A Study for Improving the Thermal Efficiency of Diesel Engines by Split Injection Strategy

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The main target of this study is to improve the thermal efficiency of the diesel engine. In order to achieve this target, two split injection strategies were adopted to control the combustion process. One is the close post injection strategy and the other is the combination of premixed charge compression ignition (PCCI) combustion and conventional diesel spray combustion.

Chapter 1 includes the background of this study. The need for the improvement of thermal efficiency for internal combustion engine used for transportation is introduced. Several operating parameters affecting the engine performance are discussed and this study focused on the improvement of thermal efficiency by simultaneously improving cooling loss and degree of constant volume (DCV). Premixed lean combustion strategy and multiple injection strategy are suggested as two possible methods to achieve the target. Both of the strategies split the conventional one stage injection into two or several stages. The cooling loss caused by the main spray impingement is expected to decrease since the main injection quantity is reduced. In addition, the heat release rate and overall combustion duration could be controlled by modifying the injection timing for each injection stage.

In chapter 2, the effect of a small quantity of post injection on the reduction of cooling loss and improvement of thermal efficiency was studied. A close post injection was applied to a commonly used injection pattern for the diesel engine to improve its thermal efficiency. The experimental results show that the cooling loss was reduced by the application of post injection with a short interval between the main injection. CFD simulation was utilized to investigate the reasons for the improvement of thermal efficiency. The results showed that the heat loss through the piston surface could be reduced by splitting the main injection. The cooling loss tendency in the CFD simulation according to the post injection amount was contradictory to the experimental results but the trend is improved by adopting the wider spray cone angle to the post injection.

In chapter 3, the effect of close post injection strategy on engine performance was further investigated. The possibility of simultaneous improvement of cooling loss and DCV was explored with various injection parameters including post injection timing, quantity, and intake pressure. Besides the metal engine, an optical engine with a bottom-view piston was used to observe the interaction of main and post spray. The images of the spray liquid phase and the high temperature flame in the combustion chamber were acquired using high speed camera. The results of metal engine experiments showed that the cooling loss showed a decrease by retarding post injection timing slightly from near zero interval between the main injection. Further retarding post injection could not decrease the cooling loss constantly. The optical experiments indicated that when the injection interval is too short, the air entrainment of the post spray is suppressed by the existence of the tail of the main spray. Due to this disruption, a fuel rich region will be formed near the chamber wall. As a result, the high temperature gas will remain near the wall for longer duration and cause higher cooling loss.

Chapter 2 indicates that the mixture formation process of the small quantity injection is different from the quasi-steady injection and chapter 3 suggests that the mixture formation of the small quantity spray is important for the estimation of heat loss transferred from the wall. Therefore, in chapter 4, a series of experiments were conducted to investigate the diesel spray characteristics with small quantity injection. The effect of injection mass, injection pressure, and nozzle diameter on spray tip penetration and fuel concentration were studied using a rapid compression and expansion machine. A hybrid of shadowgraph and Mie scattering imaging set-up is used to visualize both spray liquid phase and vapor phase at the same time. Series of experiments showed that the spray tip penetration could be suppressed by small quantity injection. In addition, the spray angle near the nozzle was larger compared to steady condition at the start of the injection. Then it experiences a decrease as the injection process continues. Finally, the spray angle near the nozzle increases at the end of the injection.

In chapter 5, the PCCI combustion was combined with conventional diesel combustion to achieve the improvement of DCV and reduction of cooling loss at the same time. The injection process was split to two stage by two individual injection systems. One is called sub-injection which introduce fuel at early stage by an injector with narrow injection angle. The other is called main injection which is characterized by the conventional diesel injection near TDC. By this injection strategy, the cooling loss is expected to reduce due to the reduction of the main spray impingement. In addition, the mixture formed by sub-injection is supposed to locate at the periphery of the combustion chamber so that it will not prevent the air entrainment of the main spray. Therefore, the combustion process is expected to occur separately. When the phases of two types of combustion process could be overlapped, the total combustion duration could be reduced to improve the DCV. However, the early ignition of the sub-injection mixture was a critical problem in the realization of the proposed combination concept. Therefore, the combustion phase of PCCI combustion was adjusted by modifying the ignition characteristics of the fuel. As a result, the cooling loss was reduced by overlapping the combustion phase of PCCI and conventional diesel combustion. Once the fuel property and injection timing of sub and main injection are fixed, the DCV could be increased by increasing the injection quantity ratio of sub injection. The cooling loss could be reduced slightly with the increase of DCV.

Chapter 6 is a summary of this study. Besides the conclusions drawn from each chapter, the suggestion of the future study is also included.