

A Study of Low Speed Preignition Mechanism in Highly Boosted SI Gasoline Engines

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ABSTRACT

The authors investigated the reasons of how a preignition occurs in a highly boosted gasoline engine. Based on the authors' experimental results, theoretical investigations on the processes of how a particle of oil or solid comes out into the cylinder and how a preignition occurs from the particle. As a result, many factors, such as the in-cylinder temperature, the pressure, the equivalence ratio and the component of additives in the lubricating oil were found to affect the processes. Especially, CaCO_3 included in an oil as an additive may be changed to CaO by heating during the expansion and exhaust strokes. Thereafter, CaO will be converted into CaCO_3 again by absorbing CO_2 during the intake and compression strokes. As this change is an exothermic reaction, the temperature of CaCO_3 particle increases over 1000K of the chemical equilibrium temperature determined by the CO_2 partial pressure. The possibility of a preignition due to particles including CaCO_3 particles is numerically simulated comparing with the experimental results.

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INTRODUCTION

In order to improve thermal efficiency of gasoline engines, down-sizing has been made. To achieve more down-sizing, a higher boost causing a preignition and a super-knocking is required. The authors have been engaged in the collaborative study of a preignition between industries and universities. In other SAE papers [1, 2, 3]. In this paper, in order to clarify the reasons of preignition onset quantitatively, numerical analyses of ignition kernel formation process and its chemical and physical ignition processes are carried out based on the experimental results.

There are main two views as the reason of a preignition: i) an ignition by deposits and ii) an ignition by a lubricating oil. Okada et al. [3] visualized preignitions of a boosted gasoline engine and explained it as an ignition by deposits. Researchers at KIT examined carefully and showed a lubricating oil is a main cause of preignitions [4]. Researchers at SwRI [5,6], FEV [7] and GM/Opel [8] have been engaged in the preignition study with many parametric experiments. A preignition caused by deposits means that solid particles in a high temperature heat the surrounding mixture gas and cause an ignition. Thereby, analyses of temperature change of a particle and the chemical reaction of surrounding gas are precisely required. One of

the authors' SAE paper [2], preignitions probably caused by oil droplets are visualized. Firstly, a mixture of oil and gasoline is attached on the piston top-land, coming out into the cylinder by the inertia of piston motion and also by the gas flow through a gap of piston ring. Secondly, the droplets evaporate and make a preignition leading to flame propagation of the surrounding mixture gas.

In this study, arguments on preignition onset are made based on experimental facts, such as the effects of cooling water temperature, fuel injection timing, Ca as an additive in lubricating oil on preignition occurrence.

EXPERIMENTAL APPARATUS

Engine Performance Test

Parametric study was carried out using mainly 4 cylinder turbo-charged production engine. Fig. 1 shows the experimental apparatus. The extra supercharger driven by an electric motor was equipped to the original system in order to get a higher boost pressure. The engine specifications are shown in Table 1.

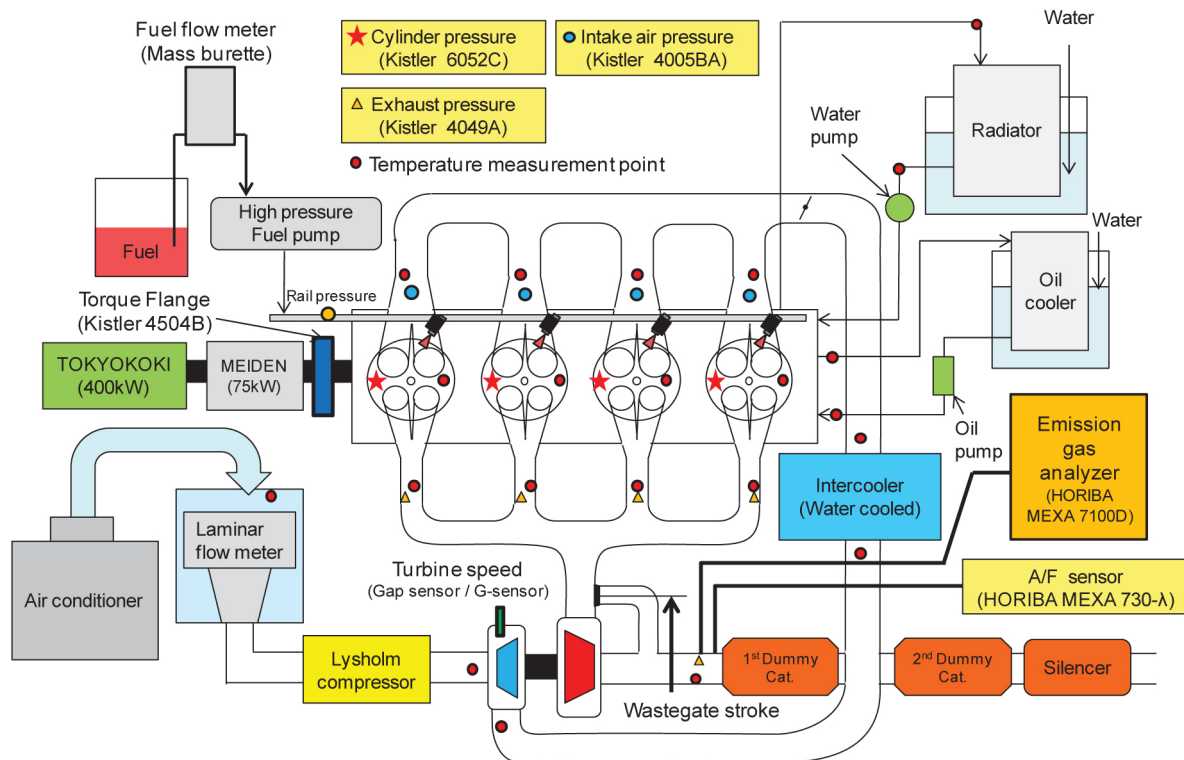


Fig. 1. Experimental apparatus of 4 cylinder turbo-charged engine

The standard test conditions are shown in Table 2. Engine speed and boost pressure were set to 1750 rpm, 190 kPa (abs.) after confirming LSPI zone by survey tests beforehand. Exhaust A/F was set to 14.5. Fuel injection system (GDI) was used as it was and fuel pressure was also fixed to the original value. Test fuel was Japanese domestic high octane gasoline (RON100) throughout this study. After finishing warm up driving three times of 30 minutes driving were performed. This condition was considered as the minimum and enough time to evaluate the frequency of LSPI judged by preceding test. Number of LSPI events (defined later) and pre-ignition cycle frequency (unit is ppm) were calculated as evaluation values.

Visualization of Preignition

High speed direct photography using an endoscope (Karlstorz REF88370AX) and high speed digital camera (Photoron SA-X and SA-X2) was examined to visualize preignition under low speed and high load operation. The endoscope was attached to the cylinder head of the test engine. Viewable field through the endoscope is depicted in Figure 2.

In addition to the direct photography of preignition, light induced fluorescence imaging technique was applied to visualize lubricant oil droplet inside the cylinder because autoignition of oil droplet have been considered to be one of the possible cause of preignition[1], [6]. Coumarin-6 was added into the lubricant oil as a fluorescence agent. A xenon lamp (Hamamatsu photonics, L9588-06A) was used as a UV excitation light source. The light source was attached on the cylinder head, near the spark plug.

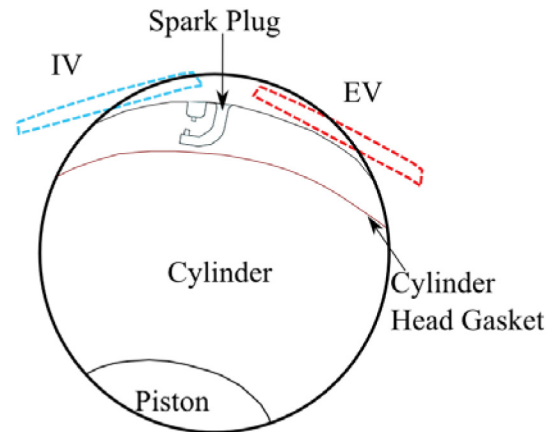


Fig. 2. Visualization field through the endoscope attached to the cylinder head (at BDC)

Table 1. Engine specifications

Bore	79.7 mm
Stroke	81.0 mm
Cylinder	Inline 4 -
Compression ratio	9.49 : 1 -
Conrod length	139.0 mm
Crank diameter	80.9 mm
Piston pin offset	-0.5 mm
Cylinder offset	-9.5 mm
Combustion chamber volume	47.6 cc
Stroke volume	404.2 cc
Total stroke volume	1616.9 cc

Table 2. Standard test conditions

Engine speed	1750 rpm
Intake pressure (abs.)	190 kPa
Intake air temp.	33-35 deg. C
Throttle valve	WOT
BMEP	2.0 MPa
A/F (Exhaust)	14.5
Ig. timing	4 deg. ATDC
Inj. start timing *1	120 deg. ATDC
Inj. pressure (DI)	10 MPa
Fuel *2	RON 100
Lubricating oil *3	Genuine oil
Coolant temp. (inlet)	87 deg.C
IVO (0.1mm lift)	21.5 deg. BTDC
IVC (0.1mm lift)	43.5 deg. ABDC
EVO (0.1mm lift)	6 deg. BBDC
EVC (0.1mm lift)	42 deg. ATDC

*1: Inj. duration: 51 deg. CA

*2: Idemitsu Super Zearth (Japanese domestic premium)

*4: Blow-by gas is opened to air

RESULTS AND DISCUSSION

Effect of Coolant Temperature and Injection Timing

Coolant Temperature

Table 3 shows the test conditions of coolant temperature. Fig. 3 shows the result. In case of abnormal combustion such as knocking and traditional pre-ignition, higher temperature tend to cause that kind of combustion. However, LSPI tends to occur in lower coolant temperature significantly. This tendency indicates a different mechanism of LSPI. An estimated cause is that the lower coolant temperature leads lower cylinder wall temperature and that will cause heavier wall wetting by fuel. Oil dilution increases and oil droplet is created and jumps into the combustion chamber [2] [3]. The size and amount of oil droplet will become suitable to create LSPI [2].

Fuel Injection Timing

Table 4 shows the test conditions of fuel injection timing. Fig. 4 shows the result. Within the range of this study, injection start timing of 120 deg. ATDC shows lowest frequency of LSPI. Both advanced and retarded timings show higher frequency. Retarded timing of 150 deg. ATDC leads significant number of LSPI. An estimated cause is as follows. In case of advanced side, fuel spray hits a piston crown and reflects to intake side by intake tumble motion. Then, fuel sticks to intake side wall and oil droplet will be created. In case of retarded side, fuel spray directly hits an exhaust side cylinder wall. Then, oil

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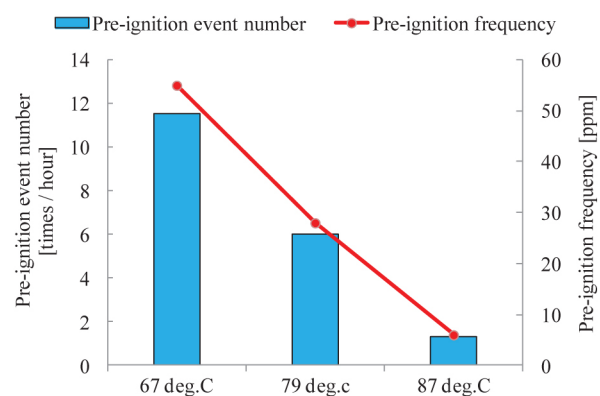


Fig. 3. Test result of coolant temperature

Table 4. Test conditions of fuel injection timing

Engine speed	1750 rpm
Intake pressure (abs.)	190 kPa
Intake air temp.	33-35 deg. C
Throttle valve	WOT
BMEP	2.0 MPa
A/F (Exhaust)	14.5
Ig. timing	4 deg. ATDC
Inj. start timing	90, 120, 150 deg.
Inj. pressure (DI)	ATDC 10 MPa
Fuel	RON 100
Lubricating oil	Genuine oil
Coolant temp. (inlet)	87 deg.C
IVO (0.1mm lift)	21.5 deg. BTDC
IVC (0.1mm lift)	43.5 deg. ABDC
EVO (0.1mm lift)	6 deg. BBDC
EVC (0.1mm lift)	42 deg. ATDC