Investigation of Cyclic Variations Effects on Mixing and Combustion Processes in a DISI IC-Engine by Using Large Eddy Simulation

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Abstract

One of the most important problem in the design of direct injection spark-ignition (DISI) engines is the cycle-to-cycle variations of the flow and their effects on mixing and combustion processes. The LES based analysis is used to characterize the cycle-to-cycle fluctuations of the flow field and their impact on the mixture preparation and combustion processes in a realistic four-stroke IC-engine with variable charge motion system.

Introduction

Direct injection spark ignition (DISI) engines have a large potential to reduce emissions and specific fuel consumption. One of the most important problem in the design of DISI engines is the cycle-to-cycle variations of the flow, mixing and combustion processes. The large eddy simulation (LES) based analysis is used to characterize the cycle-to-cycle fluctuations of the flow field and their impact on the mixture preparation and subsequent combustion processes in a realistic four-stroke internal combustion engine with variable charge motion system. Based on the analysis of cycle-to-cycle velocity fluctuations of in-cylinder flow, the impact of various fuel spray boundary conditions on injection processes and mixture preparation is first investigated. The joint effect of both cycle-to-cycle velocity fluctuations and variable spray boundary conditions is discussed in terms of mean and standard deviation of relative air-fuel ratio, velocity and mass fraction. Finally a qualitative analysis of the intensity of cyclic fluctuations below the spark plug is provided. The effect of cycle-to-cycle fluctuations of the flow as well as mixing on combustion processes will be then printed out.

Investigated Configuration and Numerical Method

The investigated configuration (see Fig. 1.a) represents a four stroke direct spray injection engine with variable charge motion (VCM) system. This is a realistic IC-engine with four canted valves, an asymmetric cylinder head and an asymmetric piston bowl.

The KIVA-3V software [3] used within this work has found widespread applications for the simulation of IC-engine flows. The code has been extended by the standard Smagorinsky model. The so-called DDM (discrete droplet model of Dukowicz) with Lagrangian, computational particles that represent parcels of spray droplets with uniform properties was applied for the spray description. The spray and fluid interactions are accounted for by means of a number of submodels, which are described in detail in the literature [3]. A simple standard Arrhenius-based combustion model [3] has been used for comparison to a FGM-based model.

A newly developed parallelization strategy [4] has been used in order to increase the number of samples allowing to perform LES of cyclic fluctuations in an IC-engine with reasonable statistical accuracy.

Results and Discussion

The present work extends the previous investigations of the authors [1, 2] of cycle-to-cycle variations of in-cylinder flow field and mixing in a realistic IC-engine (Fig.1.a) using LES method to fuel spray injection. As an example the flow field during the compression stroke (CA = 255°, see Fig. 1b) shows a pronounced tumble flow with the vortex center located at the center of the combustion chamber. The results obtained in [1, 2] have shown that during compression stroke the normalized standard velocity deviation reaches the highest value over the whole engine cycle with a peak intensity at the center of tumble motion as depicted in Fig. 1c.

After the calibration of the fuel spray injection model the impact of the cycle-to-cycle velocity fluctuations on fuel spray injection and mixing processes within a combustion chamber has been considered. Fig.2 presents the comparison of mean mass fraction (top) and intensity of cyclic variations (bottom) for the following cases: two-phase flow with constant (a) and variable (b) spray boundary conditions as well as two-phase flow with the joint effect of both velocity cyclic fluctuations and variable spray boundary conditions (c).

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The investigation has been split into 4 stages: 1) In order to highlight the effect of velocity cyclic variations on the mixing field, the initial and boundary conditions for the spray injection were kept identical for all considered cycles during the first stage (Fig. 2a). 2) In the second stage the spray injection under variable spray boundary conditions takes place into a typical in-cylinder flow field which was kept identical for all engine cycles. Figure 2b illustrates the effect of variable spray boundary conditions on the mass fraction pattern. This analysis helps to separate the effects of velocity and spray cyclic fluctuations on the mixing process. 3) In addition the joint effect of both velocity cyclic fluctuations and variable spray boundary conditions is presented in Fig.2c. 4) The effect of cycle-to-cycle fluctuations of the flow as well as mixing on combustion processes will be presented in the final paper.

In the case of single-phase flow the maximal intensity of cyclic variations is found at the center of tumble motion [4]. In the case of two-phase flow the flow field in the combustion chamber is defined by a superposition of in-cylinder charge motion and injected fuel spray jet. This interaction results in a considerable increase of the intensity of cyclic velocity fluctuations at the center of the tumble motion. The analysis has shown a great impact of velocity cyclic variations on the air-fuel mixing processes as well as fuel jet penetration and forming of fuel vapor cloud in the area near the spark plug. Crank angle resolved figures of charge motion and turbulent kinetic energy for the three considered cases will be also presented in the final paper.

Acknowledgement

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References

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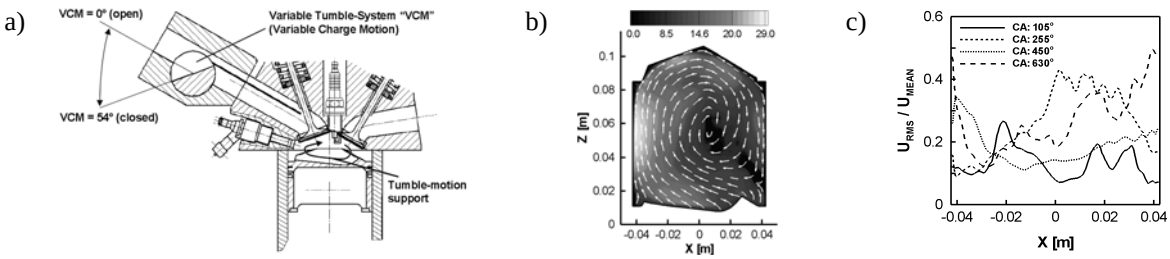

Figure 1. Configuration of the "BMBF" IC-engine (a); Mean velocity flow field in the cross section of the combustion chamber at CA = 255°, averaged over 50 engine cycles (b), the standard velocity deviation normalized with the local mean velocity at z = 0.05 m for different engine strokes (c).

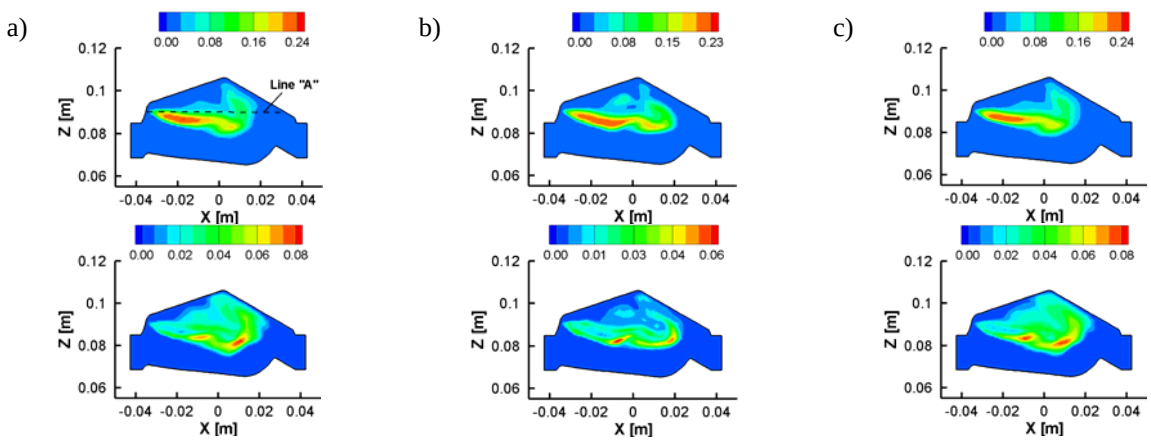

Figure 2. Mean mass fraction (top) and rms of mass fraction (bottom) at CA = 315°. (a) Two-phase flow with constant spray boundary conditions. (b) Two-phase flow with variable spray boundary conditions. (c) Two-phase flow with the joint effect of both velocity cyclic fluctuations and variable spray boundary conditions.