Effect of Pintle Lift on Spray Characteristic of Piezo Actuated Outward-opening Injector for Direct-Injection Spark-Ignition Engine

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ABSTRACT An experimental study was performed to evaluate the effect of pintle lift on spray characteristics of piezo-actuated outward-opening injector for a direct-injection spark-ignition engine. Spray characteristics, including spray structure, development process and geometric indexes, were investigated by the macroscopic and microscopic spray visualization in a constant volume chamber. The injection rate was measured by the Bosch method to evaluate the flow rate and response characteristics of the injector. Phase Doppler anemometry was applied to measure the droplet size of the spray. The near nozzle flow visualization results with the different pintle lift profiles showed that the primary break up was enhanced as the pintle lift was increased. As a result, the spray droplet size was decreased even though the nozzle area was increased. Meanwhile, with the higher pintle lift, the spray tip penetration was shortened due to the enhanced primary breakup. In addition, response for the injection signal was fastened and flow rate increased as the pintle lift was increased. Thus higher pintle lift was found to have many advantages for the combustion such as preventing piston wetting, enhanced atomization and shorter injection duration.

Keywords: Gasoline engine, DISI, GDI, piezo injector, outward opening injector, pintle lift

1. INTRODUCTION

In order to reduce hazardous emissions and to increase fuel economy, the automobile industry has focused on direct-injection spark-ignition (DISI) engines. A wall-guided DISI engine, using the internal flow driven by the piston bowl and the spray for the stratified mixture preparation, was researched actively [1]. However, the stratified combustion of the wall-guided DISI engine showed unstable combustion characteristics at different engine operation conditions because the internal flow sensitively varies with the operating conditions of the engine [2]. In addition, fuel collision with the piston resulted in hydrocarbon (HC) and smoke emissions. For these reasons, many of the recent studies on DISI engine are mainly focused on the spray-guided DISI engine, which uses the spray momentum to prepare the stratified premixed mixture [3]. High atomization and robustness of the spray are key technologies for spray guided DISI engine. Therefore outward opening and multi-hole injector were used which were known to have many advantages in robustness and atomization performance [4] rather than swirl and slit injectors which were used in wall guided type.

In this study, Spray experiments including spray visualization, droplet size measurement and injection rate measurement were performed to evaluate the effect of pintle lift on spray characteristics of piezo-actuated outward opening injector for a spray guided direct-injection spark-ignition engine.

2. EXPERIMENTAL SET UP AND CONDITIONS

2.1 Spray Visualization

Macroscopic and microscopic Mie scattering imaging were applied for the visualization of the spray and pintle lift. A schematic diagram of the optical diagnostic system for the spray visualization is shown in Fig. 1. The spray images were taken by the direct photography using Mie-scattering technique. Optical access to the pressure chamber was available through three quartz windows, 80 mm in diameter. The chamber was pressurized with nitrogen at room temperature. For the direct photography of Mie-scattering, the spark light (MVS-2061-CE96, EG&G Optoelectronics) was directed toward the sprays through a window, while a CCD (PCO CCD Imaging, SensiCam) camera captured scattered light through the window perpendicular with the one from which the light came. Images were captured by an imaging system that was synchronized with the spark light source.

2.2 Droplet Size Measurement

Phase Doppler anemometry (PDA) technique was adopted to evaluate spray atomization, as shown in Fig. 2. The transmitting and receiving optics of a PDA system were fixed onto a 3-dimensional traverse mechanism moving relative to the injector with fixed position. A low injection frequency at 5 Hz was applied to ensure that the time delay between two successive injections was long enough to allow all of the spray droplets to pass the location of the measurement points before the second injection started. The spray droplets at all
Tables: 1 and 2

Figures: 2, 3, and 4

3. RESULT AND DISCUSSION

Many studies about the effect of pintle or needle lift’s variation on spray characteristics were conducted on multi-hole injectors for diesel engines. In the previous studies, needle lift was identified to affect inside flow passage and velocity. Thus higher initial momentum of spray and faster response of injection could be achieved with higher needle lift [6,7]. However, in the case of outward opening injector, pintle lift affected on not only inside flow passage, but also nozzle exit area. These parameters could give complex and even conflicting effects on spray characteristic. Thus, effects of pintle lift on spray characteristics of outward opening injector should be evaluated for various point of view including initial spray structure, flow characteristics, injection response, spray geometry and spray atomization.

3.1 Effect of Pintle Lift on Injection Rate

Injection rate curve for 100 bar of injection pressure and 1 atmospheric pressure (atm) of ambient pressure condition is shown Fig. 5. It was confirmed in this figure that pintle lift could give a significant effect on the injection rate, which is said due to that nozzle area was close related with pintle lift intimately. The total injection quantity from the case of lowest pintle lift is even lower than 60% of that injection with highest pintle lift.

Injection rate curve for different injection pressure in each pintle lift profile is (could be found as well as) shown in Fig. 5. Initial slope of injection rate curve can be identified as an index of the injection response speed [6]. As depicted in Fig. 5, pintle lift affects on injection response speed crucially, in contrast effect of the injection pressure on the injection response speed was very little. To evaluate the response speed of injection, injection delay was defined as short time delay of the initial spray, which could be defined from spray imaging, from the initial of injection signal. Injection delay for different pintle lift profiles were shown in Table 2. Comparing Table 2 to Fig. 3, it was shown that initial spray started appeared at 0.01 mm of pintle lift for all three pintle lift case, while injection delay was shortened in higher pintle lift condition.