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FEM simulation and performance analysis of a novel heated tip SIDI injector

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ABSTRACT

A novel heated tip multi-hole spark ignition direct injection (SIDI) injector was designed and manufactured to research its coupling mechanism of the multi-physical fields and comprehensive performances. In order to realize the multi-physical fields coupling simulation, the coupling relationship and coupling formation among the electromagnetic, thermal, fluid flow and spray fields were analyzed based on coupling theories. The data information interface platform based on the commercial software was used to calculate the key parameters of the novel SIDI injector. The simulation data transfer and output mechanism were analyzed and the coupling models based on finite element method (FEM) were established to analyze the comprehensive performances systematically. The systematic experiments were utilized to validate and verify coupling mechanism and the accuracy of the simulation model. Compared to the conversional SIDI injector, the novel heated tip SIDI injector can heat the fuel and cause the temperature rising in a short time. In order to investigate the relationship between the temperature and performances of the injector, the multi-physical fields coupling analysis of the novel heated tip SIDI injector were done by simulation and experiments. According to the systematical analysis of the multi-physical fields of the novel heated tip SIDI injector, it was found that the heat generate from the heater and magnetic circuit is the most significant factor that influence on the electromagnetic, fluid flow and spray.

1. Introduction

Spark ignition direct injection (SIDI) engine have become dominant in the recent automotive market, as SIDI engines have significantly improved fuel economy, faster transient response and lower cold start emissions, comparing to the traditional port fuel injection (PFI) gasoline engines (Lee and Park, 2014; Park et al., 2009). In order to reduce emissions and fuel consumption at cold-start, some fuel-heating system with conventional heat approaches were performed, such as water bath (Zeng et al., 2012), microwave generator (Tran et al., 2011), and external heated tip (Königsson et al., 2012). However, all the heat approaches mentioned above are difficult to build the systems in a small volume, have the low heat efficiency and the low response speed. Because of the disadvantages mentioned above, a novel heated tip multi-hole SIDI injector with inner heater and controllable temperature was designed to solve the problems.

For SIDI engines, fuel is directly injected into the engine cylinder. After fast atomization and evaporation, the gaseous fuel mixes with fresh air to form combustible mixture. This is a very short time process, therefore fast fuel droplet breakup and quick evaporation are needed. In order to promote the fuel atomization and vaporization, high injection pressure is a well-accepted way for engine manufacture enterprises. Currently the fuel injection pressure for SIDI engines is higher than 25 MPa, the Sauter Mean Diameter (SMD) of the droplet sizing is in range of 5–20 μm (Fansler and Drake, 2009). Although high injection pressure can improve the fuel atomization and vaporization, there are several disadvantages associated with it. Firstly, high injection pressure normally causes long penetration of the spray which could easily hit the piston surface and/or engine cylinder walls, resulting in high level of unburned hydrocarbon (UHC) and soot emissions (Leea et al., 2004; Serras-Pereira et al., 2012). Secondly, all the fuel apply system must be tough and tensile enough to endure this high pressure which need advance materials and technology to satisfy the requirements. Besides, the droplet reduction effect is diminished when the injection pressure increase to a high level. Therefore, it high cost and low income way to reduce the droplet size by high injection pressure (Anand et al., 2012). To overcome these

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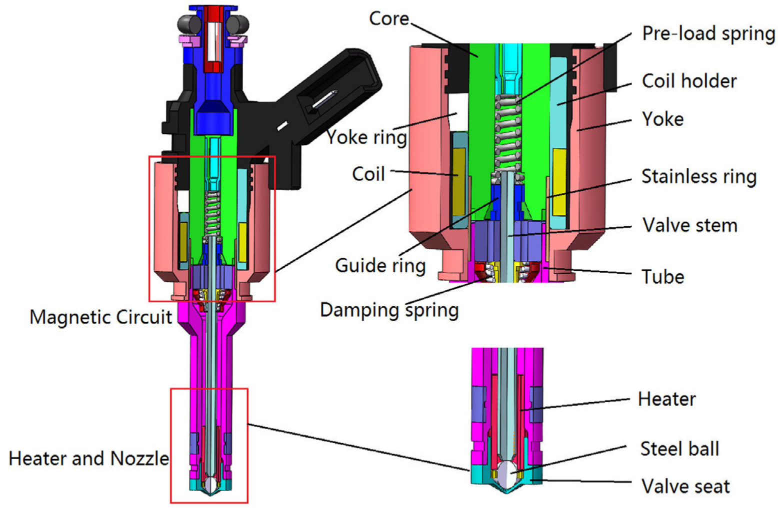

Fig. 1. Cross-sectional view of heated tip SIDI injector.

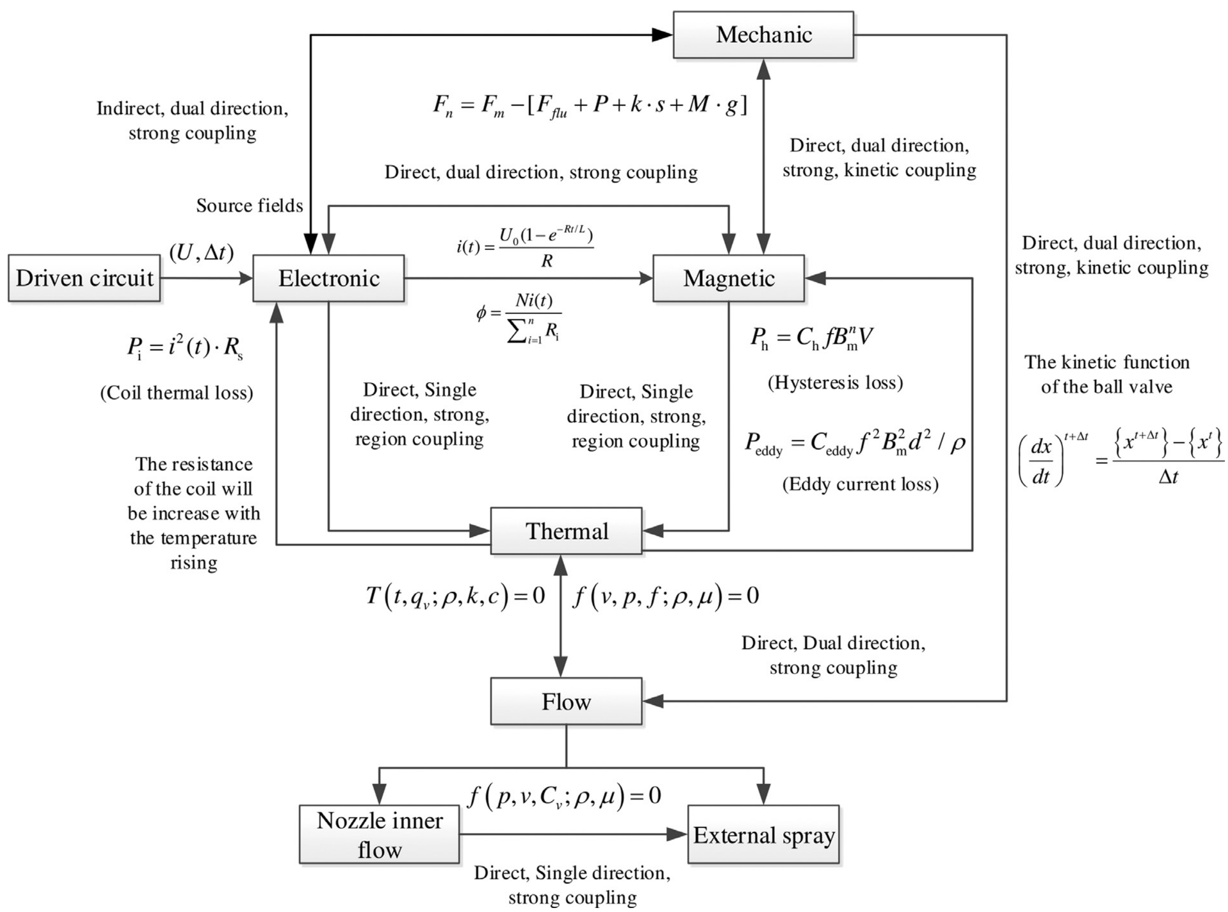

Fig. 2. Multi-physical field coupling diagram.

conflictions, a new way which utilizes high temperature to improve the spray characteristics and formation has been found by some experts, for example, Short et al. (2010), Chan et al. (2014), Levy et al. (2014), etc. Especially, when the fuel temperature exceeds the local boiling point, the fuel is superheated and the sprays experience flash boiling. Comparing to the non-flash boiling liquid spray, the flash boiling sprays show severe spray structure transformation, remarkable different fuel air mixing and significantly reduced droplet size (Sementa et al., 2012; Zeng and Xu, 2011; Aleiferis et al., 2010). All those observation indicates that different mechanisms governing the flash boiling spray atomization and vaporization process.

With the progress of the computer science and mathematical technique, large scale simulation analysis has been widely used to investigate the comprehensive performances and process principle of the mechanical–electrical products, especially for multi-physical