ENCLOSURE (B) 37

FLAME PROPAGATION IN ENGINE CYLINDERS STUDIED BY THE IONIZATION METHOD

by

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SUMMARY

Flame propagation in aero engine cylinders was studied by the ionization gap method. For an air cooled engine, the Kotobuki 9 cylinder radial engine was used and for a water cooled engine, the BMW single cylinder testing engine was used. Running conditions were varied and their effects upon speed were determined.

I. INTRODUCTION

A. History of Project

This work was carried out during the period from April, 1935 to March, 1940. There were still problems to be investigated with small testing engines, but our interest was directed to the study in full scale engines. As it was very difficult to put a quartz window over the head of a full scale engine, the ionization gap method was used. For this purpose, a specially designed small plug was prepared by the Tachikawa factory for the air cooled engine. As the engine did not belong to our party, experiments were performed intermittently when the engine was not occupied by other persons. For the water cooled engine, usual spark plugs were used as ionization gaps.

B. Key Research Personnel Working on Project

Eng. Lt. Comdr. K. NAKATA

II. DETAILED DESCRIPTION

A. Description of Test Apparatus

For an air cooled aero engine, the Kotobuki nine cylinder radial engine was used Its essential dimensions were as follows:

Bore	146mm
Stroke	160mm
Compression ratio	5.25
Rated hp	460 hp
Rated revolution	2100 RPM

One cylinder was installed with one indicator and eight ionization plugs as shown in Figure 1(B)37. The structure of the ionization gap is shown in Figure 2(B)37.

For a water cooled engine, the D.V.L. variable compression testing engine was used. B.M.W. engine single cylinder was installed in this engine. Its main dimensions were as follows:

Bore	160mm
Stroke	180mm
Compression ratio	7.0
Speed	1400 RPM

Six holes were drilled equidistantly around the combustion chamber, as shown in Figure 3(B)37. One or two holes were used for ignition spark plugs and the remainder for ionization plugs.

ENCLOSURE (B)37

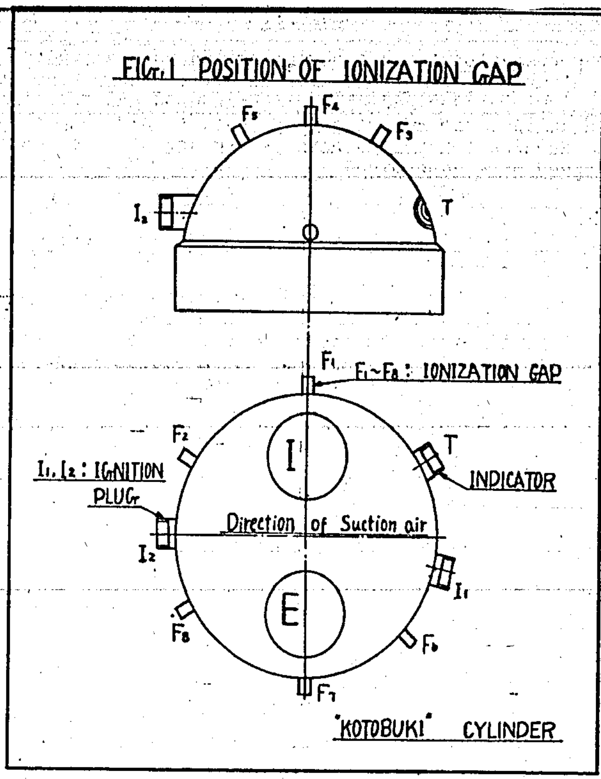

Figure 1(B)37
POSITION OF IONIZATION GAP

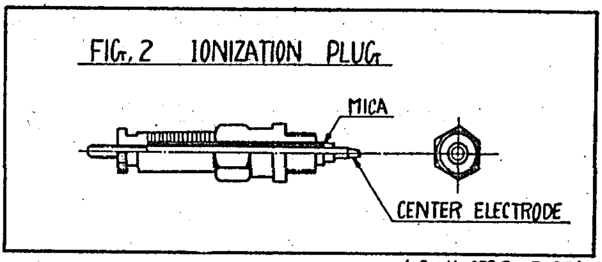

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Figure 2(B)37
IONIZATION PLUG

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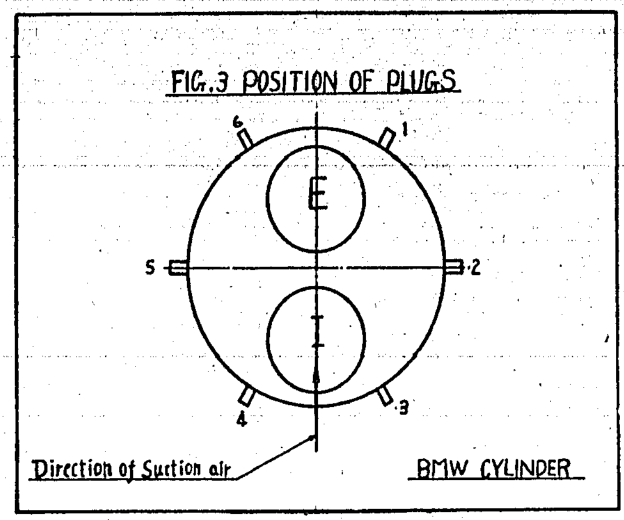

Figure 3(B)37
POSITION OF PLUGS

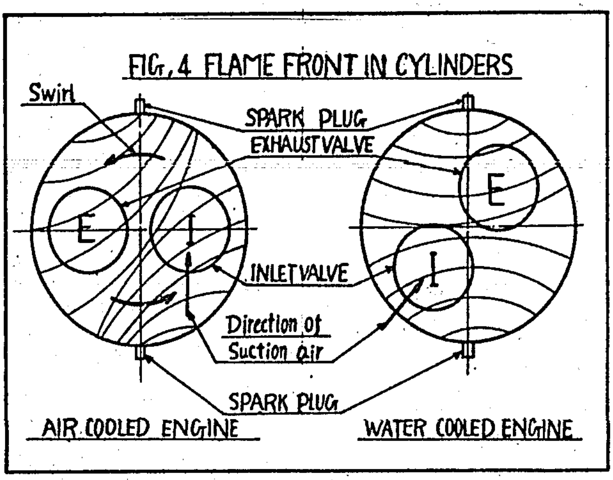

Figure 4(B)37
FLAME FRONT IN CYLINDERS

B. Test Procedures

Experiments were performed as experimental conditions were varied as follows.

1. With Kotobuki engine

 a. Three fuels of different octane values
 b. Boost pressure
 c. Mixture strength

2. With BMW engine

 a. Engine speed
 b. Number and position of spark plugs

The ionization current which flowed when the flame reached the ionization plug was the order of microamperes, so a X171A amplifier was used. The amplified current was led to an electromagnetic oscillograph. Fifty cycle AC waves were used for a time scale.

Oscillograms were developed and the distances between spark timing marks and ionization current marks were measured with a comparator. These were changed to propagation time using the time scale recorded on the same film.

C. Experimental Results

1. Kotobuki engine

a. Three fuels, with octane values 87, 85, 65 respectively, were tested under the same running conditions. It was found that the higher the octane value, the faster the velocity of flame propagation.

b. The effect of boost pressure on the flame propagation velocity was not remarkable. It was frequently masked by the effect of other running factors and could not be determined decisively, but it can be said that the higher the boost pressure, the greater the flame velocity.

c. The fuel supply was altered by operating an AC lever, but no air-fuel ratio meter, such as a Cambridge gas analyser was used at that time. Therefore, the accurate mixture strength could not be determined. The flame velocity was greatest when the output of the engine was largest. The flame velocity was greatly reduced with both rich and lean mixtures.

The flame ignited with two plugs, filled up the cylinder when the crank shaft was at an angle of 40-50 degrees. The mean velocity of flame propagation, calculated from this value, was about 20 m/sec. This was about twice the velocity obtained by the small L-head engine with a quartz window.

2. BMW engine

a. Revolution of the engine was varied from 500 RPM to 1400 RPM and the effect of engine velocity upon flame velocity was examined. Flame velocity was greatly increased with the engine speed. When the time for the flame to travel through the cylinder was plotted against the engine speed, a straight line inclined to the right hand side as shown in Figure 5(B)37 (drawn from memory) was obtained. This must be due to the increase of vaporization of fuel in the carburetor and of the turbulence in the cylinder.

b. The mean flame propagation velocity, ignited by a single spark, was about 35 m/sec, and about 50 m/sec when ignited by two plugs. The effect of the position of the spark plug upon the flame velocity was also examined. The flame velocity was maximum when the plugs were situated between the inlet and exhaust valves.

c. When detonation occurred, it was also ascertained by this method that the last charge was burnt vigorously.

The flame front in the cylinder is supposed to be as in Figure 4(B)37. In the water cooled engine cylinder the flame propagated symmetrically referring to the line connecting two plugs, but in the air cooled engine it was distorted as shown in the figure. With the air cooled engine cylinder, the intake tube was connected tangentially to the cylinder, and the vortex was generated in the anticlockwise direction. The side of the flame assisted by this vortex went far from the plug, while the procedure of the side against the vortex was hindered. The intake tube to the water cooled engine was perpendicular to the cylinder; thus, no general circulation of the charge in the cylinder was generated. This was the reason why there was a difference in flame propagation between the air cooled and water cooled engine cylinders. The position of the last portion where detonation occurred was determined by drawing imaginary flame fronts. When unsuitable fuel was used, foreboding of piston burning was noticed in every cylinder at this portion. showing rough and granular appearances.

III. CONCLUSIONS

From the above results, the following conclusions were derived:

1. The velocity of flame propagation is increased with the speed of engine revolution.
2. The effect of boost pressure is not remarkable, but there is a tendency of increase of flame speed with boost pressure.
3. The flame velocity is much reduced by rich or lean mixture.
4. The flame velocity is higher with high octane fuels than with low octane fuels (within the limits of this experiment).
5. The last portion is instantaneously burnt when knocking occurs.
6. In a cylinder which has a tangential intake tube, the flame front is distorted by swirls.

In conclusion, the ion gap method is very convenient to investigate flame propagation in the cylinder of a full scale engine.

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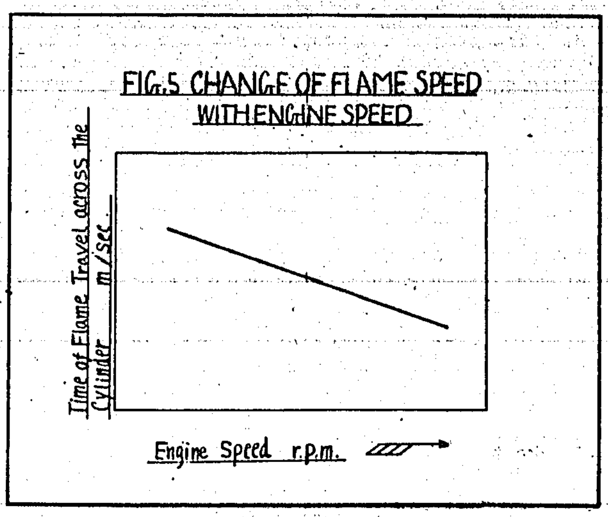

Figure 5(B)37
CHANGE OF FLAME SPEED WITH ENGINE SPEED