ENCLOSURE (B) 36

ENGINE DETONATION STUDIED BY PIEZOELECTRIC INDICATOR

by

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LIST OF TABLES AND ILLUSTRATIONS

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SUMMARY

To catch precisely the detonation waves in engine cylinders a pressure indicator of high natural frequency must be used. For this purpose, piezoelectric indicator was most suitable, but there was no reliable one in Japan when this work started. An effort was made to make this. Many types were made. Some types gave a good indicator card but they were innient in practical use, and some were rather brittle. The best one is shown in Figure 3(B)36. Tests were performed by C.F.R. engine, L-head engine with quartz window and B.M.W. single cylinder testing engine and they were proved to be satisfactory. It was used in many full scale engines including HOMARE, 2000 hp class engine to find detonation or to explore combustion phenomena.

Although it gave good indicator cards for small engines, there appeared vibrations on pressure line when used in high power engines. Since the frequency of these vibrations was not so high, it was not due to the defect of pick-up itself. Perhaps it was due to the vibration of amplifier valves caused by the severe pressure changes of surrounding air due to exhaust gas pulsation. This is unavoidable unless the amplifier is put in a sound-proof box. But these vibrations were not troublesome to find out detention or to calculate indicated horse power from the indicator card.

I. INTRODUCTION

A. History of Project

In the previous work in which flame propagation was photographed, bright striped patterns were found in the detonation flame. To determine whether this is due to the adiabatic compression or rarefaction in the detonation waves, it is necessary to measure the pressure inside the cylinder with an indicator of small inertia and high natural frequency. At that time, the Maihak indicator (spring type), the Farnboro indicator (balanced pressure type) and the Nakanishi indicator (optical type) were used at the First Technical Depot at YOKOSUKA. The Maihak indicator is not suitable for high speed engines. With the Farnboro indicator, one indicator card is obtained by a great many explosions and it is difficult to examine vibrations on the indicator card. With the Nakanishi indicator, the pressure line is broadened and faint. So it is not suitable for accurate measurement.

A piezoelectric indicator had been used at the Aeronautical Institute of Tokyo Imperial University. It was a water cooled type and as the rod which transfers pressure from diaphragm to quartz was long and the natural frequency was so low that undesirable vibrations were observed on the pressure line, even used on a small engine. It is necessary to give to the moving part a natural frequency of the order of 50,000 cycle. From April 1935 onwards the author tried to make an indicator of the air cooled type. So, many types were constructed, and many experiments were performed by many kinds of engines. These experiments were completed in the year 1939.

B. Key Research Personnel Working on Project

Naval Engineer K. NAKATA.

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II. DETAILED DESCRIPTION

A. Description of Test Apparatus and Test Procedure

The structure of the indicator designed at the outset is shown in Figure 1(B)36. The author was not free from the idea of old type using steel ball and lead wire conducted from the side of the case. The diaphragm was made from the same block as the case but the supporter of the quartz was a different piece from the diaphragm, so undesirable vibration appeared on the pressure line in the indicator card. So the second type was made, the structure of which is shown in Figure 2(B)36. In this type, the quartz supporter and the diaphragm were made in one piece and this was screwed in the case with a heated fitness. Four quartz pieces were used to get high sensitivity. This type gave a satisfactory results in regard to the smoothness of the pressure line, but as the height of the quartz was small, it had the tendency of leakage in a hot, humid season. After many trials, a type was reached which is shown in Figure 3(B)36. This type gave satisfactory results and preferably used in all cases.

Lead wire from the indicator to the amplifier must be shielded to avoid the disturbances from the ignition spark. When the wire vibrates, the distributed capacity between the wire and the shielding metal changes and this causes vibrations on the pressure line, so the wire must be kept rigidly in the center of the shielding metal. The wire, the structure of which is shown in Figure 4(B)36, gave the best results.

The vacuum tubes used in the amplifier was U X 54 for the first stage and six U X 171 A tubes in parallel for the second stage. Batteries were used as electrical source. These were put in a steel case to protect from electromagnetic disturbances.

The output from the amplifier was put in YOKOGAWA'S 6 element electromagnetic oscillograph, and the pressure-time curve in the engine cylinder was observed on the rotating mirror or photographed on the rotating film. A-type vibrator whose natural frequency in air is 6000 cycles was generally used.

The time mark on the film was made by the alternating current wave from the 1000 cycle vibrator.

A small hole was drilled at the periphery of the fly wheel. Light from a small pealamp was so arranged to pass through this hole when the piston was at Top Dead Center. The light which came through the hole fell on a photocell and the photocurrent flowed at the instant when the piston was T.D.C. The photocurrent was amplified by vacuum tubes and led to the oscillograph to give a T.D.C. mark on the film.

Ignition timing was marked on the film in the following manner. A wire was wound 2 or 3 times on the high tension wire used for spark ignition. Electric inductions were caused in this wire when ignition spark passed through the spark plug. These inductions were amplified and led to the oscillograph.

The indicator was always calibrated before and just after it was used by a Gauge tester of the oil pressure type.

Cooling air for the indicator was sent from a small compressor. The oil vapour and the humidity in the cooling air were removed by the oil separator and $CaCl_2$ respectively.

B. EXPERIMENTAL RESULTS

1. Indicator Cards of C.F.R. engine. Figures 5(B)36 and 6(B)36 show the indicator cards taken with the C.F.R. engine and the former corresponds to no knocking and the latter knocking conditions. As the engine is small and the speed is low, the pressure lines are smooth. There are vibrations of small amplitude on the expansion line of the knocking indicator card. The frequency is measured and plotted against the crank angle shown in Figure 7(B)36. This is over 7000 cycle at T.D.C. and decreases as the piston goes down from T.D.C.

2. Indicator Cards of "Hinode" L-head Engine with the Quartz Window. By this engine, the indicator card and the photograph of flame propagation were taken simultaneously. A new cylinder head was constructed which had two plug holes, one of which was used for the ignition plug and the other for the indicator pick-up. In Figure 8(B)36, the indicator card and flame photograph corresponding to detonation are shown while in Figure 9(B)36 those corresponding to preignition. In the case of normal combustion, the pressure curve in the indicator card is smooth and no striped patterns were observed in the flame photographs. But in the case of detonation or preignition, pulsating pressure changes are observed corresponding to the striped patterns in the flame photographs.

Figure 10(B)36 is the plot of this frequency against the crank angle. The frequency of the striped patterns is also plotoed in the same figure. It is very curious that the frequency of the vibration in the pressure line is almost double that of the flame.

3. Indicator Cards of B.M.W. Testing Engine. This testing engine was constructed at the D.V.L. Laboratory in Germany. It has a water cooled B.M.W. single cylinder and is a variable compression type. In Figures 11(B)36 and 12(B)36 are shown some indicator cards of this engine. Figure 11(B)36 shows the normal combustion. Knocking occurred occasionally in the case of Figure 12(B)36. These indicator cards were taken in the early stage of this work (1937) and the indicator was not refined and so we find unfavourable vibrations on the pressure lines. The frequency of the knock vibration is plotted against the crank angle in Figure 13(B)36. The frequency is small compared with those observed in the C.F.R. engine or other small engines. This is due to the larger bore of this engine.

4. Indicator Cards of Kinsei, Homare, and other Full Scale Aero Engines. Many indicator cards were taken for the study of combustion and detection of detonation in full scale aero engines such as "Kinsei" and Homare. But none of them was left to-day. They were more improved than those shown in Figure 11(B)36 or 12(B)36. But when the engine was running with high power, vibrations began to appear on the pressure line. Judging from the nature of these vibrations it was supposed to be due to the vibrations of amplifier tubes which were compelled to vibrate by the severe pulsations of exhaust gas.

III. CONCLUSION

Piezoelectric indicator of the air cooled type was constructed and tested on every kind of engine. After many improvements the best type was determined.

There appeared vibrations in the pressure line when the engine detonated. The frequency of the vibration was larger when the engine was smaller and smaller

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when a large cylinder was used. The frequency decreased as the piston went down from T.D.C.

When the indicator card was taken simltaneously with the photograph of engine flame, the number of vibration on pressure line was almost twice the number of bright striped patterns in the detonating flame.

As to the absolute value of the pressure, it was not satisfactory to use such an oscillograph of low natural frequency as was used in this work. It was preferable to use cathode ray oscillograph. The author had been preparing a cathode ray oscillograph but had no time to use it.

Figure 1(B)36

PIEZOELECTRIC INDICATOR - TYPE I

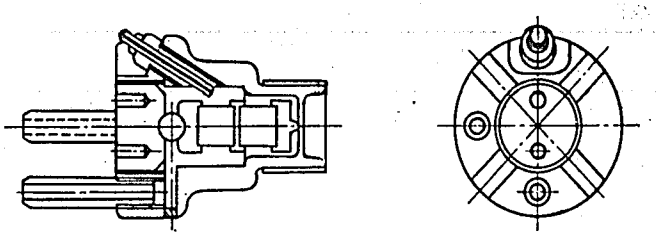
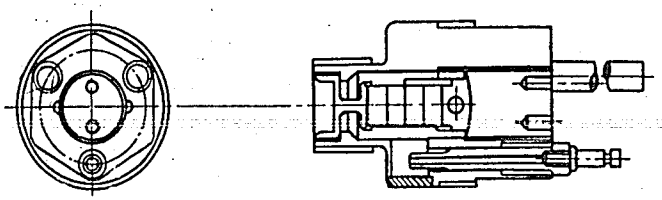


Figure 2(B)36

PIEZOELECTRIC INDICATOR - TYPE II



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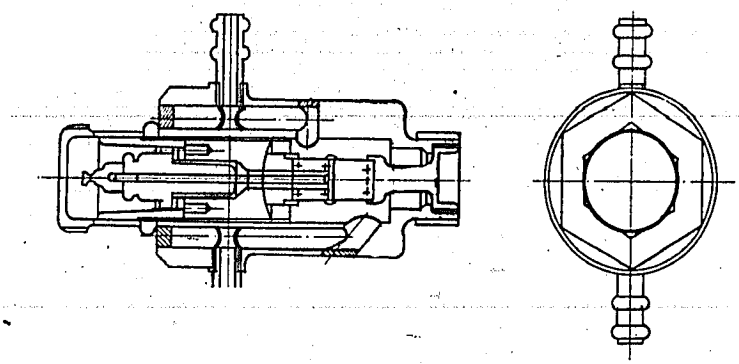

Figure 3(B)36
PIEZOELECTRIC INDICATOR - TYPE VII

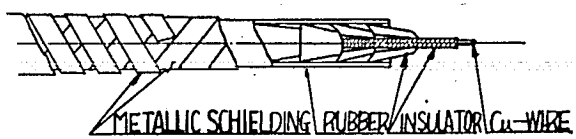

Figure 4(B)36
LEAD WIRE

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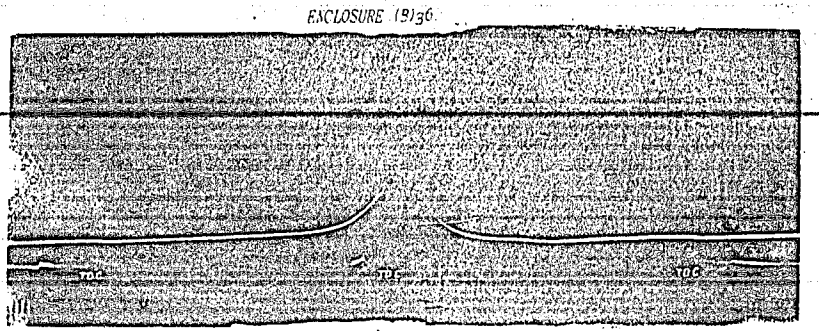

Figure 5(A)56

INDICATOR CARD OF A C.F.R. ENGINE
NORMAL COMBUSTION

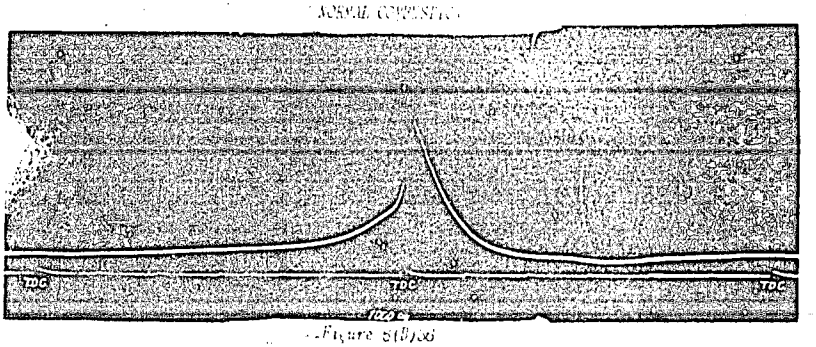

Figure 5(B)56

INDICATOR CARD OF A C.F.R. ENGINE
KNOCK CONDITIONS

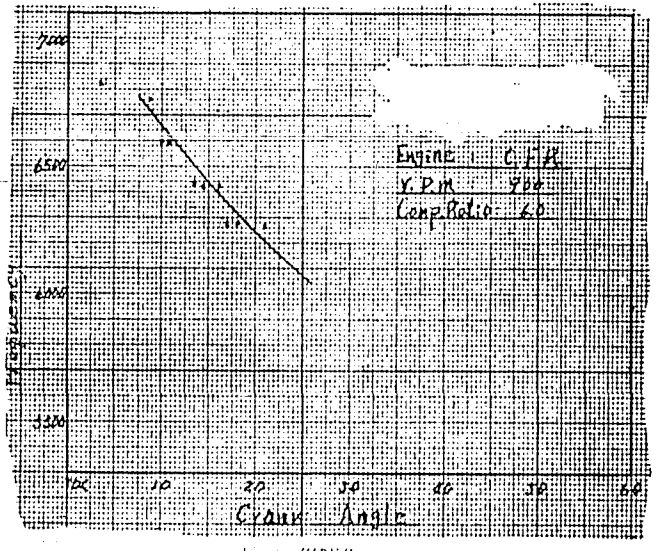

Figure 7(B)56

FREQUENCY OF DETONATION WAVES

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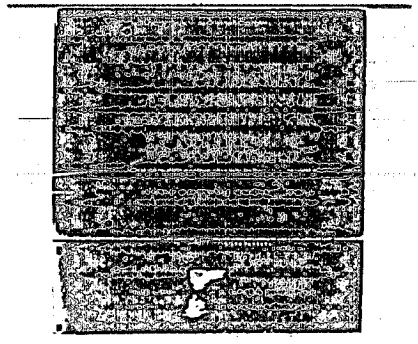

Figure 8(B)36

INDICATOR CARD TAKEN WITH HINODE L-HEAD ENGINE
FLAME PHOTOGRAPH CORRESPONDS TO DETONATION

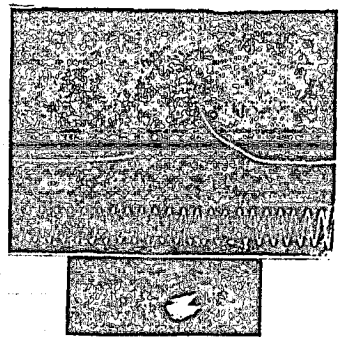

Figure 9(B)36

INDICATOR CARD TAKEN WITH HINODE L-HEAD ENGINE
FLAME PHOTOGRAPH CORRESPONDS TO PREIGNITION

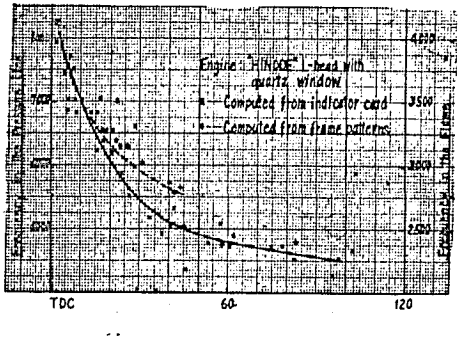

Figure 10(B)36

FREQUENCY OF DETONATION WAVES

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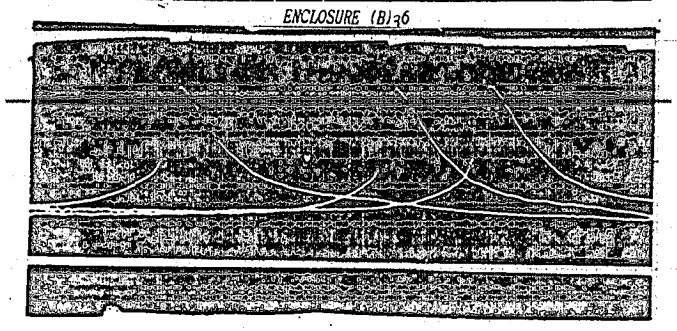

Figure 11(B)36

INDICATOR CARD OF B.N.W. SINGLE CYLINDER ENGINE
NORMAL COMBUSTION

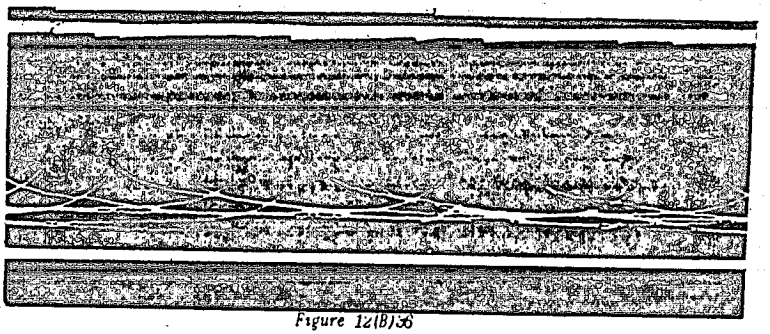

Figure 12(B)36

INDICATOR CARD OF B.N.W. SINGLE CYLINDER ENGINE
OCCASIONAL KNOCKING

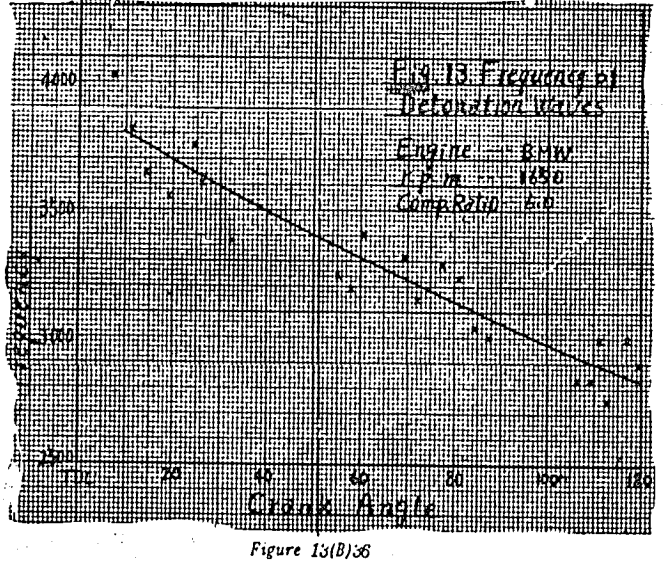

Figure 13(B)36

FREQUENCY OF DETONATION WAVES