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ALTERATIONS AND TESTS OF THE "FARNBORO" ENGINE INDICATOR

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Summary

The "Farnboro" electric indicator was tested as received from the manufacturers, and modifications made to the instrument to improve its operation. The original design of disk valve was altered so as to reduce the mass, travel, and seat area. Changes were made to the recording mechanism, which included a new method of locating the top center position on the record. The effect of friction on the motion of the pointer while taking motoring and power cards was eliminated by providing a means of putting pressure lines on the record.

The modified indicator gives a complete record of the average cyclic variation in pressure per crank degree for any set of engine operating conditions which can be held constant for the period of time required to build up the composite card. The value of the record for accurate quantitative measurement is still questioned, although the maximum indicated pressure recorded on the motoring and power card checks the readings of the balanced diaphragm type of maximum cylinder pressure indicator.

Introduction

In the study of engine operation, it is of great importance to examine the cycle of events occurring in the cylinder in order to determine the effect of variations in engine operating conditions. A number of indicators have been developed to aid this study, and from those available the "Farnboro" was selected, because tests indicated that it was inherently a good type of high-speed indicator (Reference 1). However, the records obtained at the laboratory were incomplete, which showed that the instrument required modification in order to make its operation suitable for high-speed engine testing.

The "Farnboro" indicator is classified as an electro-pneumatic type of indicator (Reference 2). The principle employed consists in balancing the cylinder pressure, by means of gas pressure, on a small disk valve near the cylinder walls. This balancing pressure also acts on a piston whose motion is restrained by springs. The motion of the piston is transmitted by a link to a pointer which moves parallel to the axis of a drum rotating in time with the engine. The position of the pointer indicates the balancing pressure. The disk acts as a circuit breaker in the primary circuit of an induction coil, and induces a high tension spark at the instant the disk is lifted from its seat. This spark, in its path from the pointer to the drum, perforates a sheet of paper which is rotated on the drum. Two balance points are obtained for each cycle, one on the up-stroke and one on the down-stroke, and the card is progressively built up as the pointer moves parallel to the axis of the drum (Fig. 1) (Reference 3).

The "Farnboro" indicator was developed originally by the Royal Aircraft Establishment at Farnborough (Reference 4). This development has been continued by different institutions and reports published recommending minor changes in design and material (Reference 5). The present work covers a redesign of the indicating unit and additions and alterations to the recording mechanism.

The limiting conditions of speed and pressure of the modified indicator were not determined, since this work was done in conjunction with routine engine testing. The majority of tests were run at 1500 engine r.p.m., although the indicator was used at engine speeds up to 1800 r.p.m. The maximum pressure recorded during the tests was 1100 pounds per square inch.

Indicator Development and Results

The indicator, as received from the manufacturer, was set up and records taken from 5-inch by 7-inch single cylinder, four-stroke cycle carburetor and compression ignition test engines under normal operating conditions (Fig. 2). A reproduction of the photograph of a card taken with the original instrument under motoring conditions, is shown in Figure 3. It will be noticed that as the pressure increased, the number of points on the original card diminished, and that for about a 30-degree interval on the expansion line there are no points. An analysis of the cards was made to determine which elements of the indicator required improvement.

Indicating Unit.- The most serious difficulty found with the apparatus was in the indicating unit, and the trouble seemed localized in its disk and seats. They were, therefore, redesigned so as to reduce the mass of the moving element and decrease its travel. In the original design, the mass and travel of the disk is excessive so that at higher pressures there is not sufficient time between the balance point of compression and expansion for the disk to reach its other seat, or if it does make contact, the coil does not have time to become sufficiently energized to cause a spark at the pointer. A reproduction of the photograph of a card taken with the modified instrument is shown in Figure 4. The line of the record is complete. However, there is a slight decrease in the number of points as the pressure is increased, because the time available for the disk to complete its operation for registering the expansion line becomes so short that all conditions must be favorable for completing the circuit.

An enlarged view of the original disk and seats as contrasted with the modified design is shown in Figure 5. At a pressure of 700 pounds per square inch, the theoretical differential pressure required to operate the former was 253 pounds per square inch, while that required for the latter is only 1.5 pounds per square inch. These calculated differential pressures are based on the seat widths of the two designs, which are .034 and .004 inch, respectively. The disk movement of the old design was approximately .0125 inch with no provision for control, while the allowable motion of the new design is within the limits of .004 to .006 inch, and can be readily changed by varying the number of shims between the seats. The weight of the new disk is only 20 per cent of the weight of the original one. This reduction in weight, with its corresponding reduction in the inertia of the moving element, is of great importance in this type of indicator. These three major changes in the design of the actuating unit, weight, travel, and seat area, allow the disk to perform its function in such a short time that the card is complete even at high cylinder pressures and engine speeds. This disk valve has been successfully used to record rates of pressure rise of 1,000,000 pounds per square inch per second, which is about three times that of high-speed carburetor engines.

The disk and seats are made of stainless steel and can be used for 12 to 18 cards without repolishing. They can be repolished approximately 15 times before they are worn too thin for further use.

The electrical circuit to the disk in the original design was completed through a sliding contact with the guide stem.

This was found to be unsatisfactory, because sparking at the stem electrically welded the disk in place and stopped its operation. A positive contact was made to the floating disk, which eliminated the sparking. This contact was obtained by securing one end of a coil of copper wire to the spindle and the other end to the disk. The coil was 1/4 inch long and consisted of five turns of .010-inch diameter copper wire. The dimensions of the coil are relatively unimportant; however, the wire must be of sufficient size so that the electrical resistance is not too great. The coil must also be adjusted to give no spring action against the disk. The contact to the disk was obtained by fastening the wire to a duralumin plug and riveting this plug in the hollow stem of the disk. The other end of the coil was soldered to the guide with soft solder, which was found to be satisfactory as long as the seats were gas-tight.

Considerable difficulty was experienced because of arcing between the disk and seats. This trouble was reduced by correctly balancing the circuit by connecting a .2 mf. condenser across the disk and seats. This size condenser was selected after trying a number of different capacities in the circuit and observing the spark made at a telegraphic key inserted in the circuit. The detrimental effect of the spark on the disk and seats was further decreased by using an inert gas instead of air as the balancing pressure. In this work helium was used, because of a convenient local supply; however, nitrogen would be just as satisfactory. The use of carbon dioxide is recommended where the cylinder pressures do not exceed 750 pounds per square inch because the normal pressure of the liquid is not great enough to over-stress the disk in case the valve is accidentally opened.

Excessive gas leakage from the valve body gave a great deal of trouble during the tests. In an effort to stop the gas leakage of the valve, the clamping nuts around the original porcelain insulator were finally made so tight that the porcelain was broken. It was replaced by a laminated micarta insulator of the same dimensions. This material allowed the nuts to be screwed down tight enough to stop the leaks, and no more trouble was experienced from this source. Leakage of gas around the spindle was stopped by means of a packing nut.

The greatest defect in the actuating unit at the present time is the limited life of the disk and seats. This appears to be an inherent difficulty with this type of valve. The present work was directed towards using small voltages with the corresponding smaller currents to be handled by the disk. Voltages of the order of 16 to 24 volts are also being tried, using a resistance in the circuit. This is the practice recommended from the tests made at McCook Field (Reference 5). A possible line of future development of the indicating unit is the use of double contact diaphragm type of valve that can be used in an electrical circuit employing small currents which can be amplified for recording. A mechanical problem to be solved in connection with this type of valve is that the diaphragm must operate either flush with the cylinder walls or within a short distance from them with no connecting passages. The present type of valve can be operated satisfactorily with the disk within 1/4 inch of being flush with the cylinder walls.

Recording Mechanism.- It was suspected that some of the missing at the pointer was due to leaks in the high tension system, so the insulation was examined and several points were located which looked as if the sparks were being shorted to the ground. The failures were attributed to defective material; therefore, the whole electrical system was overhauled. This same difficulty was experienced at McCook Field (Reference 5). The coil supplied with the indicator became punctured, so several different spark coils were tried until one was found which gave satisfactory operation. The selection was based on the ability of the coil to produce a spark which would make a visible perforation in the recording paper using a minimum voltage in the primary circuit and the sensitivity of the coil in responding to rapid changes of voltage in the primary circuit. The coil selected was a 6-volt ignition coil which gave good operation on 2 volts.

Following the recommendations of an industrial laboratory, a paper designated as "Litho-black" was tried and found to be very satisfactory. This paper, which was black on one side and white on the other, resulted in the points on the diagram being very distinct even when using 2 volts on the primary circuit. A comparative test was made with this paper and that supplied with the indicator, using 2 volts on the primary electrical circuit. The perforations in the paper supplied with the indicator could not be located while those in the new paper were very distinct.

The indicator drum was driven from an extension of the engine cam shaft (Fig. 2). The rigid connection with this shaft caused excessive vibration of the sparking point. To absorb the shocks causing this vibration, one of the universal joints of the drive-shaft was replaced by a short length of rubber hose. The method of driving the drum is an individual problem for each condition of service. In any set-up, the indicator must be free from excessive vibration. The importance of this was clearly demonstrated in these tests, since the dispersion of the points along the lines of the cards was reduced approximately one-half by using the flexible drive-shaft coupling.

The static method of timing the drum recommended by the manufacturers, had never been considered satisfactory, and the use of this shock absorbing drive-shaft made the development of an accurate method of timing necessary. A circuit breaker was connected to the crank shaft of the test engine and another induction coil was added to the indicator, so that the top center line could be generated by sparks at the same time the balance points in the cycle were being recorded. The circuit breaker was timed to break at top center and then checked by pasting a piece of paper to the flywheel of the engine and allowing the sparks to jump from a fixed electrode to the flywheel at test speed. The perforations in the paper were compared with the top center line which was located on the paper before making the check. The use of this circuit breaker on the crank shaft makes the rotational phase of the drum independent of that of the engine, since the perforation on the paper indicates the true top center at the same time the balance points are recorded.

The value of the cards is closely related to the known degree of accuracy with which the indicated pressures can be read. To facilitate this reading, pressure lines were placed on the record by means of sparks (Fig. 4). A calibrated Bourdon spring gauge was placed in the pressure line at a point near the recording piston. At the same time the pressure diagram is being recorded, the operator causes a shower of sparks to be made as the gauge indicates predetermined pressures by pressing a button to close the primary circuit of a vibrator coil.

The design of the moving parts of the pressure indicating element of the recording mechanism has inherently too much friction. This causes the motion of the pointer to lag behind the true pressure when indicating balance points at the cycle. The manufacturer claims that the method of calibration recommended takes care of this. However, that is not quite true since the indicated pressures will be different for different operating speeds of the recording mechanism. The method of calibration described in this report gives not only a running calibration, but permits calibration lines to be placed on each record. Using this method, the maximum indicated pressure checks the readings of the balanced diaphragm type of maximum cylinder pressure indicator to within ±2 per cent at 750 pounds per square inch. This type of indicator is similar to that described in Reference 1, and has been further developed at the laboratory.

The same induction coil was used for both the top center line and the pressure lines with the high tension terminal connected directly to the pointer (Fig. 1). This method of completing the circuit resulted in grounding the sparks which indicated the balance points in the engine cycle. To avoid this difficulty, a 1/4 inch gap was left in the high tension line, and since the auxiliary system was operated on 6 volts and the main system on only 2 volts, this gap acted as a one-way electrical valve. There has been no difficulty in operating the various electrical systems using this safety gap.

The manufacturer recommends that the voltage on the primary of the induction coil be kept at 6 volts; however, the lower voltage used with its corresponding decrease in current is desirable to increase the life of the disk and seats. This is particularly important when using the sharp seats of the present design. The initial reduction in voltage of 2 volts was permitted by using the new paper. Then the effective length of the spark gap in the main circuit was reduced by using a piece of .005-inch spring brass to make a wiping contact along the high tension bar, the friction of which was negligible as compared with the friction of the air piston. This change permitted the new coil to operate in the main circuit of the indicator with good results. The resulting spark at the pointer when using the low voltage, is less liable to be drawn out along the direction of rotation of the drum. The spark has been constantly under observation since making the changes for evidence of dispersion, and only an occasional case has been noted. To all appearances, the spark jumps straight from the pointer to the drum. This observation is borne out by the narrow lines of the resulting cards.

The friction in the pressure indicating element causes considerable distortion of the light spring diagram. The same method of eliminating the effect of friction as used in taking motoring and power cards could not be used in taking the low pressure cards, because the forces acting are not large enough to cause uniform motion of the pointer. An attempt was made to decrease the friction and leakage by improving the fit of the air piston in its cylinder. The piston was turned down and a sleeve pressed on which was turned and lapped to fit the cylinder. Using the new piston, the pointer could be displaced a slight amount and it would more nearly return to its original position. However, the movement of the pointer is still too sluggish to give good light spring diagrams. This difficulty was overcome at McCook Field by the use of an oil reservoir placed near the recording piston, and allowing the pressure to be transmitted by the oil to the piston (Reference 5). In the present work at the laboratory, the low pressure cards were unimportant and did not justify the application of an oil reservoir to the indicator.

Conclusions

The "Farnboro" indicator modified, as described in this report, gives records which can be used to determine the effect of variables in the engine operating conditions. The value of the record for quantitative measurements requiring a high degree of accuracy is still questioned, although the maximum pressures recorded on the motoring and power cards check the pressures indicated with the balanced diaphragm type of maximum cylinder pressure indicator to within ±2 per cent at 750 pounds per square inch and normal rates of pressure rise. The deviation of the pressures indicated on the motoring and power card, as determined by the location of the pressure lines, is ±5 pounds per square inch.

The chief defect in the records obtained with the modified indicator is found in the light spring record. The point at which a definite variation occurs in the suction or exhaust stroke can be located, but its magnitude cannot be determined due to the inaccuracy of the indicated pressures.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 9, 1930.

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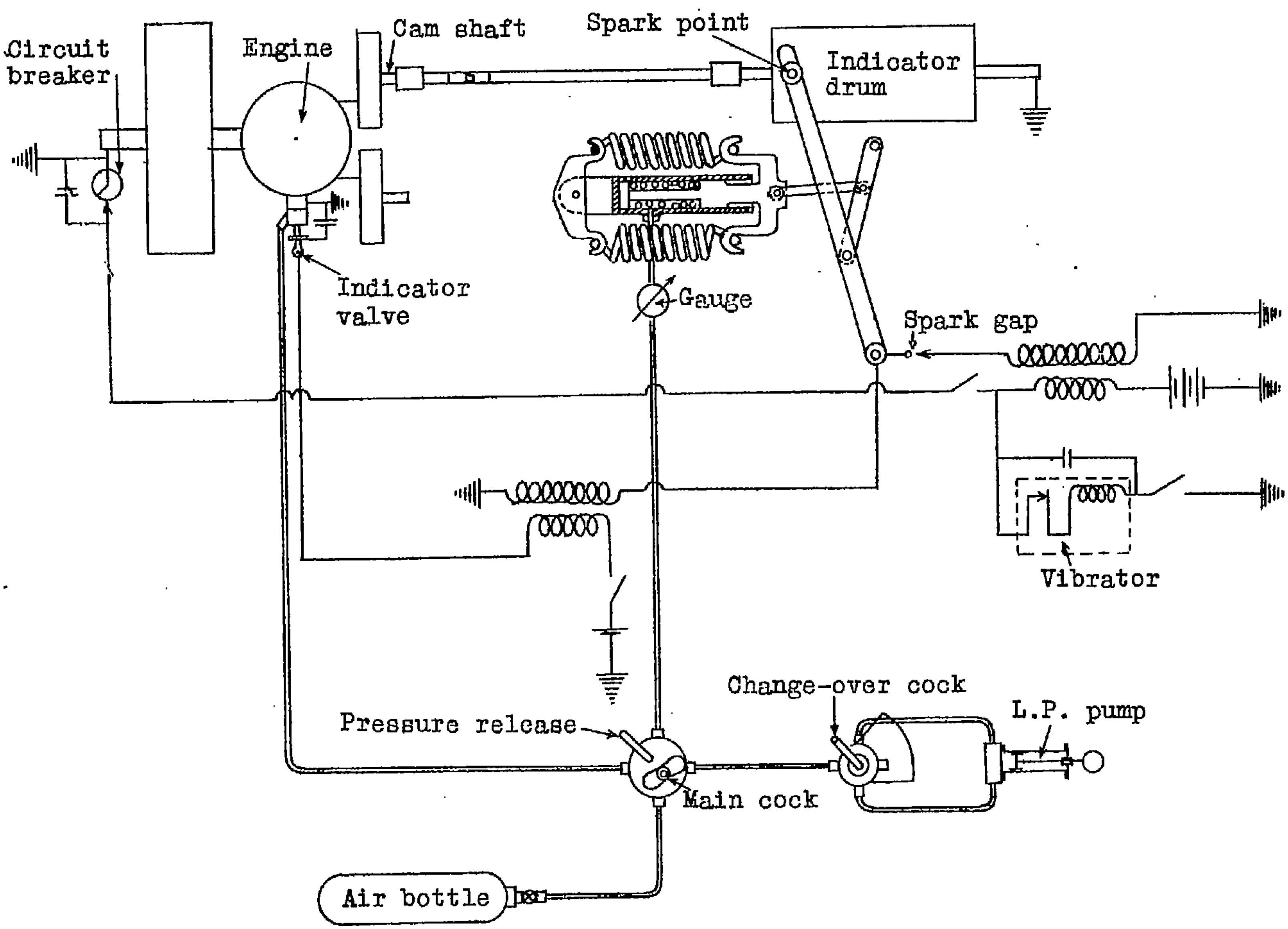


Fig.1 Diagrammatic sketch of Farnboro indicator with auxiliary circuits.

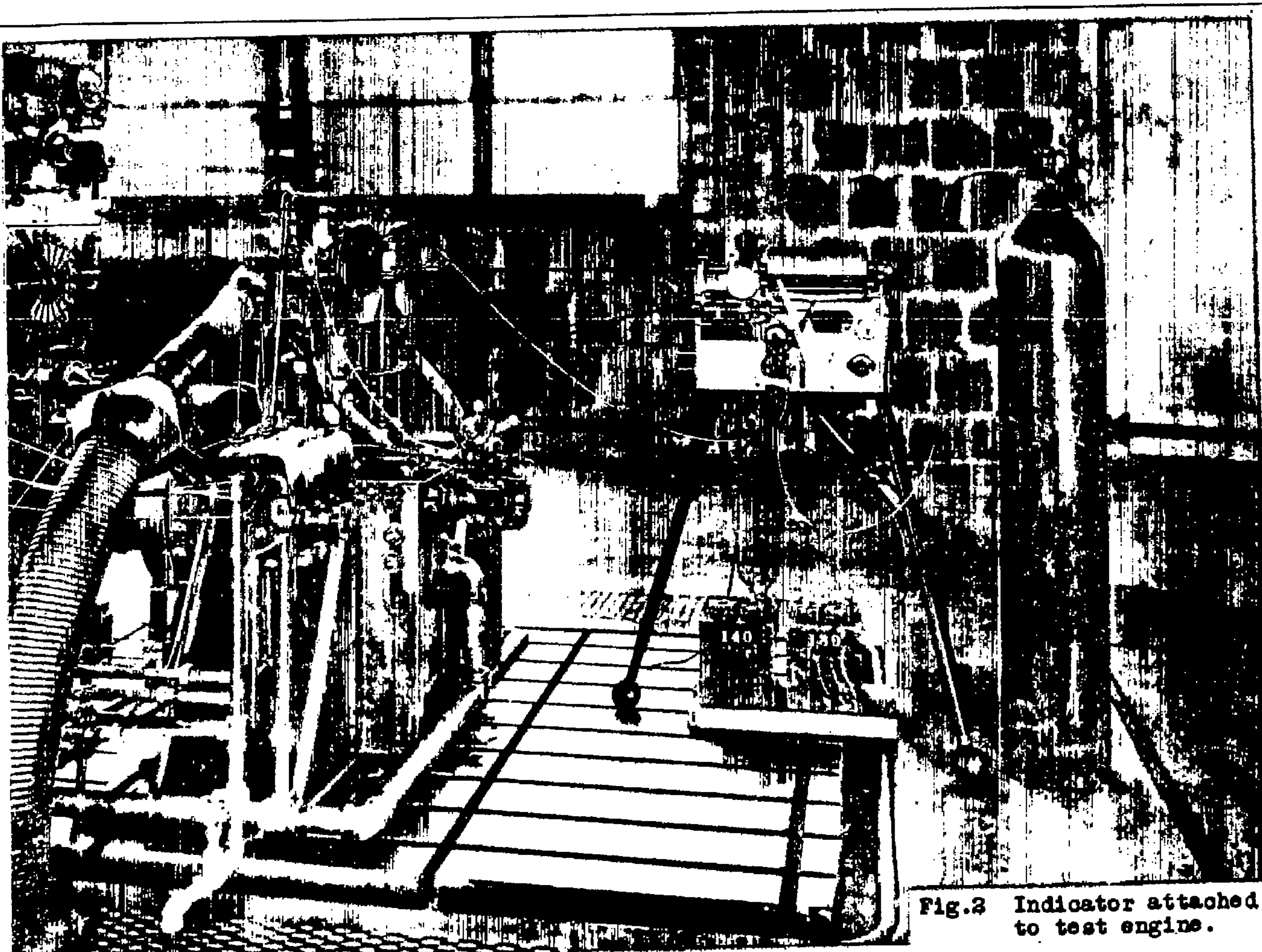


Fig.2 Indicator attached to test engine.

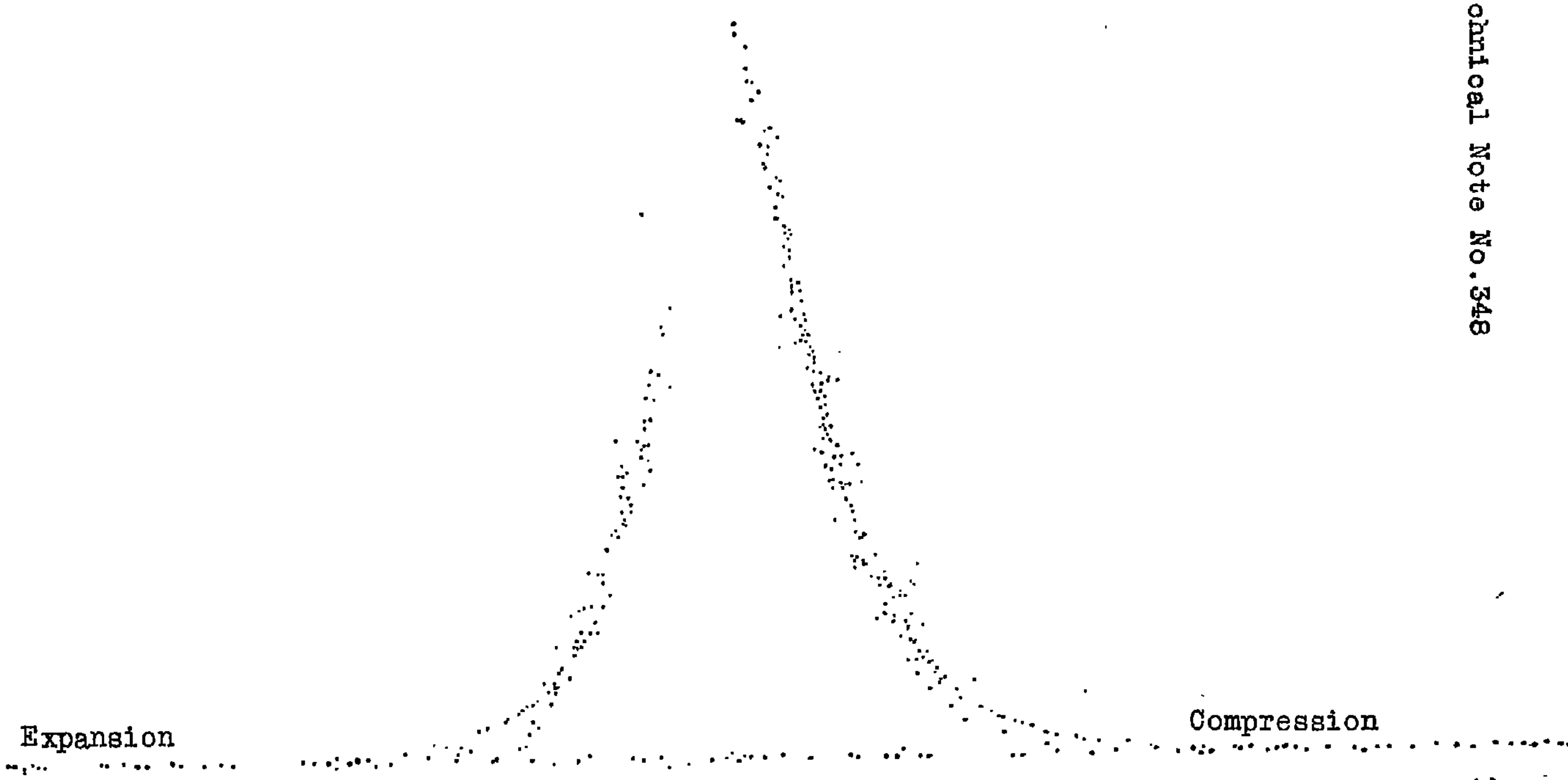


Fig.3 Reproduction of photographs of card taken with indicator as received from manufacturer. Engine motored at 1600 r.p.m. Compression ratio = 13.5.

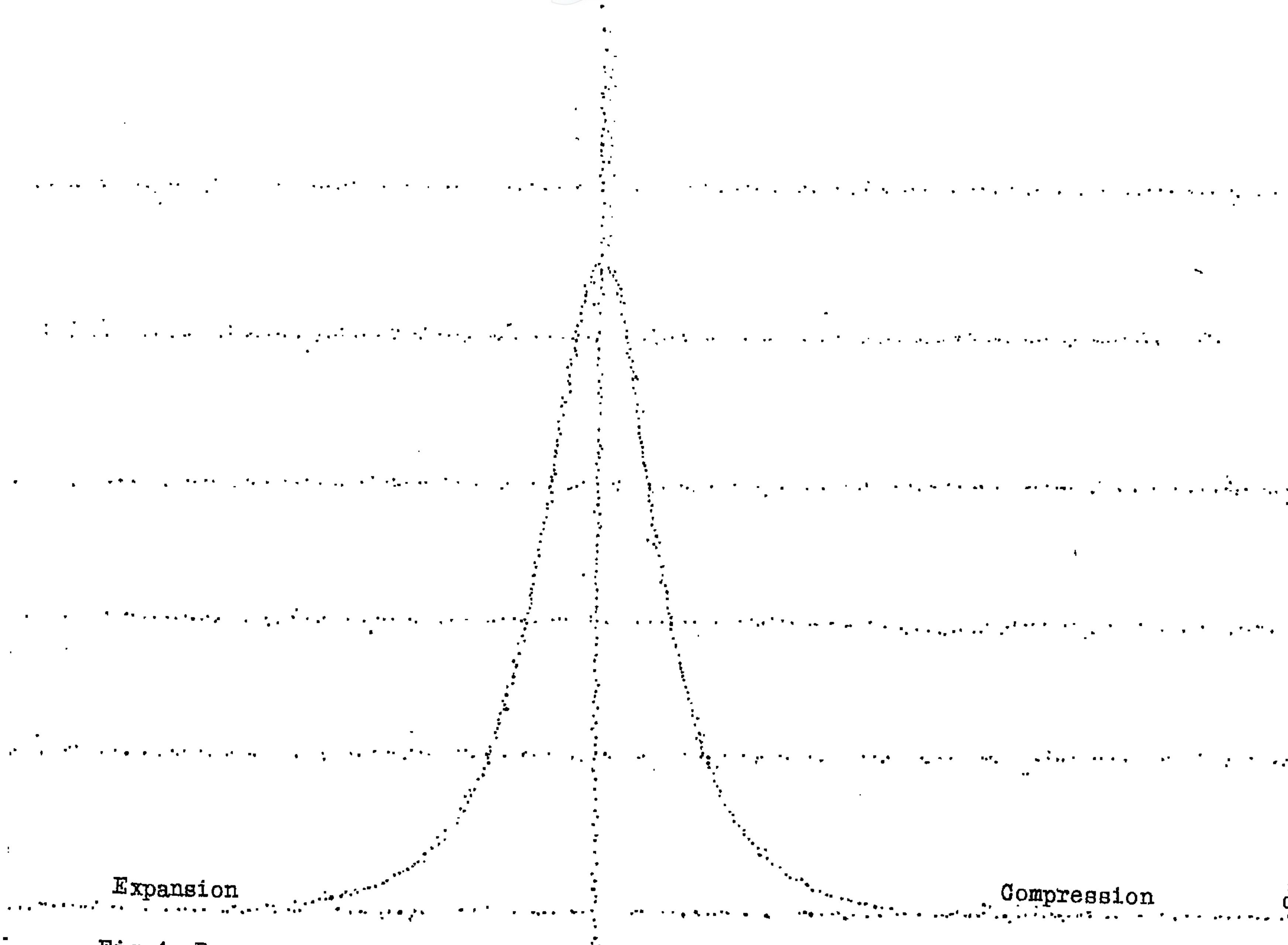
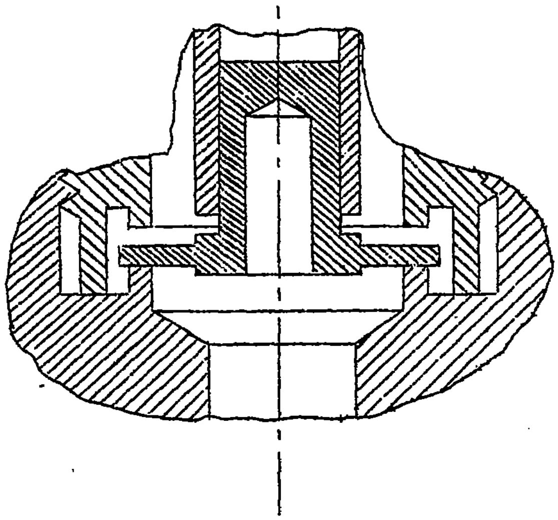
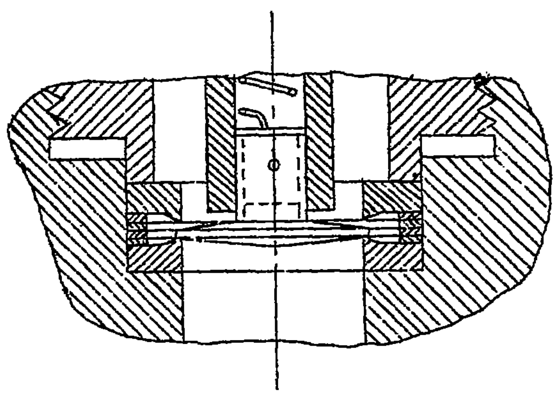


Fig.4 Reproduction of photograph of card taken with modified indicator.
Engine motored at 1600 r.p.m. Compression ratio = 13.5.



Original design



Modified design

Fig.5 Enlarged view of original design of disks and seats as contrasted with modified design.