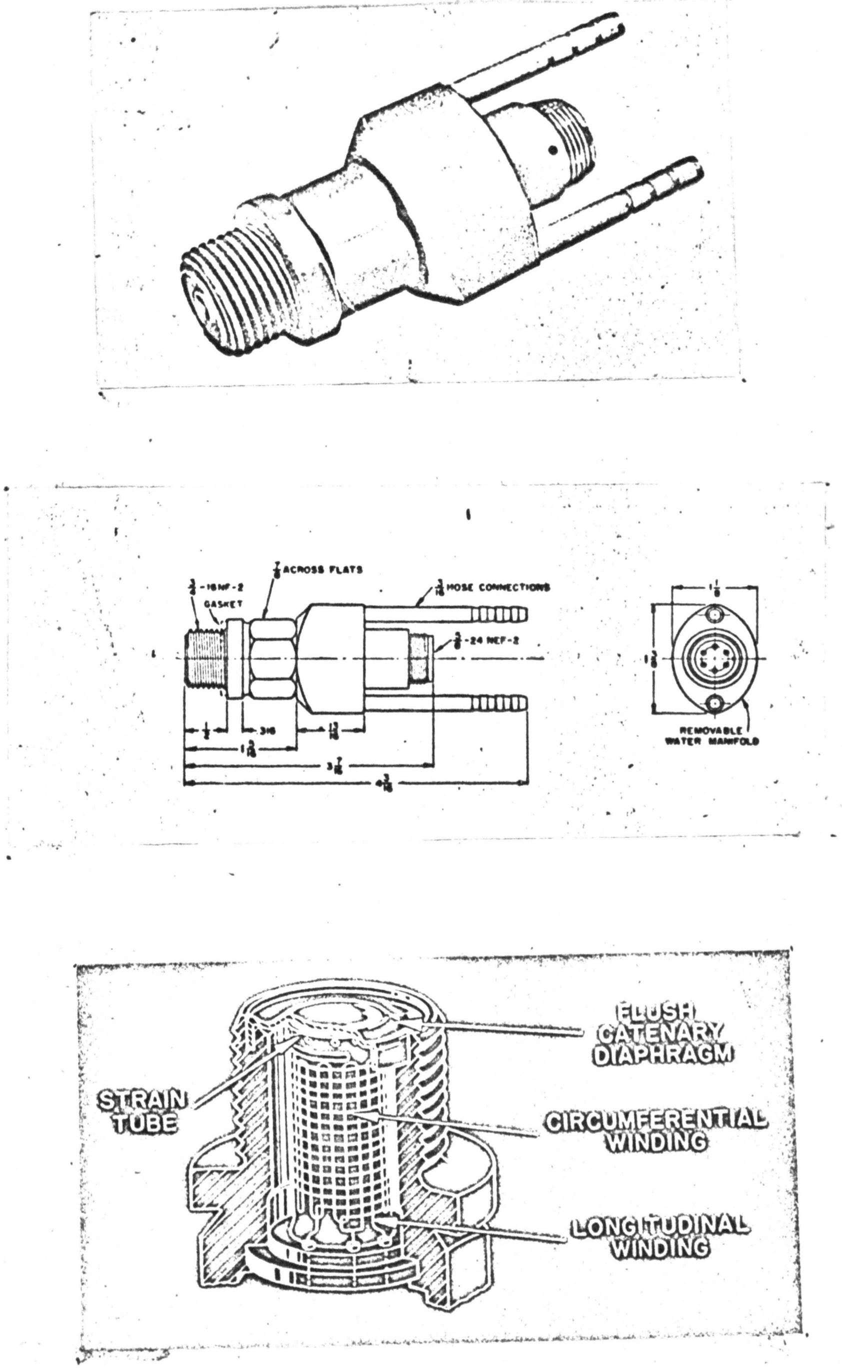


Figure 1. Pressure Transducer

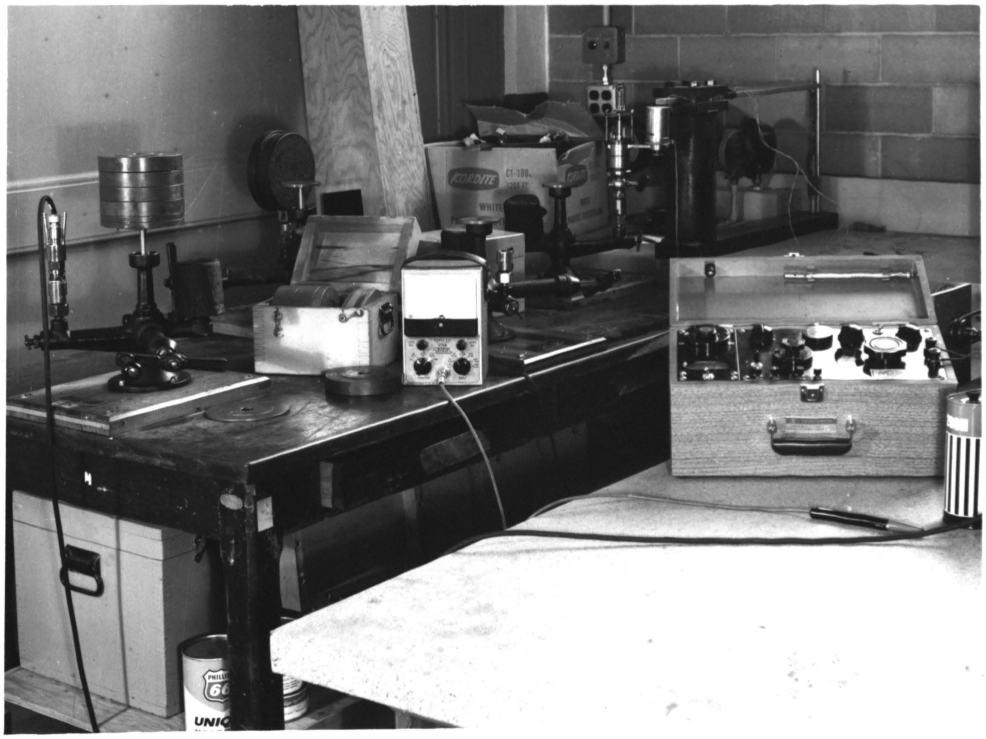


Figure 2. Dead Weight Gauge Tester

rectifier and it's use succeeded in eliminating the noise. Since 10 V batteries are not commercially available, a 12 V unit was used and, the pressure transducer was recalibrated accordingly. This calibration is presented in Figure 3. This same 12 V battery was subsequently used throughout the investigation.

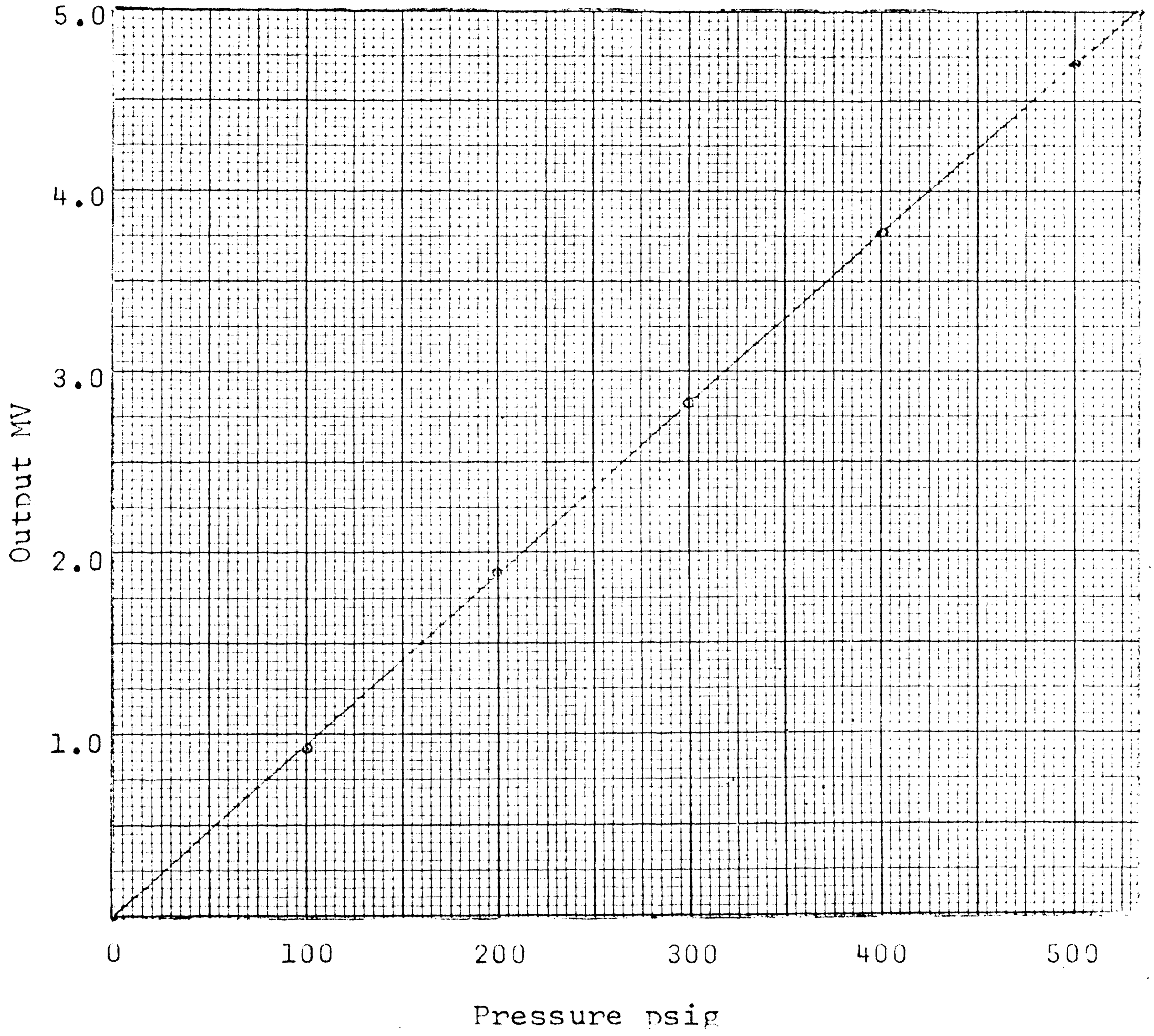


Figure 3. Calibration Curve of Pressure Transducer

TEMPERATURE MEASUREMENT

The progress of technology made the knowledge of temperature measurements so important that a multitude of instruments were constructed.

In particular, the following devices are most commonly used for the measurement of transient temperature as close as possible to the surface of the solid bodies:

1. thermocouples
2. resistance thermometers
3. thermistors
4. radiation pyrometers.

Measurement of the surface temperatures by radiation pyrometry techniques requires that the surface being measured should be viewed by the detector. This method is generally used for high temperature measurements. In our case, however, its use is impracticable. Resistance thermometers and thermistors will not give accurate measurements of rapidly changing surface temperatures. They interfere with the heat transfer to the metal surface, because they have to be attached to that surface. Their mass absorbs heat, thus introducing the problem of thermal inertia. Therefore, our choice was restricted to thermocouples. A thermocouple consists of two dissimilar metals joined together at both ends. If a temperature difference is maintained between these two junctions it generates an electric current through the circuit. The magnitude of this current is a function of the temperature difference.

For accurate measurements, the configuration of the thermocouple must not interfere with the heat transfer characteristics of the wall. The thermal junction must be exactly flush with the measuring surface. Moreover, the heat flow through the thermocouple body must be nearly identical to that of the undisturbed metal wall. Therefore, the body and probe of the thermocouple should be made of materials that have the same thermal properties as the wall to which the thermocouple is mounted.

The thermocouple used in this investigation was of the 'eroding' type. The leads were thin, flat ribbon wires which were separated by sheets of mica at the sensing tip, as shown in Figure 4. The thermal junction was formed by abrading the tip, producing small slivers of metal which link one thermocouple wire to the other. Consequently, should erosion oocur and the original junction be destroyed, a new junction would be created automatically.

The wires were Chromel-Alumel, C/A, the overall length of the thermocouple well was one inch, and the assembled weight about 5 grams. A special feature of this thermocouple was its very short response time to transient surface temperature changes. It withstood extremes of pressure, velocity, and vibration, like those present in our case,

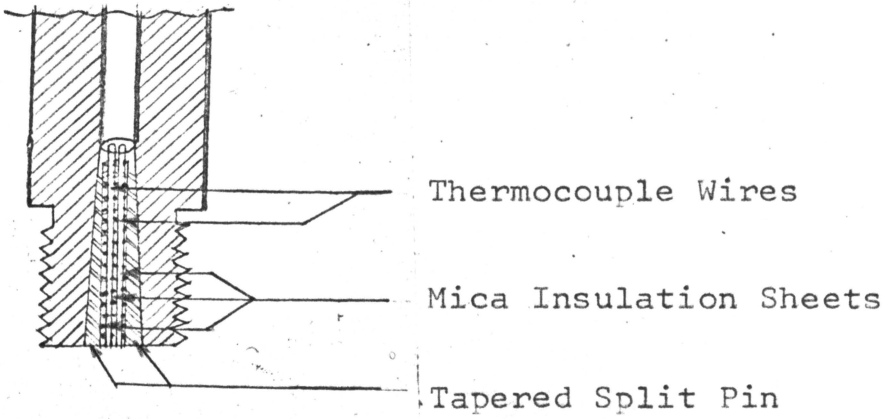


Figure 4. Cross-sectional View of Thermocouple Sensing Tip

without degradation.

The thermocouple was fixed in the cylinder head with the sensing tip flush with the wall surface of the combustion chamber. The particular arrangement of the thermocouple and pressure transducer on the cylinder head are shown in Figure 5. The cross-section of the cylinder head and location of the thermocouple are shown in Figure 6. The joint between the thermocouple gland and the cylinder head was made gas and water tight. Complete assembly of the thermocouple is shown in Figure 7.

In the absence of a reliable high temperature source, the thermocouple was not calibrated. Instead, Standard Reference Tables for Thermocouples, were used (10) to determine the thermocouple output. These tables are based on a temperature of 32°F at the cold junction. This base temperature can best be obtained by immersing the cold junction in a thermos jug filled with ice water. Care should be taken to prevent the positive and negative leads of the thermocouple from shorting in the jug. Temperatures slightly above 32°F at the cold junction can produce errors of about 3°F. These result from temperature gradients in the ice water, and can be ignored since they are within the limits of error of the C/A thermocouple.

In trying to keep this junction at 32°F it was discovered that portions of the wires were unshielded. More-

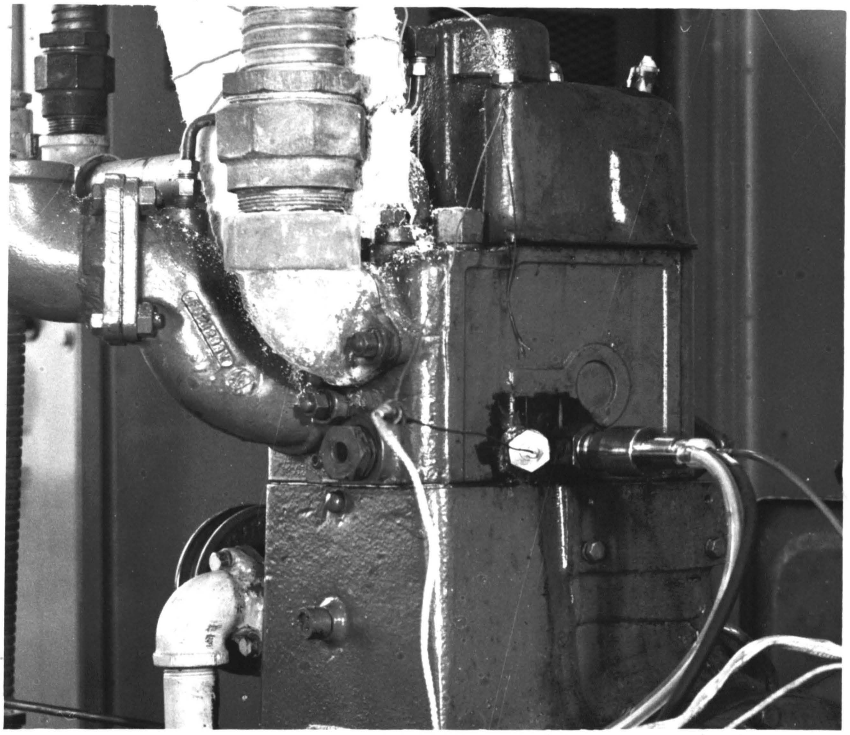


Figure 5. View of Cylinder Head with Thermocouple and Pressure Transducer

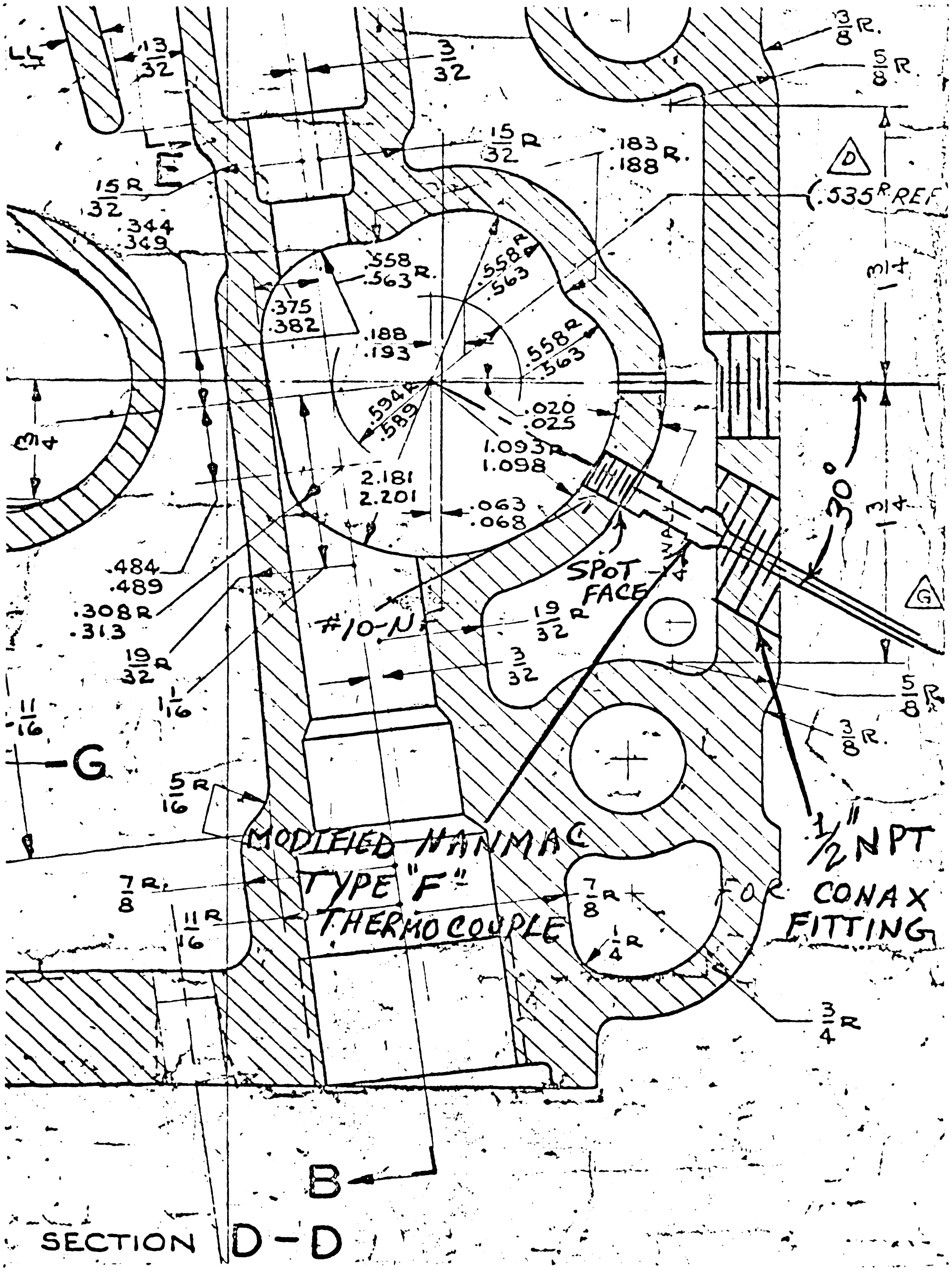


Figure 6. Location of the Thermocouple in Cylinder Head

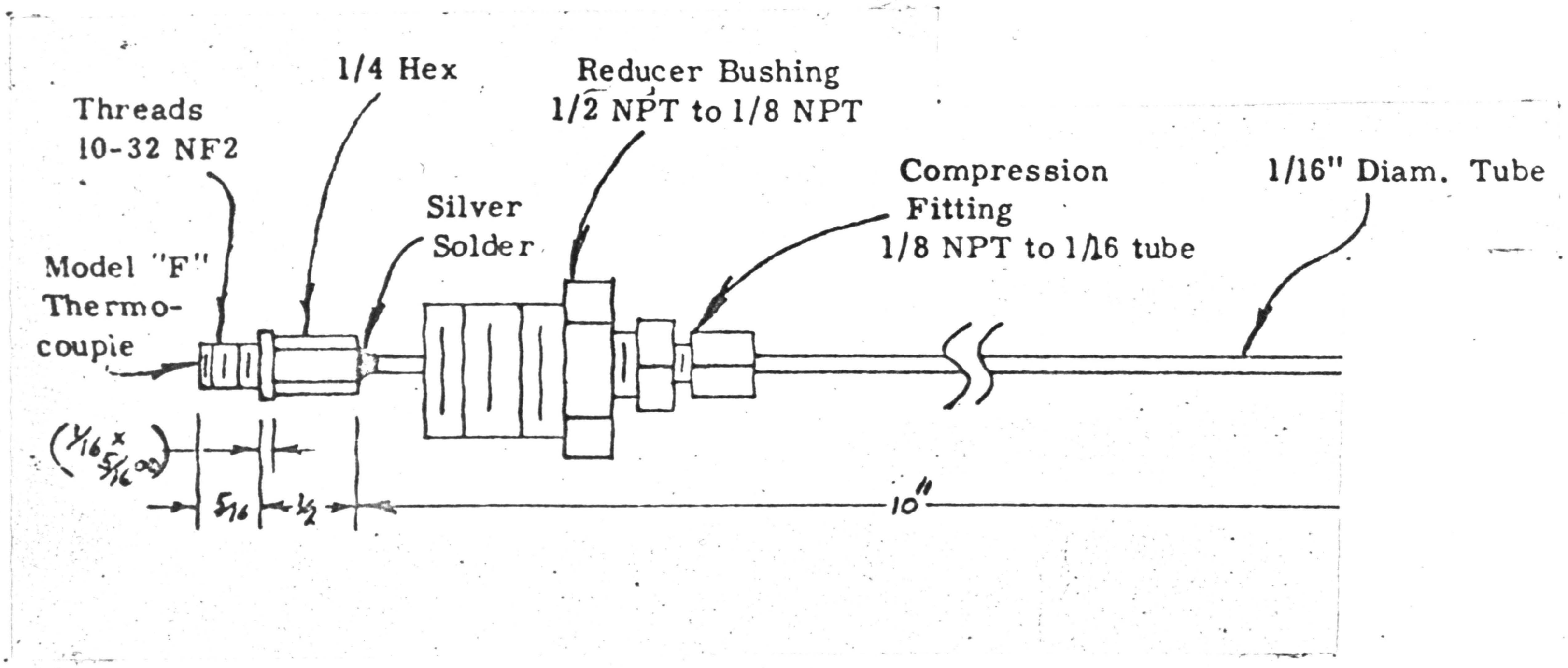


Figure 7. Complete Assembly of the Thermocouple

over, the recorder leads from the cold junction to the oscilloscope were not of a low noise type. This would cause electrical noise, which would initiate the output signal. The idea of keeping the cold junction at 32°F was, therefore, dropped. The correct temperature was calculated by another method. It was assumed that the cold junction remained constant, at room temperature. The difference between 32°F and room temperature was then added to the observed thermocouple output. This gave the correct value of temperature. The accuracy of this method was verified by immersing the thermocouple sensing tip in boiling water. The results obtained were the same as those tabulated in the reference.

The effects of carbon deposits on the thermocouple sensing tip may be seen in (11). It is apparent that the carbon deposits caused the error in heat transfer and heat transfer rate calculations. The performance of the engine is also influenced by these deposits. As the running time of the engine increased, some carbon deposits were found on the thermocouple sensing tip. Therefore, for greater accuracy the sensing tip should be cleaned frequently.

CRANK-ANGLE MARKER CIRCUIT

It was necessary to provide a time co-ordinate, or a crank-angle marking system in order to interpret the pressure and temperature diagrams correctly.

This system can be built with photo-electric, optical, or magnetic apparatus. The electro-magnetic method was chosen because of its relative simplicity and accuracy.

The equipment consisted of:

1. an iron disc mounted on the crank-shaft
2. a round iron bar, chisel-shaped at one extremity
3. primary and secondary windings on the iron bar
4. a 6 Volt DC storage battery
5. A cathode ray tube oscilloscope.

The chisel was mounted on the engine body and the primary winding was connected to the battery. This created a magnetic flux in the chisel. The sharp edge of the chisel was mounted very close to the periphery of the iron disc which was keyed to the crank-shaft. A set of appropriate slots was cut on the periphery of the disc. During the rotation of the engine the slots appeared in succession before the chisel. This caused variations in the magnetic flux depending on the size and shape of the slots. These changes produced a current in the secondary winding of the chisel. This current was used to produce an image in the form of a wave on the screen of an oscilloscope.

Figure 8 shows the chisel, the heavy support on which it was mounted, and the slotted disc. For clarity of details the parts are shown separated, in Figure 9. The chisel had to be mounted so that its edge was very close to the disc, but not too close for safety. The exact distance, which produced the best image on the screen was found by trial and error. A double-nut locking feature was provided to allow a vertical displacement of the chisel during the preliminary tests.

The original support for the chisel proved to be of insufficient rigidity which introduced variations in the air gap between the chisel and the disc. This was evidenced on the screen by the superposition of an extraneous wave on the one produced by the slots. This effect was all but eliminated by the use of an extremely heavy and rigid mounting. The effects of the residual vibrations may be observed in Figure 10. These residual effects are negligible in our investigation and the timing mark can be read with utmost clarity and precision.

The whole circuit works as a closed-circuit magnetic pick-up. Because soft iron is a non-permanent magnetic material, it was used in the construction of the disc and the chisel.

The iron disc was fifteen inches in diameter and one half inch thick. The first groove to be cut on the disc

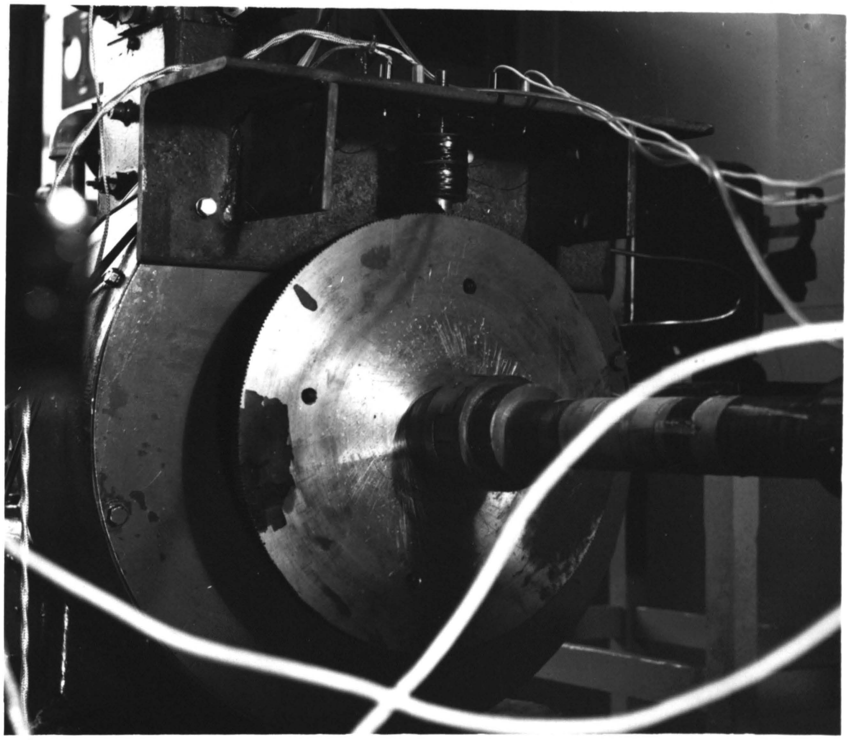


Figure 8. View of a Crank-Angle Marker Circuit

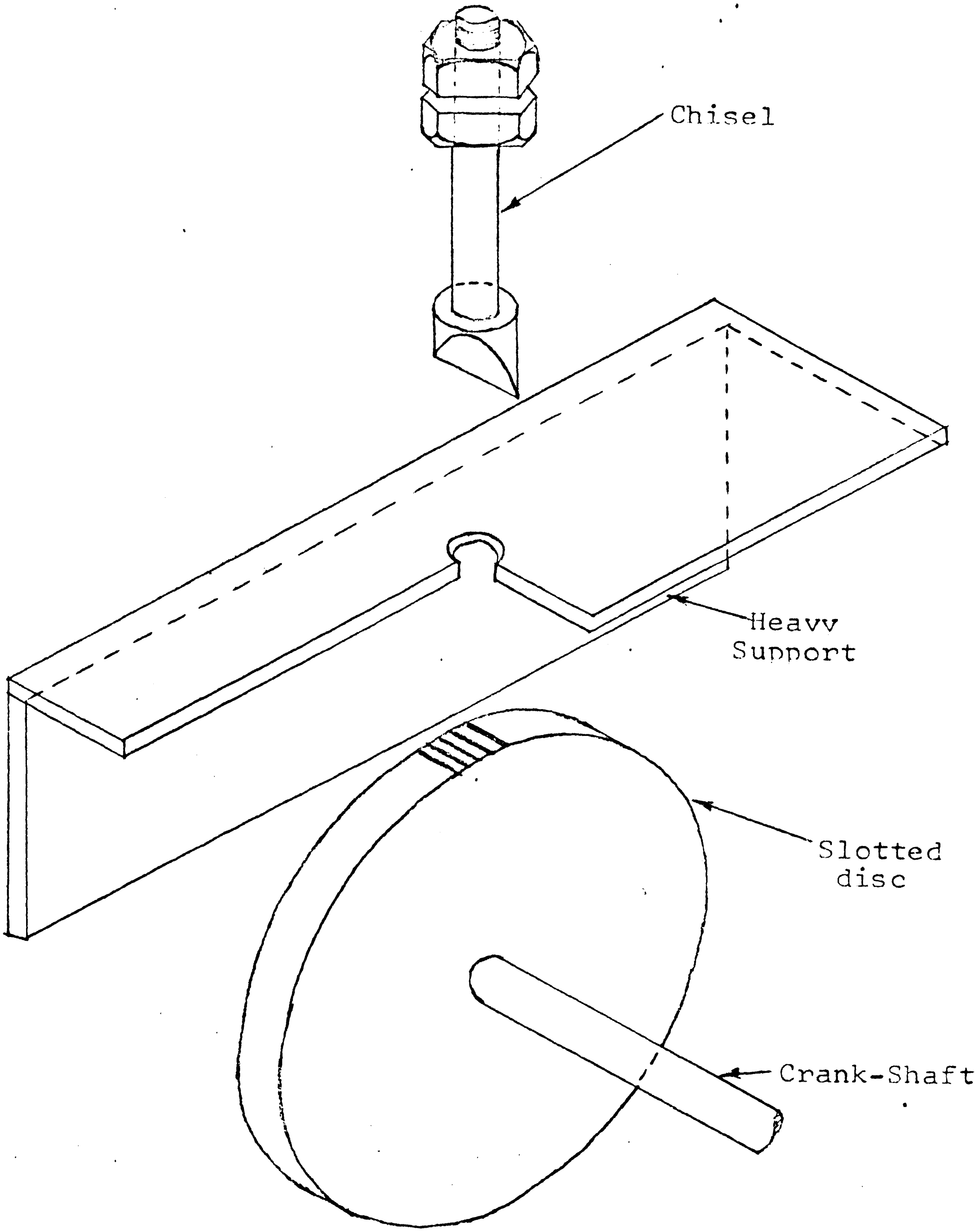


Figure 9. Details of a Crank-Angle Marker Circuit

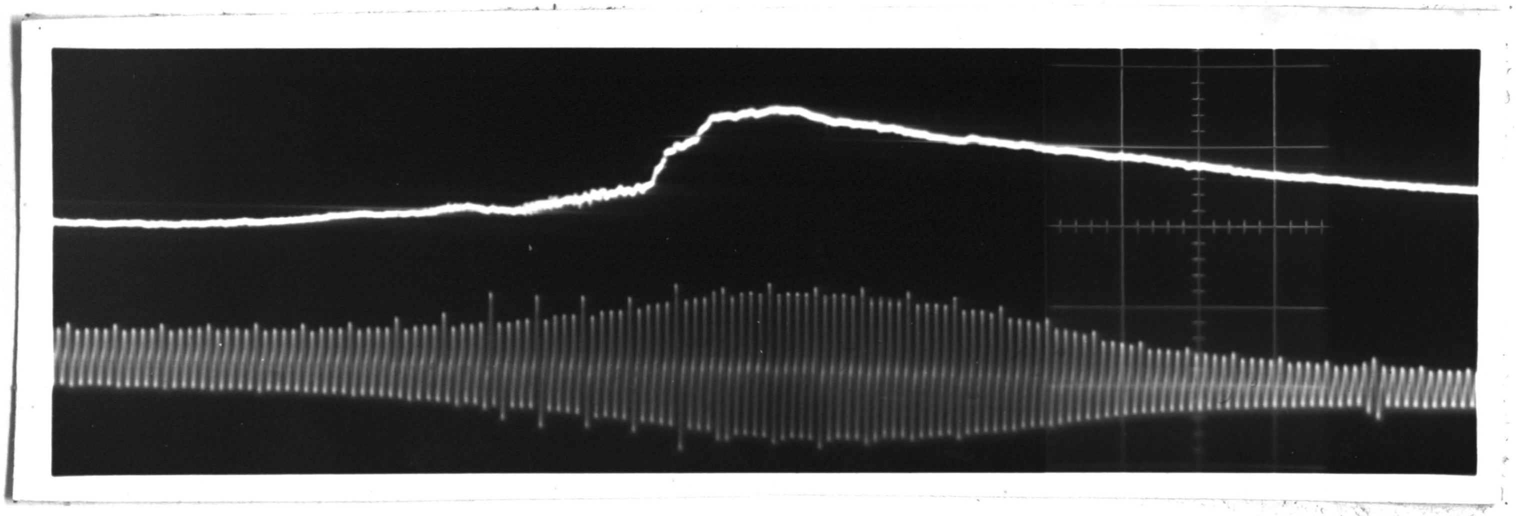


Figure 10. Diagram of Temperature Versus Crank-Angle

was the one corresponding to the T.D.C. For this purpose the engine head was removed and the piston was positioned somewhat below T.D.C. A reference mark was then made on the disc opposite the sharp point of the magnetic chisel which has been fixed to the body of the engine as described above. The engine was rotated until the piston, after having passed T.D.C., was again brought to the position that it occupied when the first mark was made. Another mark was made on the disc opposite the chisel. The groove corresponding to the T.D.C. was cut midway between the two marks. The circumference of the disc was divided into 360 equal parts. Each part represented one degree of crank-angle. The division was made on a dividing head starting from T.D.C. The groove representing T.D.C. was made 0.08 inch deep and 0.04 inch wide, and at every fifth degree of crank-angle, the grooves were 0.06 inch deep and 0.04 inch wide. The remaining grooves were 0.04 inch deep and 0.04 inch wide.

The primary and secondary windings of the chisel, each consisted of 200 turns of No. 17 gage wire. The sharp edge of the magnetic chisel was mounted perpendicular to the disc.

Since every fifth groove was deeper than the others, the induced voltage corresponding to this groove was of greater magnitude. This made easily identifiable marks, on the oscilloscope image.

Similarly, the position of the T.D.C. could be localized because the mark at that point would have an even greater amplitude than those at every fifth degree of crank-angle.

In practice, this T.D.C. mark was not clear enough on the photographs. Therefore, five deep grooves were cut on the disc, with T.D.C. corresponding to the middle one. These are clearly visible in Figure 10.

Some difficulties had to be removed before the circuit was able to work in a satisfactory manner. Low frequency waves were superimposed on the image produced by the crank-angle marking device. Two distinct effects were found. First of all, the leads from the secondary winding to the oscilloscope were picking up electric noise from the atmosphere. They were replaced by low-noise cables. These are insulated wires with a metallic shield over the insulation. This shield is grounded, thus preventing the inside wire from picking up disturbing signals from the environment. Then, it was found that the engine vibrations were being transmitted to the oscilloscope. The machine was a single-cylinder engine that was mounted on a concrete block which was improperly connected to the floor. Thus, the increased vibration was even stronger than it would have been in comparison with a multicylinder engine.

Fortunately the frequency of the vibration was considerably lower than the frequency produced by the timing marks. The large frequency difference simplified the reduction of vibrational frequencies. The original circuit, Figure 11a, was modified to include a simple filter, consisting of a capacitor and a resistor, as shown in Figure 11b.

The series capacitor blocks the lower vibrational frequencies and passes the higher marker frequencies. This follows from the equation for capacitive reactance, $X_c = \frac{1}{2\pi fc}$, since the reactance varies inversely with frequency.

An optimum adjustment of R and c will permit maximum marker signal to pass for a given level of the disturbing signals.

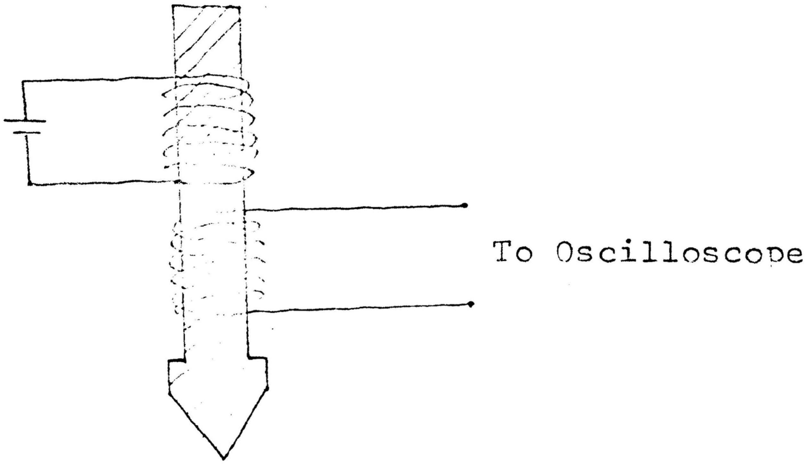
A good compromise adjustment can be made by tuning c to resonate with L_2, the inductance of the secondary winging on the chisel. At resonance, which is the condition for maximum current, $X_{L2} = X_c$, and $I = \frac{V}{R}$.

Since $X_{L2} = 2\pi fL_2$ and $X_c = \frac{1}{2\pi fc}$, the frequency at resonance, F_o, is found by equating X_{L2} and X_c, or:

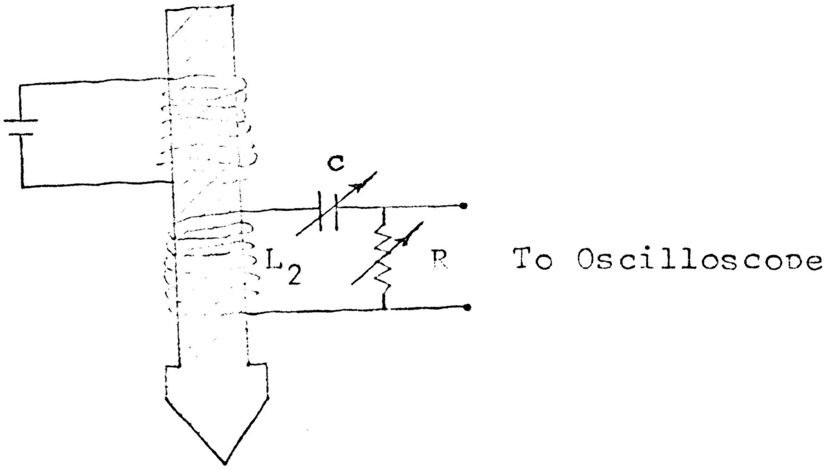
$$2\pi F_oL_2 = \frac{1}{2\pi F_oc}$$

or

$$F_o = \frac{1}{2\pi\sqrt{L_2c}}$$



(a) Simple Circuit



(b) Capacitor and Resistor as a Filtering Unit

Figure 11. Development of Crank-Angle Marker Circuit

F_o is the marker frequency determined by the number of slots and the speed of rotation. L_2 is the inductance of the chisel secondary and is determined by the wire size, chisel diameter, and number of turns of wire. Therefore, c is the only variable required to achieve resonance. R is varied to change the marker amplitude independently.

DATA RECORDING APPARATUS

The visible trace on the fluorescent screen is usually photographed by means of a lens camera, and owing to the very short duration of the spot and its high writing speed, a high intensity and a good actinic color are of importance. When the utmost sensitivity is needed for photography, or when there must be a minimum of afterglow, a screen with zinc sulphide as a fluorescent material is used. Such a screen has about six times more actinic effect on all photographic films, than other materials. For transient records it is usually necessary to employ an expensive lens having an aperture of f/1.9 or less, together with the fastest photographic films that can be obtained.

Note that the method of recording the oscilloscope images, as discussed herein, is not perfect. Thus, when the speed of the light spot on the screen is moderately high, the trace is apt to be somewhat blurred and requires a considerable amount of enlargement on account of the small scale on which the photograph must necessarily be taken.

The screen of the oscilloscope may be recorded by means of high speed camera, oscilloscope camera, or drum camera. Pictures taken by oscilloscope camera are small and will not retain accuracy for our purpose. For similar reasons, high speed cameras are also eliminated. The drum camera was constructed especially for this purpose. It consisted of a ten and one half inches diameter drum, driven by an electric motor. Photographic film was wrapped around the drum. The camera was also equipped with a conventional lens and shutter, (Figure 12). The pictures obtained by this camera were 33 inches long and 70 mm. wide, thereby retaining high accuracy for our purpose.

Figure 13 shows the drum camera with the black cloth removed. The drum was housed in a chamber which was covered with black camera cloth. The drum had a circumference of 33 inches and rotated at a maximum speed of 900 R.P.M., with the result that the traversing speed of the film was almost 0.5 miles per minute. The ends of the film were fastened by means of a screw-down wedge. Attachment for fixing the film must be extremely tight and rigid, and must ensure that a negligible quantity of the record is lost at the joint. The drum was directly placed on the motor shaft. Precautions were taken to minimize the vibrations of the electric motor. Motor was supported on the rigid base and the drum was balanced by attaching the balancing weight. For one complete engine cycle, the drum speed should be exactly one half of the engine speed. Therefore, during this investigation, a varidrive electric motor was used. Specifications of the lens and the electric motor are as follows:

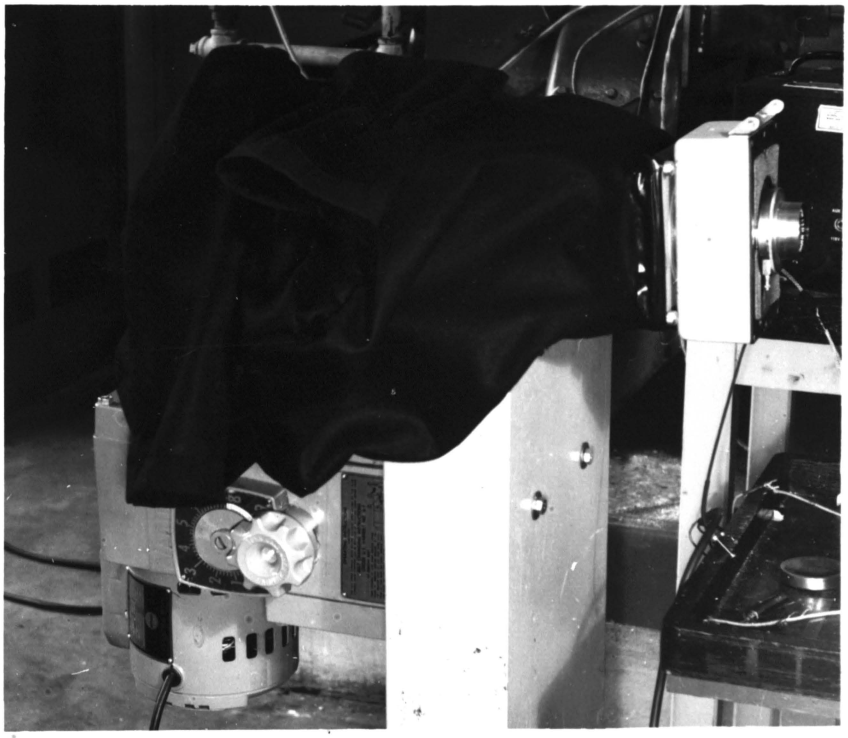


Figure 12. Drum Camera

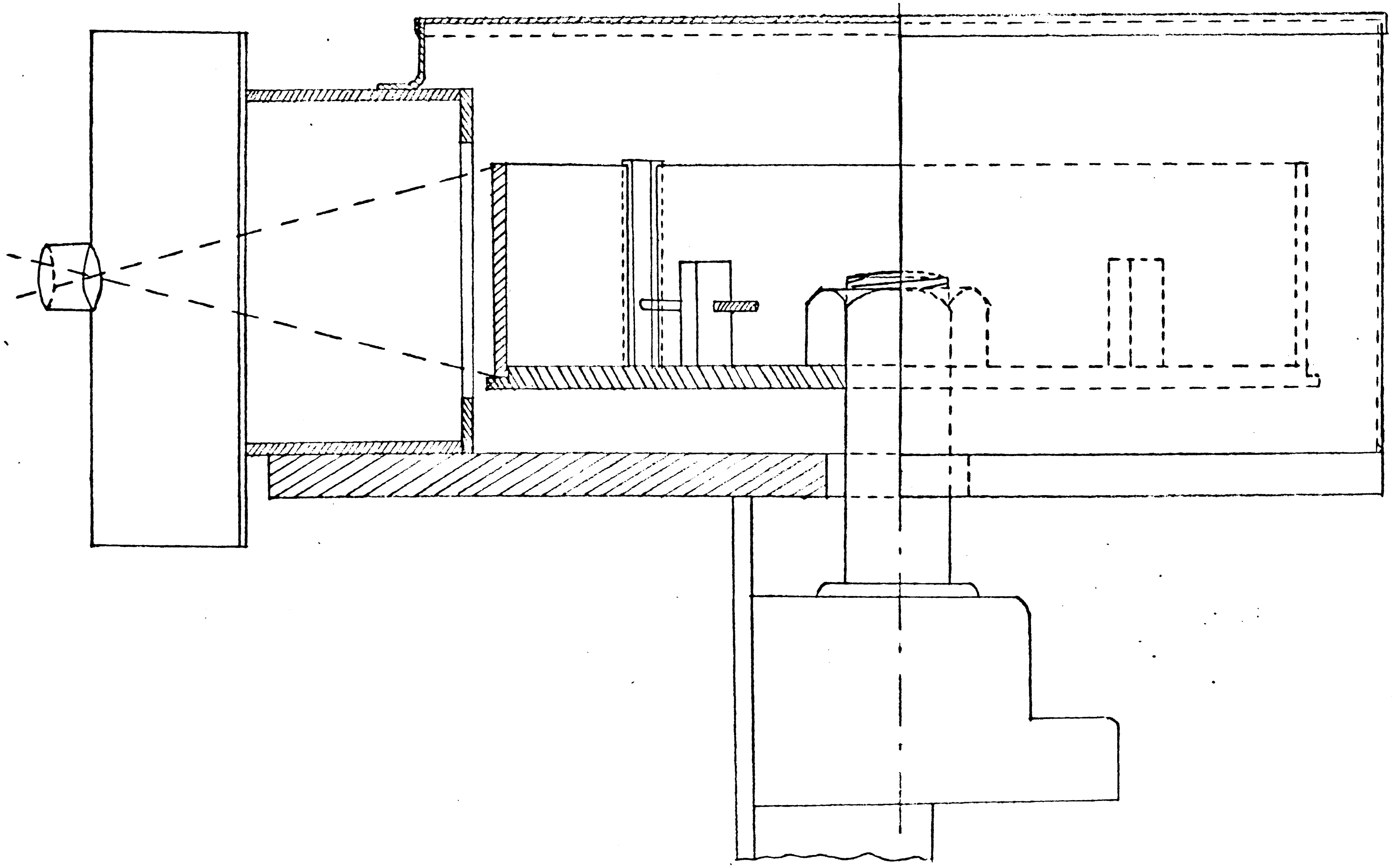


Figure 13. Details of Drum Camera

Lens:

Wollensak 3" (75 mm.)

f/1.9

Electric Motor:

H.P. 1/2, Phase 1, Cycles 60

Volts 115-230

Amps. 8.6-4.3

R.P.M. 106 minimum, 1055 maximum

Motor R.P.M. 1800

Figure 14 shows an arrangement of data recording apparatus. A Tektronix Model 502 dual beam differential input oscilloscope was also used. It employs one cathode-ray tube. Traces of two variables could be displayed simultaneously on the same X-co-ordinate base of the oscilloscope. Thus, pressure and crank-angle marking (or temperature and crank-angle marking) may be displayed simultaneously in such a manner that the actual pressure (or temperature) may be read directly for any desired engine position.

The recording of the oscilloscope traces were made by a different method. The usual pattern of crank-angle marker and pressure (or crank-angle marker and temperature) were displayed on the screen, and during a specific photographic time duration the sweep circuit was disconnected thereby only vertical motion of the points was obtained on the oscilloscope screen, whereas the horizontal sweep of the

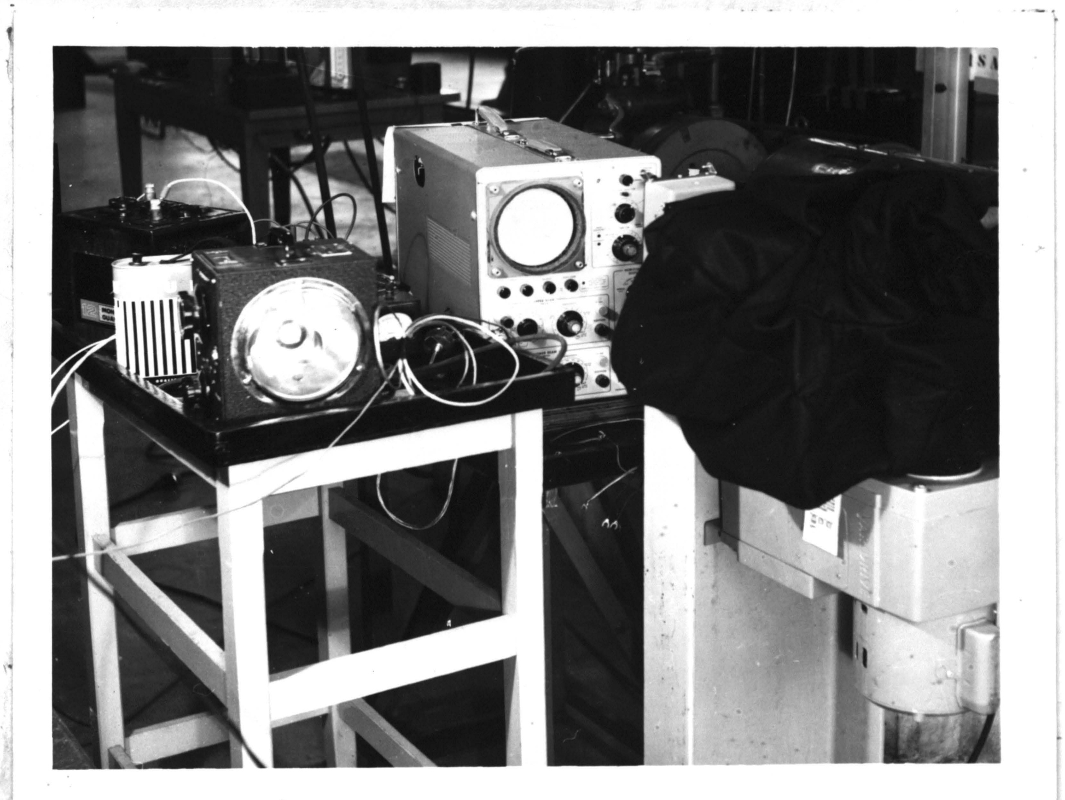


Figure 14. Arrangement of Data Recording Apparatus

oscilloscope was given by the drum rotation.

The distance between the lens and the film depends on the focal length of the lens and desired magnification. To ensure high accuracy, magnification, M, was kept nearly equal to one. It can be calculated as follows:

u = object distance
v = image distance
f = focal length

According to the lens equation: $1/u + 1/v = 1/f$,
$f = 75$ mm., $u = 150$ mm.,
Therefore, $1/150 + 1/v = 1/75$
or $v = 150$ mm.

The magnification, $M = v/u$

$$= 150/150$$

$$= 1.0$$

Because the lens used herein was of the compound type, the exact adjustment of the object or image distance became difficult; with the result that the actual magnification, M, that was obtained was 0.95.

This investigation included very high speed photography. Loading the drum camera was a challenging problem. Films of proper length were cut out in the photographic room and were placed, in total darkness, in a small tube. While loading the camera, this small tube was brought near the drum through the sleeve of camera cloth. The enclosed film was then wrapped around the drum with due care, thereby avoiding exposure to light and contamination. The quantity of light passing through a lens varies inversely with f^2, where f is the aperature of lens. As a result, when the camera was originally equipped with a f/4.5 lens, a smaller amount of light was passing through it and results obtained were very poor. In order to obtain better photographic results, extensive studies in processing the film had to be made.

CONCLUSIONS AND RECOMMENDATIONS

The results achieved in this investigation were as expected. However, there is still room for improvement. If more accurate results are to be obtained the instrumentation should be refined in the following manner:

1. For a better crank-angle trace on the oscilloscope (and photographic film), either the ratio of turns in the primary and secondary windings should be changed, or the primary supply voltage should be changed so that the difference in peak voltage with slot size becomes larger when compared to the magnitude of the voltage wave.

2. Regarding the placement of the pressure transducer on engine, the adapter on the cylinder head should be removed and the diaphragm of the pressure transducer should be fixed flush with the wall of cylinder head. This procedure serves two purposes. First, it eliminates any time-lag that may exist in the present arrangement. Second, and more important, it will eliminate an initial compression of the diaphragm which previously resulted in an initial reading of pressure transducer output.

3. From the Figures 15 and 16 of pressure versus crank-angle, it is evident that a sharper and clearer oscilloscope trace is required for improved accuracy. Decreasing the intensity made the crank-angles trace too faint thus making it difficult to read correctly. Therefore,

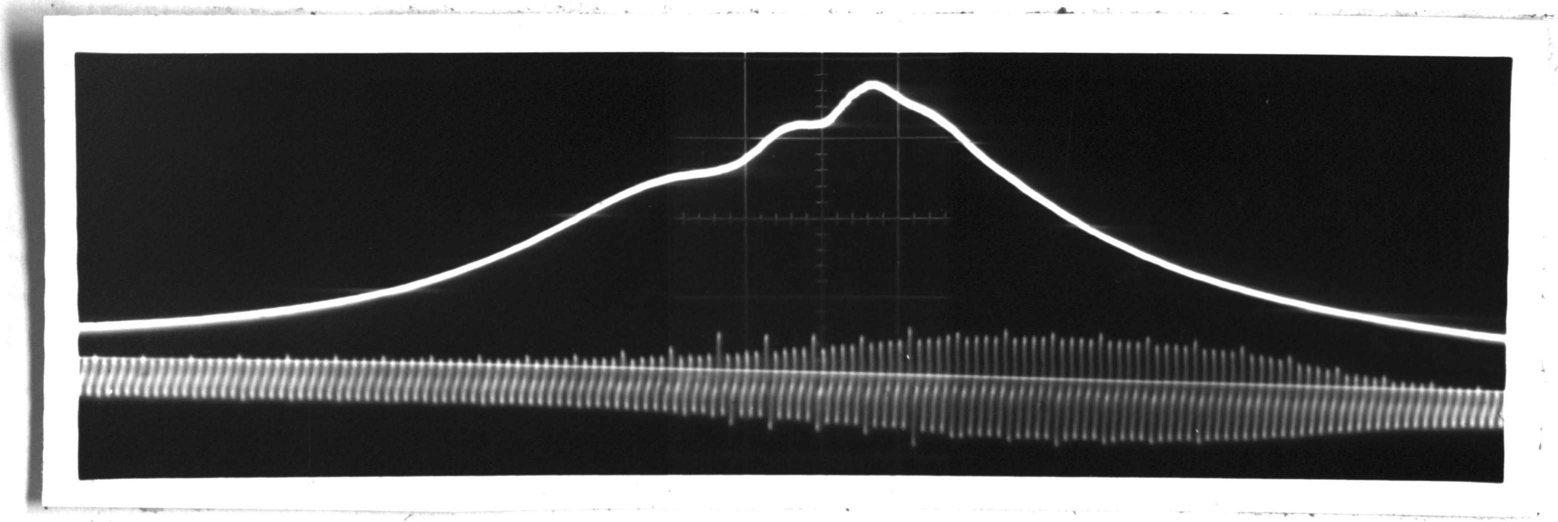


Figure 15. Pressure Versus Crank-Angle Diagram

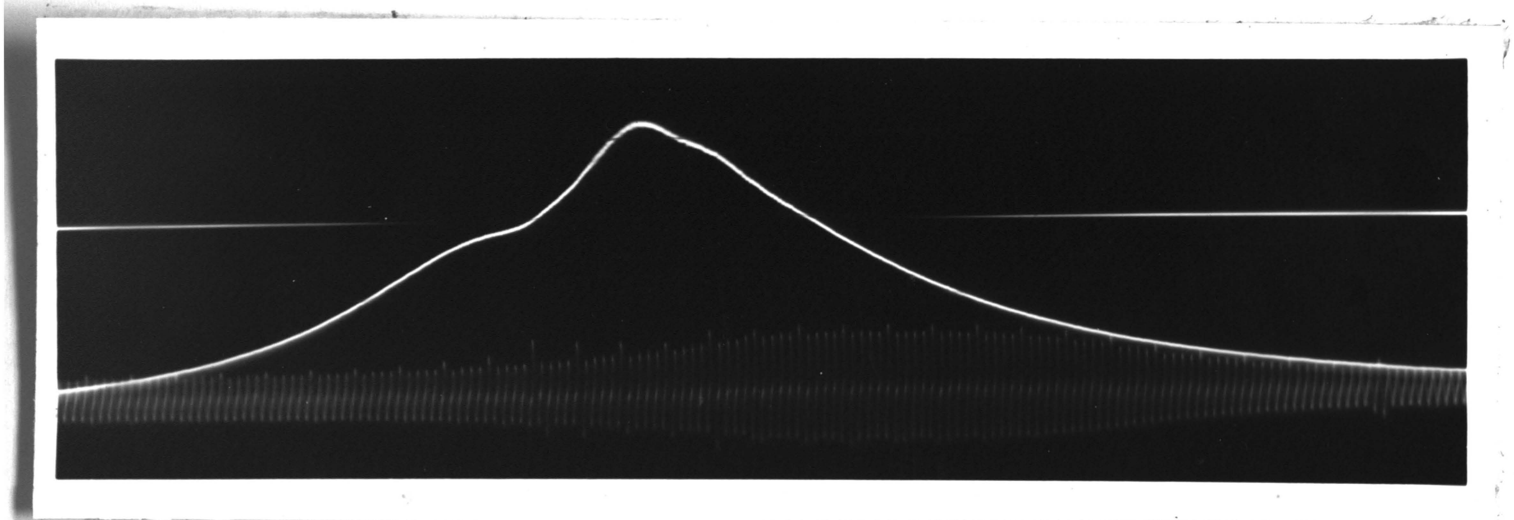


Figure 16. Pressure Versus Crank-Angle Diagram

if possible, an oscilloscope with separate intensity controls should be used in conjunction with the fastest possible film available.

4. The quantity of light passing through a lens varies inversly with f^2, where f is the aperture of the lens. For better results f should be kept to a minimum. With the present lens and shutter assembly, a smooth variation of shutter speed was not possible. Therefore, for some engine speeds, the shutter had to be kept open for a longer period of time than that needed to complete one engine cycle. This resulted in an overlapping of cycles on the film, with partial superposition of one crank-angle trace on another. An electronic trigger circuit operated by the exhaust valve of the engine should be developed. It could operate an oscilloscope sweep and thus put the trace on the screen for one cycle only.

BIBLIOGRAPHY

1. Wadman, R. W., "Diesel and Gas Engine Progress," Diesel Engines, Inc., May, 1948.

2. Judge, A. W., "The Testing of High Speed Internal Combustion Engines," Chapman & Hall Ltd., 1955, p. 19.

3. Livengood, J. C., Taylor, C. F., and Wu, P. C., "Measurement of Gas Temperature in an Engine by the Velocity of Sound Method," S.A.E. Trans., Vol. 66, 1958, p. 683-699.

4. Wienke, H. J., Myers, P. S., and Uyehara, O. A., "A Resistance Thermometer for Engine Compression Temperatures," S.A.E. paper No. 701 A, June, 1963.

5. Burrows, M. C., Shimizu, S., Myers, P. S., and Uyehara, O. A., "The Measurement of Unburned Gas Temperatures in an Engine by an Infrared Radiation Pyrometer," S.A.E. Trans. p. 514-528.

6. Nagel, "The Transfer of Heat in Reciprocating Engines," Engineering, Vol. OXXVII, p. 59, 1929.

7. Eichelberg, G., "Some New Investigations on Old Combustion-Engine Problems," Engineering, 1939, p. 463-466.

8. "General Information on Nanmac Thermocouples," Nanmac Corporation, Mass.

9. Bockemuehl, R. R., and Weller, E. F., "An Instrument for Recording Cylinder Pressure Versus the Crank Angle of an Internal Combustion Engine," S.A.E. paper No. 683, January, 1956.

10. United States Department of Commerce, "Reference Tables for Thermocouples," NBS Circular 561.

11. Overbye, V. C., Bennethum, J. E., Uyehara, O. A., and Myers, P. S., "Unsteady Heat-Transfer in Engine," S.A.E. Trans., p. 461-494.

VITA

Raman A. Patel

Born: October 7, 1938, Ahmedabad, India.

Education: Graduate of Gujarat University, India.

B. S. in Mechanical Engineering, 1962.

B. S. in Electrical Engineering, 1963.

Professional Societies: Student member of,

American Society of Mechanical Engineers.

Society of Automotive Engineers.