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Study on Premixed Charge Compression Ignition Combustion Control using Multi Pulse Ultrahigh Pressure Injection and Offset Orifice Nozzle

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Thesis Outline

Compression ignition engines provide higher thermal efficiency compared to other internal combustion engines. However, large amounts of soot and NO_x are produced during combustion. Soot and NO_x emissions can be simultaneously reduced by applying Premixed Charge Compression Ignition (PCCI) combustion. The main purpose of this study is to investigate the effect of ultrahigh injection pressure and multi pulse injection on PCCI combustion and to verify the new PCCI combustion concept.

In chapter 1, The most current PCCI research has been reviewed. PCCI combustion produced high indicated thermal efficiency (ITE) while emitting less Soot and NOx. However, the operating range of conventional PCCI combustion is restricted due to rapid combustion. This issue can be solved by applying ultrahigh injection pressure to shorten the time it takes for the mixture to form. To maximize the effect of ultrahigh injection, spray penetration must be reduced. Multi-pulse injection can decrease spray penetration. In this chapter, a new combustion concept was proposed that combines a combination of ultrahigh injection pressure and multi pulse injection to control PCCI combustion.

In chapter 2, the effect of injection pressure had been investigated. The combustion characteristics were observed under single pulse injection condition with various injection pressure, injection amount and oxygen concentration. The 5 mg injection amount had been selected to represent the one pulse of multi pulse injection. The injection pressure had a strong effect to reduce ignition delay. However, the effect of injection pressure shows in the different ways depends on injection amount. In case of 5 mg injected amount increasing the injection pressure made the duration become longer due to too lean equivalence ratio. Once the injection amount increased to 10 and 15 mg, the combustion duration decreased with increasing the injection pressure. Increasing injection show the significant effect on short ignition delay by accurate mixture formation process. The higher fuel flow rate also made benefits on shorten combustion. On the other hand, the longer

lift off length from increasing injection made more distant form fuel air mixture before ignite, result in soot reduction. The higher OH* chemiluminescence intensity form increasing injection pressure is an evident for more combustion reaction occurred combustion chamber. This implied to higher thermal efficiency. On the other hand, decreasing oxygen concentration made less oxygen available for mixture formation process. This made ignition delay and combustion become longer. On the other hand, decreasing oxygen concentration also made significantly reduce flame temperature due to decreasing of chemical reaction. That shows in term of less OH* chemiluminescence intensity and area. However, the lower flame temperature from decreased made less cooling loss. Under the 5mg injection amount operating condition, the effect of increasing injection pressure on ignition delay, combustion duration NOx, CO, THC show in the opposite way compared to other injection amount. This due to too lean equivalence ratio of this operating condition.

In chapter 3, until this chapter the proposed combustion concept had been clarified. The experiment was conducted with a single cylinder engine. The engine was operated under constant load condition with various injection pressures and pulse number. The experiment found that PCCI combustion can be controlled by applying ultra-high pressure and multi pulse injection allowing fuel to be injected near TDC. Increasing injection pulse number shows the significant effect on reduce peak pressure and peak RoHR due to less fuel injected for each pulse. On the other hand, increasing injection pulse number made less equivalence ratio for each pulse result to lower flame temperature. This led to NOx emission reduction. However, the advance injection is required in order to compensate the extend combustion duration. On the other hand, the combination of ultrahigh pressure and multi pulse injection is an effective method to increase ITE and simultaneously reduce soot and NO_x emission. Unfortunately, too high injection pressure casts ITE decreased and CO, THC increased for fuel impinge. In order to maximize the benefits of ultrahigh injection pressure the shorter spray penetration is required.

In chapter 4, As the results show in the previous chapter, too high injection pressure made ITE reduction from spray impinging. To maximize the benefits of increasing injection pressure, shorter spray penetration is required. Generally, spray penetration can be shortened by reduce orifice diameter. However, this led to a reduction of the fuel flow rate and loss of ITE. The offset orifice nozzle is offers short spray penetration and without prolonging actual injection duration. The offset orifice nozzle was designed by shift orifice aliment from into the sac center to the edge of sac follow swirl direction to create unsymmetrical fuel velocity at the nozzle orifice outlet. This made fuel spray bend following the offset direction. In this chapter the new design of nozzle had been examining under single pulse injection condition. The experiment was carried out on single cylinder engine both without and with optical access. The offset orifice nozzle provides similar ignition delay and combustion duration compared to standard design nozzle. However, the combustion duration of offset orifice nozzle is shorter in every operating condition, especially under injection amount 5mg conditions. This due to benefit from shorter Lift off length of offset orifice nozzle. This implied to higher equivalence ratio off offset orifice nozzle. This will be a benefits for low oxygen concentration and high injection pressure conditions. On the other hand, offset orifice nozzle also provides higher ITE under all operating conditions. This due to more combustion occurs inside the combustion chamber that can see from the larger OH*

chemiluminescence area and intensity. The higher flame temperature of offset orifice nozzle also benefices for the oxidation process of CO and THC.

In chapter 5, the new combustion concept using ultrahigh injection pressure, multi pulse injection and offset orifice nozzle had been verified. As the results of the previous chapter, the 3 main injection pulses had been selected. The experiments were also conducted on single cylinder engine both without and with optical access. The offset orifice nozzle provided advance rate of heat release rate, higher gross ITE under all operating conditions. The advance rate of heat release of offset orifice nozzle was observed under multi pulse injection. This is due to the benefits from shorter liftoff length and higher equivalence ratio inside spray area. On the other hand, orifice nozzle also provided lower CO and THC emission as in the single pulse injection condition. The offset orifice nozzle also shows significantly larger OH* chemiluminescence area and intensity throughout the combustion as under single pulse condition. The flame temperature of offset orifice nozzle also shows in the same way as under single pulse condition. On the other hand, the offset orifice nozzle also provide less cooling loss that possibility may case from slower gas velocity near cylinder wall. The gross ITE over 47.5% can be achieved with low CO and THC emission can be achieved. From the study the ultrahigh injection pressure and multi pulse injection can be use for control PCCI combustion. The combination of 3 pulse injection with 350 MPa injection pressure and offset orifice nozzle is recommended, due to high thermal efficiency and low soot, CO and THC emission.

Chapter 6 is summarization of all the research works had been taken. From the study the ultrahigh injection pressure and multi pulse injection can be used for control PCCI combustion. The combination of multi pulse injection with the highest injection pressure and offset orifice nozzle is recommended, due to high thermal efficiency and low soot, CO and THC emission. The offset orifice nozzle can improve ITE under the ultrahigh pressure injection condition by reducing the cooling loss. However, this still had disadvantage on higher NOx and high smoke emission at low injection pressure condition. The reduction of common rail pump power usage is recommended in order to use the ultrahigh injection pressure on low and medium load.