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Full Length Article

Effects of lateral swirl combustion chamber geometries on the combustion and emission characteristics of DI diesel engines and a matching method for the combustion chamber geometry

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ABSTRACT

Previous experimental results show that a lateral swirl combustion system (LSCS) significantly improves the fuel consumption and the soot emission in direct injection (DI) diesel engines. To further improve LSCS performance and effectiveness, this study undertook numerical simulation to analyze the effects of the LSCS chamber geometries on combustion and emission characteristics under the condition of 2500 r/min and full load, revealing the relevant influence mechanisms. Based on a sensitivity analysis on the indicated power, the chamber geometry optimization was accomplished. The performance improvement of the optimized LSCS was verified using a single-cylinder DI engine. However, due to the interplay between fuel spray jets and wall surfaces, the optimized results are different for various fuel supply systems. To apply the LSCS effectively in different fuel supply systems, a matching method for LSCS chamber geometry is proposed in this paper.

The results show that the combustion performance of the LSCS is primarily affected by the geometries of the split-flow creation, in which θ (the deviation angle of flow-guide) plays a dominant role. When θ was in the range of 15–27°, the combustion chamber created favorable flow guidance for spray and promoted the fuel/air mixture formation. After the geometrical optimization of the LSCS, fuel consumption decreased by 2.8–4.1 g/(kW.h) and soot emission decreased by 69–75% under various engine speeds as compared with the double swirl combustion system (DSCS).

1. Introduction

With ever-increasing injection pressures, direct injection (DI) diesel engines have become mainstream in diesel engines [1]. DI diesel engines are widely used in transportation, engineering and agricultural machinery due to the excellent dynamic performance and fuel economy [2]. In DI diesel engines, the key to effective fuel/air mixture formation and combustion is optimizing the fuel spray along with the combustion chamber geometry and the in-cylinder air flow [3]. Therefore, improving the combustion chamber geometry is an important component of enhancing combustion and emission performance [4].

In view of the interplay between the fuel spray and the combustion chamber, DI combustion systems can be divided into two types: the encompassing combustion system (ECS) and the wall-flow-guided combustion system (WFGCS). The ECS has a combustion chamber that can well-envelop the spray profile, including such systems as the traditional omega combustion system (OMECS), the dumbbell-shaped combustion system [5] and the toroidal re-entrant combustion chamber (TRCC) [6]. However, special combustion chamber geometry has been designed in the WFGCS to guide the fuel spray along an intended trajectory. The WFGCS includes such systems as the double swirl combustion system (DSCS) [7], the BUMP combustion system [8], the umbrella-curtain spray (UCS) combustion system [9] and the swirl chamber combustion system [10]. Under the high injection pressure condition, the spray ejected from the nozzle penetrated into the ambient gas of combustion chamber with high speed [11]. Owing to the high spray speed and small combustion chamber, the fuel spray might impinge on the piston wall before being fully vaporized in real DI diesel engines and “wall-wetting” problem appears, especially in downsized engines [12]. Wall-wetting mainly causes excessive soot emissions to the DI diesel engines [13]. Obviously, the spray impingement worsens the performance of diesel engines by altering the fuel mixing, combustion and emissions [14]. Therefore, the ECS has encountered difficulties in adapting to present fuel supply systems, while the aforementioned WFGCS shows great potential by utilizing special chamber geometry and injection energy to promote the formation and subsequent combustion of the fuel/air mixture.

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Nomenclature

DI	direct injection
LSCS	lateral swirl combustion systems
DSCS	double swirl combustion systems
OMECS	omega combustion systems
ECS	encompassing combustion systems
WFGCS	wall-flow-guided combustion systems
r_t	central boss radius
δ_t	inclination angle of central boss
h_t	central boss depth
r_c	connective arc radius
β	radius angle of the combustion chamber
D	combustion chamber diameter
h_a	convex edge height
r_a	split arc radius
TDC	top dead center
BDC	bottom dead center
FS	full scale
FSN	filter smoke number
FSO	full-scale output
P_i	indicated power
θ	deviation angle of flow-guide
$h_{a,opt}$	optimal convex edge height

In a combustion chamber, the circumferential air zone can be divided into two parts: A and B, as shown in Fig. 1 [15]. In previous ECS and WFGCS chambers, the fuel/air mixture was mainly focused on zone A, while the air in zone B was not fully utilized unless an appropriate intake swirl was induced. However, the intake swirl causes a loss of intake flow and intake mass as well as subdue the effectiveness of the wall-flow-guide. To fully utilize the fuel injection energy and the air in zone B, a lateral swirl combustion system (LSCS) was developed as a new WFGCS [16]. Fig. 2 shows the schematic diagram of the LSCS. As compared with the OMECS, special split-flow creations are introduced in the LSCS, the number of which is 2 times the number of nozzle holes. Every split-flow creation contains a convex edge and two split arcs. After colliding with the convex edge, a fuel jet spray splits into two scrolled parts, and lateral swirls form. In this way, the air utilization in zone B is increased, whereupon the mixing effectiveness of fuel and air is improved. Experimental results indicate that the flame spread space of the LSCS is obviously increased after the spray impingement as compared with the OMECS; meanwhile, the LSCS achieves better fuel consumption and less soot emission than the OMECS in test engines [17]. The LSCS also shows strong adaptability to the excess air coefficient and has satisfactory combustion performance under a low excess air ratio of 1.3. Furthermore, the thermal load of the cylinder head is low because the combustion occurs mainly in the bottom of the combustion chamber, and the convex edges will not be ablated in virtue of the cooling effects of the fuel spray jets [18].

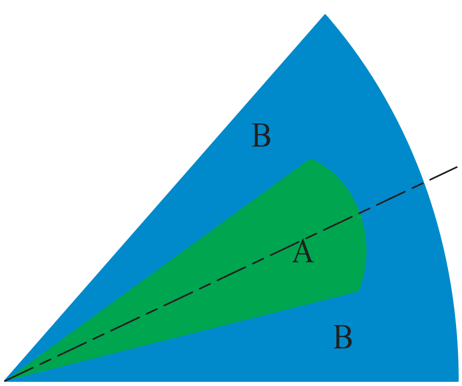

Fig. 1. Circumferential air zone in a combustion chamber.

Evidently, due to its unique fuel/air mixing method, the LSCS shows remarkable combustion performance as well as fuel economy and soot emission quality, demonstrating great research value and potential. As the core of the LSCS, the combustion chamber geometry has a significant effect on the combustion performance. Moreover, the wall-flow-guided effectiveness of the LSCS is closely related to the fuel injection energy, so it is of great importance to achieve an appropriate match between the LSCS chamber geometry and the fuel supply system. Simply put, the optimal LSCS chamber geometry varies in different fuel supply systems. However, previous LSCS chambers were designed primarily based on the OMECS chambers. Up until now, the effect of LSCS chamber geometry on combustion performance has not been studied, and the geometrical optimization of the LSCS chamber has not been conducted. As such, there is no effective matching method for LSCS chamber geometry, which greatly limits the practicability and applicability of the LSCS.

In this study, the effects of the LSCS chamber geometries on the combustion and emission characteristics of DI diesel engines were

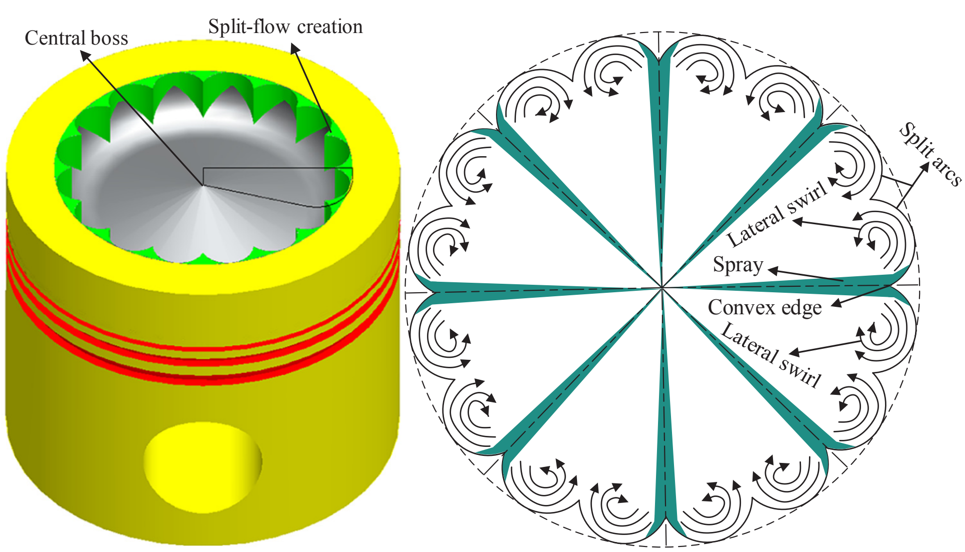

Fig. 2. Schematic diagram of the LSCS.