A comprehensive Lagrangian flame-kernel model to predict ignition in SI engines

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Abstract

A correct prediction of the ignition process represents a fundamental pre-requisite for a successful CFD simulation of combustion SI engines. Ignition involves many scales, physical and chemical phenomena that need to be described in detail. Within this context, the authors developed a Lagrangian model that can be used to predict the first stages of the combustion process in SI engines, when the size of flame kernel is small compared to the mesh size, and flame development is influenced by heat transfer from the spark, local flow, turbulence and air/fuel mixture distribution. In the proposed model, the spark channel is initially represented by a set of Lagrangian particles that are convected by the mean flow. Flame kernels are launched locally for all the particles satisfying an ignition criterion based on the local Karlovitz number. For each of them, equations of energy and mass are solved accounting for electrical power transferred from the electrical circuit, local turbulence and flame speed. The flame surface density in the initial stages of combustion is then reconstructed from particle positions and their diameter. Such quantity is then used to compute the chemical species reaction rates in the Eulerian gas phase.

This paper presents in detail the proposed approach to predict the initial flame kernel growth, focusing also on the different sub-models that need to be included for a realistic description of the entire process. In particular, a simplified model for the electrical circuit was included to estimate the instantaneous current and voltage on the secondary circuit, that are then used to compute the amount of electrical power that is transferred to the flame kernel. The plasma expansion velocity, which is very important immediately after the spark discharge process, was estimated by solving the heat conduction equation in each flame kernel. Possible re-ignition events are predicted by means of two different criteria, based on spark-channel length or secondary circuit voltage. The algorithm for reconstructing the flame surface density distribution is based on the use of intersecting triangulated surfaces.

A simplified geometry including a spark-plug and constant pressure conditions were used to test the consistency and predictive capability of the proposed flame kernel model. Effects of the following parameters were evaluated:

- influence of charging time

- air/fuel ratio

- velocity field