

Investigation of Engine Oil Effect on Abnormal Combustion in Turbocharged Direct Injection - Spark Ignition Engines

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ABSTRACT

Abnormal combustion referred to as Low Speed Pre-Ignition (LSPI) may restrict low speed torque improvements in turbocharged Direct Injection (DI) - Spark Ignition (SI) Engines. Recent investigations have reported that the auto-ignition of an engine oil droplet from the piston crevice in the combustion chamber may cause unexpected and random LSPI. This study shows that engine oil formulations have significant effects on LSPI. We found that the spontaneous ignition temperature of engine oil, as determined using High-Pressure Differential Scanning Calorimetry (HP-DSC) correlates with LSPI frequency in a prototype turbocharged DI-SI engine. Based on these findings, we believe that the oxidation reaction of the oil is very important factor to the LSPI. Our test data, using a prototype engine, shows both preventative and contributory effects of base oil and metal-based engine oil additives.

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1. INTRODUCTION

Automotive manufacturers have increased the number of gasoline engine vehicle models equipped with turbocharged DI-SI engines as a way of improving vehicle fuel economy while maintaining driving performance. Advantages come from the reduction of mechanical friction due to down-sizing of engine displacement and down-speeding of the engine by using higher transmission gear ratios allowed by the higher engine torque at lower engine speed developed by turbocharged DI-SI engines as shown in Figure 1. However the higher torque at lower engine speed may cause irregular combustion, unexpected and random pre-ignition, which is often referred to as a "Low Speed Pre-Ignition" (LSPI) and LSPI is a constraint which prevents optimization of engine torque at lower engine speed.

The abnormal combustion appears, when the intercept point (start point where boost pressure is controlled not to exceed a set value) is set at a lower rpm value and the brake mean effective pressure power is higher. Figure 2 shows the combustion pressure traces for normal combustion and pre-ignition occurring at the intercept point rpm of a turbocharged DI-SI engine. Figure 3 shows a typical LSPI phenomenon. The randomness of LSPI is demonstrated by

LSPI appearing suddenly during a normal combustion cycle, followed by a normal combustion and pre-ignition alternately occurring over several cycles, followed by the return of normal combustion.

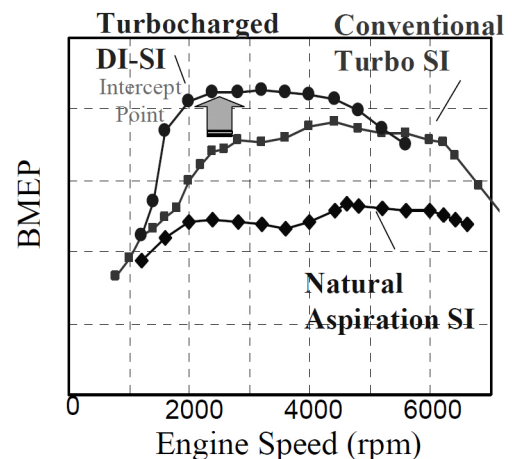


Figure 1. Low-speed torque improvement with Turbocharged DI-SI Engine

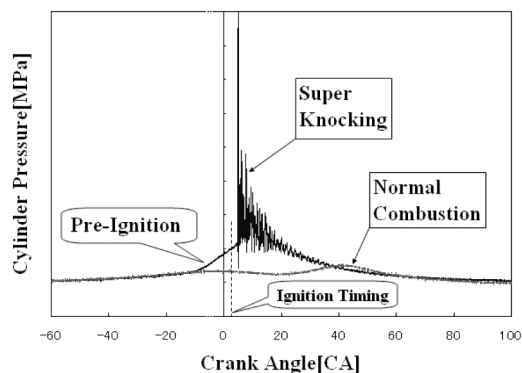


Figure 2. Pressure Traces for Normal Combustion and Pre-Ignition

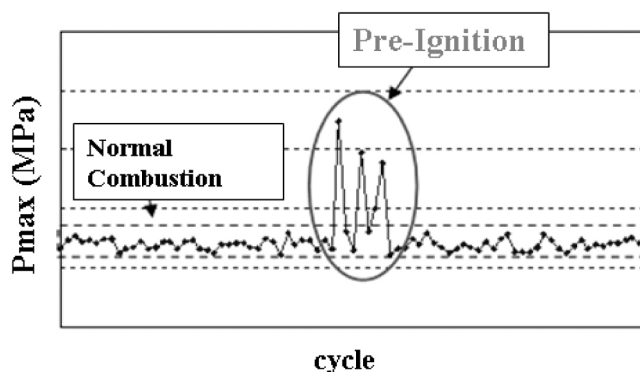


Figure 3. Typical Low Speed Pre-Ignition Event

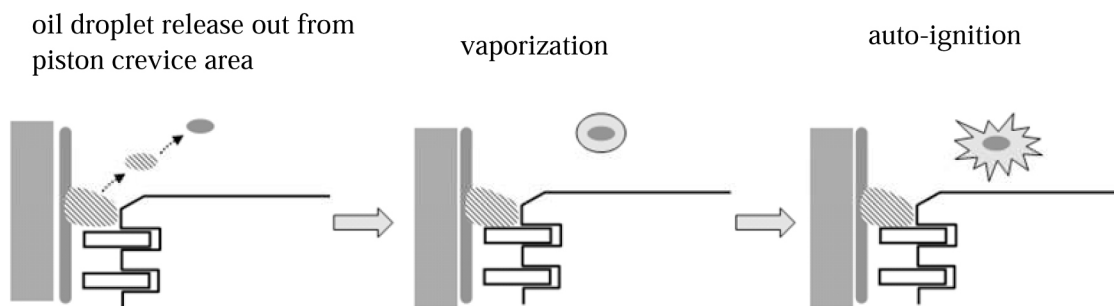


Figure 4. Mechanism for auto-ignition of oil droplet from piston crevice

There are various reports in the literature which hypothesize that oil droplets from the piston crevice area might be ignited before the spark timing and engine oil properties might be correlated with LSPI frequency (Reference 1, 2). We also have conducted various tests including filming LSPI by high speed camera. As shown in Figure 4 as our assumed mechanism, an oil droplet is released from the piston crevice area, is vaporized and self-ignites in the combustion chamber and causes a pre-ignition event. Based on this assumption, we investigated the possible engine oil effects on LSPI.

2. EXPERIMENT

2.1. Engine Test Procedure

The specifications for the prototype engine used for the LSPI testing are shown in Table 1.

Figure 5 shows the method of LSPI evaluation using the turbocharged DI-SI engine. The test used the conditions of 1800 rpm at wide-open-throttle (WOT) which was the intercept point of rpm and turbocharged pressure where LSPI occurred most frequently. The number of pre-ignition events per hour in this condition was measured by combustion pressure sensors which were installed in each cylinder. In order to avoid the effects of deposits, since it is understood

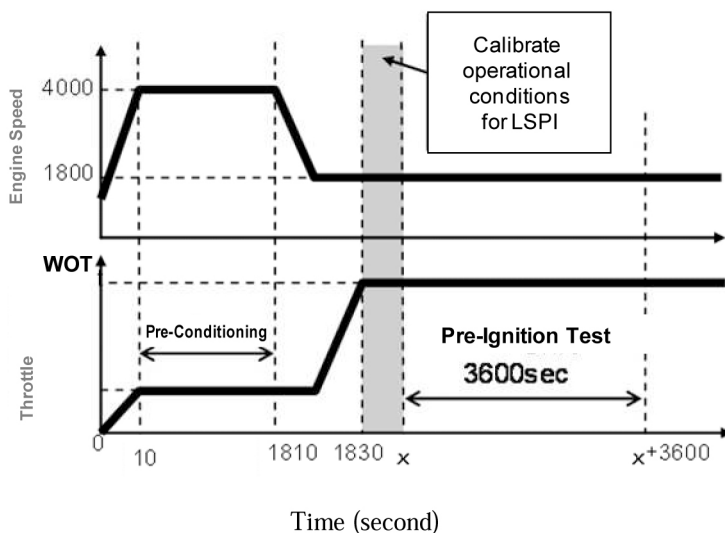
Table 1. Test Engine Specifications

Engine	Prototype
Air Intake System	Turbocharged
Fuel System	Direct Injection (Lateral)
Number of Cylinder	L-4
Fuel Quality	98 RON

Table 2. Base Oil Test Matrix

Sample No.		Oil -A	Oil -B	Oil -C	Oil -D	Oil -E	Oil -F	Commercial Oil	
								0W-20	5W-30
Base Stock	Group	Gr.I	Gr.II	Gr.III	PAO	PAO	Gr.III	-	-
	KV100	4cSt			8cSt	4cSt	-	-	-
Additive System (Quality)		GF-5				GF-5 w/o Detergent	API SM	ACEA A3/B4	

that deposits generated in the combustion chamber influences LSPI, a pre-conditioning segment of the procedure of 4000rpm partial load (30minutes) was executed immediately before the LSPI measurement segment (Reference 3). For improving repeatability of the LSPI test and in order to cause LSPI frequently, prior to the measurement of pre-ignition, fuel injection timing, air fuel ratio, and other operational conditions were calibrated.

**Figure 5. Dyno Test Procedure**

2.2. Evaluation of Base Oils

A variety of base oils as shown in Table 2, all using the same ILSAC GF-5 additive system, were evaluated to determine the sensitivity of base oils to LSPI (Oil-A to Oil-F). The effect of a metal-based detergent was evaluated in comparison between Oil-C and Oil-F. Furthermore, two commercial oils were also evaluated.

2.3. Evaluation of Engine Oil Additives

Table 3 shows 12 test oils with different additives in order to evaluate the sensitivity of various additive systems to LSPI. As the parameter that might be more likely to cause LSPI, various metallic elements and an antioxidant were selected. All 12 sample oils used the same base oil, Group III (4 cSt), and baseline oil was composed of Calcium Sulfonate (0.1mass% of Ca), Zinc Di-Alkyl-Dithio-Phosphate (ZnDTP) (0.06 mass% of P), no Molybdenum Di-Thio Carbamate (MoDTC), phenolic Anti-Oxidant(AO), and Poly-Methacrylate (PMA). To determine the effects of the metal-based detergent on LSPI, the quantity of Calcium was varied from 0.1 to 0.3 mass%. Two Calcium Sulfonates having different structures and two Calcium Sulfonates with different total base number (TBN) levels, and one Calcium Salicylate were evaluated. To determine the effects of MoDTC, the quantity of Mo content of 0 to 0.07 mass% were evaluated. The effects of ZnDTP were evaluated by using a variety of phosphorus levels from 0.06 to 0.15 mass%. In addition, the relative quantity of the Phenolic AO was tested at 0.5 and 1.5 times the original phenolic AO level. The effect of the type of the viscosity index improver, PMA versus Olefin Co-Polymer (OCP) was also evaluated.

3. TEST RESULTS

3.1. Sensitivity Evaluation of the Oil

Figure 6 shows the result of the LSPI frequency tested with the oils in Table 2. The LSPI frequency on the vertical axis is the relative number of times, as the number of occurrences of pre-ignition for Oil C in Table 2 is assumed to be 1. The LSPI frequency of Oil-A (Group I base oil) was the highest, and Oil-B (Group II), Oil-C(Group III) decreased with increasing Group number. Poly-Alpha-Olefin (PAO) base oil gave results very similar to those for Group III. The