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MEASUREMENT OF TDC IN ENGINE BY MICROWAVE TECHNIQUE

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ABSTRACT

A microwave technique for determining the top dead center (TDC) of engine has been developed. Factors affecting systematic errors were investigated experimentally using high resolution pulses (0.015°) and a uniquely designed probe. Consideration is made for cycle change of the cylinder wall temperature. The main factors are attributable to the thermal expansion of the cylinder and the cylinder pressure change. Under well defined engine conditions, accuracy of ±0.1° is possible for TDC measurement.

INTRODUCTION

Cylinder pressure measurement is very important for evaluation of engine performance. For statistical data acquisition of the dynamic phenomenon, sensors and a computer have been used. Improvements in transducers, amplifiers and recording equipment have allowed error reduction in determining the pressure amplitude. However, there still remains the problem for determining the correct phasing of the pressure data with respect to crank position. It is required to determine TDC within an accuracy of ±0.1° CA (crank angle) under dynamic conditions with minimum disturbance to the engine operation.

As a precise method, microwave technique for determining TDC was proposed [1] and the timing apparatus using this technique has been developed [2,3]. This method has many advantages such as high degree of precision, dynamic measurement capability, simple apparatus configuration. We also developed an apparatus [4] for ignition timing measurement which can easily acquire and handle experimental data, and we confirmed such advantages as described above. However, some doubts have been raised on the accuracy of the TDC measured by the microwave technique. Therefore, we made experimental investigation of the factors affecting systematic errors by use of high resolution pulses and estimated the accuracy of this method.

PRINCIPLE OF TDC MEASUREMENT

The combustion chamber of a diesel engine can be regarded as a variable length microwave resonator. It is possible to determine TDC from examining a series of resonance location data taken as a function of crank angle. The probe, prechamber, and cylinder comprise a microwave cavity which is tuned by piston as shown in Fig. 1. Reflected signals from the cavity vary in amplitude as the piston ascends in the compression stroke and descends in the power stroke as shown at the lower part of Fig. 1. The detected microwave signal exhibits a peak at every resonance dip because a detector with a negative output signal was used as indicated in Fig. 1. Although these signals are complicated and difficult to be analyzed, they should be symmetrical with respect to TDC in principle. TDC can be measured by determining the center of symmetry.

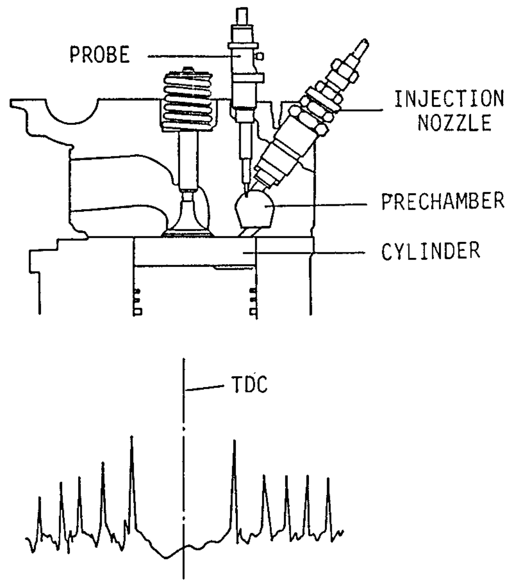

Figure 1 Cutaway view of a probe installed in a diesel engine (upper) and a typical microwave signal near TDC (lower).

EXPERIMENTAL SET-UP

Figure 2 shows a schematic diagram of the set-up used to measure TDC positions with a resolution of 0.015° CA (24 000 pulses per revolution). A microwave signal is led to a combustion chamber (cylinder) through a connecting passage in a prechamber. The signal is coupled to the cylinder by a dipole antenna in a probe, which is mounted on the spot for a glow plug in the prechamber. Figure 3 shows a cross-sectional view of the probe with an enlarged view of microwave antenna.

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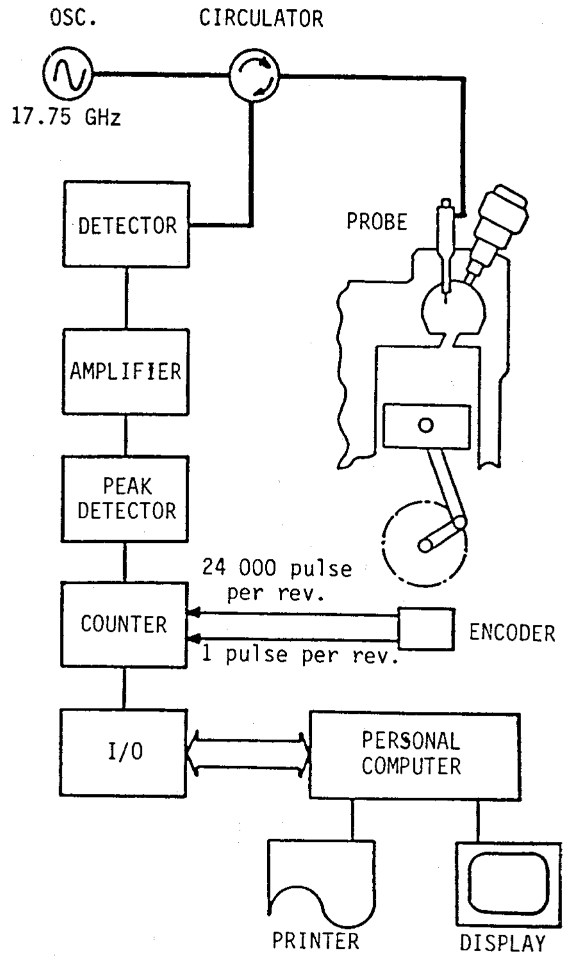

Figure 2 Schematic diagram of experimental set-up.

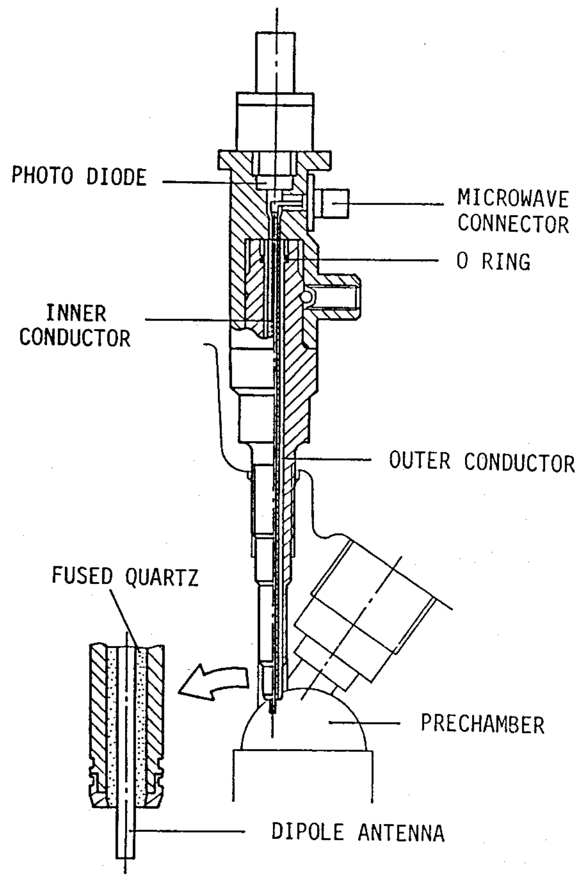

Figure 3 Cross-sectional view of the probe.

As the probe is exposed to high temperature gas, its design is unique; dielectrical material of the coaxial part is fused quartz, and the inner and outer conductors are made from tungsten and stainless steel, respectively. For conductivity improvement both inner and outer conductors are plated with gold. The probe also has a photo diode which can detect combustion light in the prechamber for measurement of ignition timing.

Microwave signals from a microwave detector were processed in synchronization with the timing pulses generated from an encoder mounted on the engine crank shaft. Detecting peaks in microwave signals and counting the crank angle location of these peaks were made by circuits. The crank angle location of the TDC timing pulse (1 pulse per revolution) from the encoder is also determined by digital circuits. Personal computer was used both for calculation of TDC locations and for statistical data processing.

RESULTS

For installing convenience, the probe was mounted on the spot for a glow plug. In order to be fixed in the screw hole for the plug, the probe was designed to have a maximum outer diameter of 6 mm, and a rotational symmetry with regard to its axis. A cylinder is considered as a single aperture resonator. The probe is connected to the cylinder through a connecting passage acting as a wave guide and prechamber acting as a filter. Such cavity configuration is too complicated to design a probe theoretically. Therefore, we measured coupling characteristics by changing frequency and insert length of the probe. Figure 4 shows a typical result of measured reflection coefficient of power and Q value against insert length. We determined the insert length and the frequency from these experimental results.

Several sets of experiments were run to examine the effect of engine operating conditions on the precision of this method and on the accuracy of TDC calculation. Figures 5 and 6 show the results in an engine speed range of 12.2 and 16.7 rps, and over a load range between motoring (no firing) and full load. The TDC values are expressed by the difference between calculated TDC and the TDC timing pulse from the encoder set to the TDC mark on the crank pulley. The standard deviation of TDC values was between 0.03° CA and 0.06° CA for a sample number of 32. The change of TDC values in compression stroke by engine operating conditions is almost the same as the

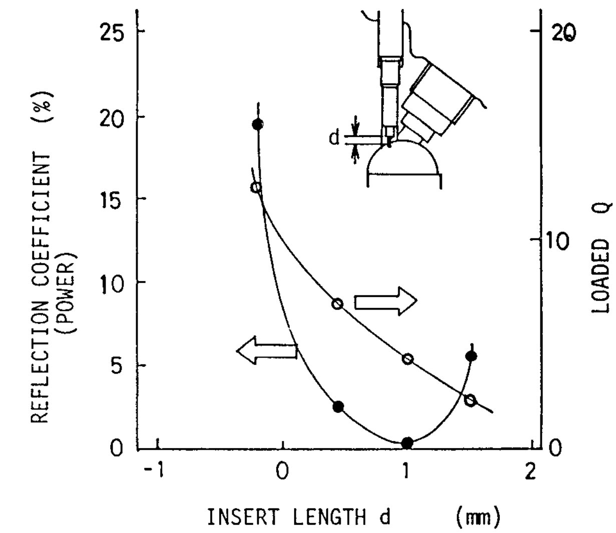

Figure 4 Coupling characteristic at 17.7 GHz. Solid lines are to guide the reader's eye.

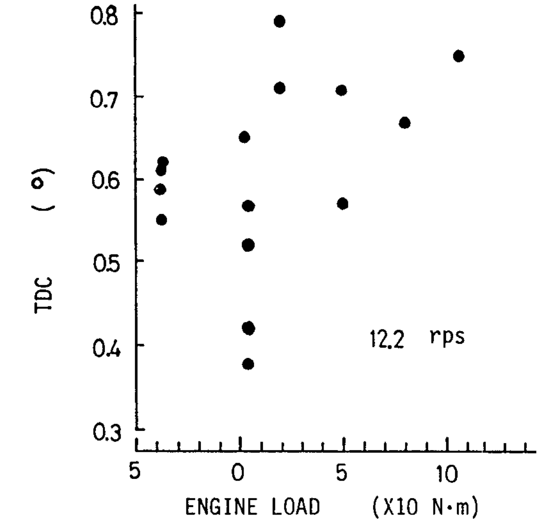

Figure 6 TDC vs. engine load in suction stroke.

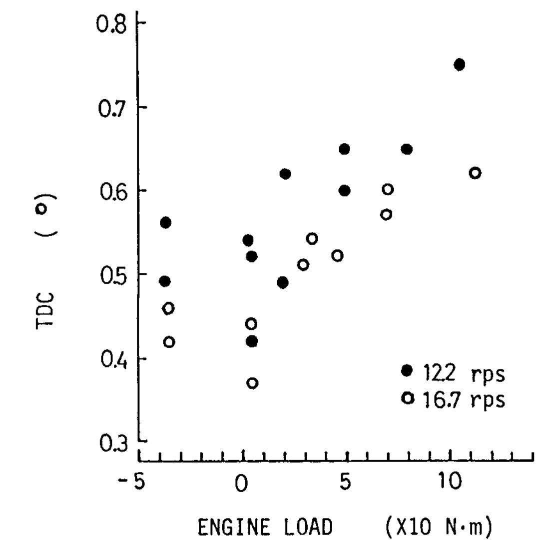

Figure 5 TDC vs. engine load in comression stroke.

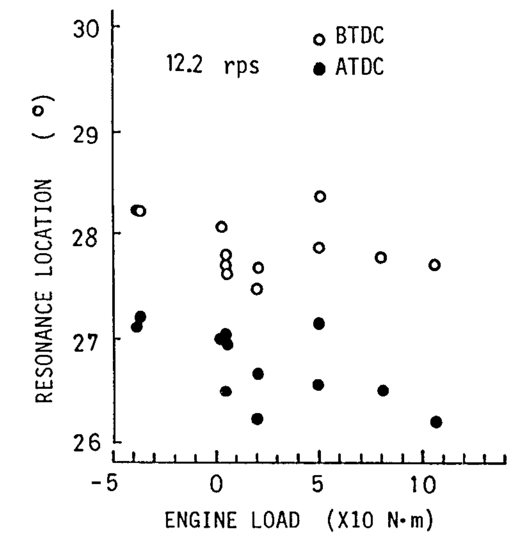

Figure 7 Resonance location vs. engine load in compression and power stroke.

data reported by other authors. There is clear difference between the change of TDC values in compression stroke and that in suction stroke. Figures 7 and 8 show resonance locations in BTDC (before TDC) and ATDC (after TDC) over these engine operating conditions. From these results, we can know dynamic piston positions in detail.

The resonance locations in compression stroke (BTDC) scattered within resolution of the encoder (0.015° CA). Therefore, the dispersion of calculated TDC resulted mainly from that of resonances in the power stroke. These results also indicate that the resonance sharpness is adequate enough even with its very low Q value (20-30).

DISCUSSION

It is clear that engine operating conditions affect measurement of TDC (Figs. 5 and 7). Other authors [3] explained that this effect results from asymmetry of the piston motion around TDC, caused by the difference in the dielectric properties between combustion products and air. However, this effect cannot be explained quantitatively, because it is about ten times as large as the effect estimated by them. We examined carefully changes of TDC values when engine operating conditions were changed from motoring to firing and vice versa. We found a hysteretic change.

Therefore, as factors causing the asymmetry,

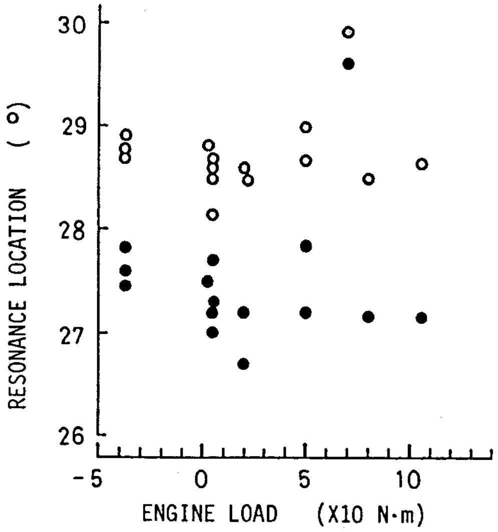

Figure 8 Resonance location vs. engine load in exhaust and suction stroke.

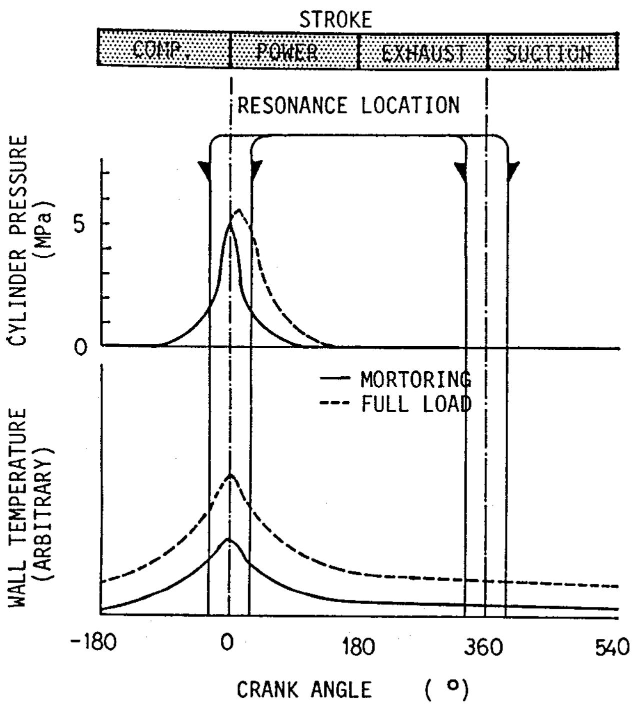

Figure 9 Schematic diagram of the wall temperature change and cylinder pressure change in one cycle.

we assumed a thermal expansion of the cylinder due to compression and combustion, and gas pressure change therein. In order to examine the pressure effect, we removed injection nozzles and measured resonance locations and TDC values, immediately after half an hour motoring operation of engine. Engine speed was 11.6 rps in both engine operation and measurement. After 11 minute operation of the

Table 1 Quantitative effect on piston position at engine speed of 12.2 rps

Factor	Resonance Location (28° CA) at BTDC	Resonance Location (28° CA) at ATDC
Cylinder pressure	0.10°/1.5MPa	0.17°/1.5MPa
Wall temperature	0.38°/Tb*	0.41°/Ta*

* Cylinder wall temperature under motoring at BTDC and ATDC, respectively.

nozzleless engine, we measured resonance locations and TDC values again in order to examine the effect of thermal expansion of the cylinder.

From analysis of these data, previous data of resonance locations (Figs. 7 and 8) and experimental pressure data by using a transducer, the cylinder pressure and the wall temperature are considered to change as schematically shown in Fig. 9. Table 1 shows numerical values of the pressure and the wall temperature on resonance location, deduced from consideration described above. Therefore, we can estimate the systematic error of TDC value from the pressure and the wall temperature of engine. The present method provides the possibility of attaining an accuracy of ±0.1° for TDC, the target value, required for analysis of engine indicator diagrams if the engine operating conditions are well defined and an appropriate statistical analysis is made for data.

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