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IGNITION MODEL AND ITS IMPACT ON FLAME KERNEL FORMATION IN SI ENGINE

Physical background of ignition modelling

Ignition resulting from spark discharge between spark plug electrodes strongly influences the combustion process in spark ignited engines [3],[9]. As a consequence, it influences engine work repeatability and toxic components concentration in exhaust gases. That is why in-depth knowledge, analysis and proper mathematical description of ignition phenomenon is extremely important because it significantly influences results of SI engine work cycle numerical modelling and conformity of numerical and experimental research results.

Detailed description of all processes that occur during ignition in SI engine is very complicated mostly due to thermodynamic characteristics of flame kernel. For that reason simple and empirical methods of estimating energy passed from ignition system to discharge circuit during spark discharge between spark plug electrodes are used to describe this phenomenon[4], [8], [21]. Thermal ignition model of spark discharge is commonly applied in software used in industry and research such as KIVA-3V[10], [12], [14]. The model assumes constant volume of the electrical arc and constant energy flux passed from ignition system to fuel-air mixture during individual phases of spark discharge.

This model is therefore very imperfect because it does not take into account factors influencing the ignition process such as [20]:

- influence of fuel-air mixture local velocity on the region to which the energy from ignition system is passed during ignition[2], [7] – Fig. 1;
- variation of energy and energy flux delivered to the mixture during breakdown, arc and glow phase of spark discharge;
- spark plug geometry and its influence on the level of minimal energy needed to initiate the combustion process and volume of ignition region;
- spark discharge duration resulting from the type of applied ignition system;

– influence of pressure and temperature in combustion chamber at the time of ignition on the value of spark discharge minimal energy.

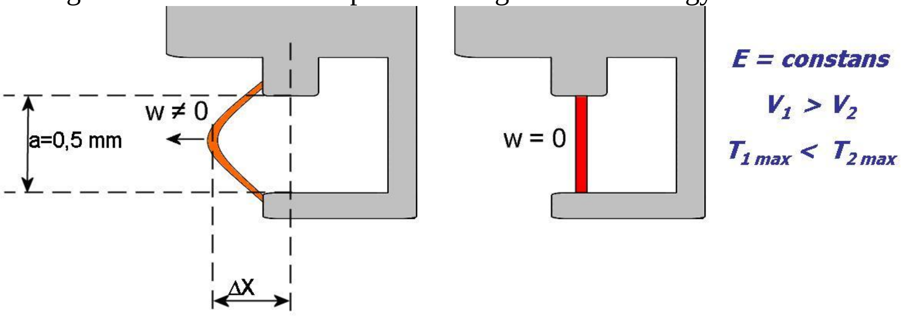

Fig. 1. Example of flow parameters influence on volume of mixture activated by spark discharge and on flame development; *w* – local velocity of mixture, *E* – energy of spark discharge, *V* – volume of discharge region, T_{max} – maximal temperature

Computational domain, initial and boundary conditions

A geometric hexahedral mesh describing sector of constant volume combustion chamber with a spark plug (Fig. 2) built of 221 blocks and 44 143 active cells (total number of cells is 49 452) was designed in order to compare the results of flame development numerical modelling using standard and newly developed, advanced ignition model (implemented by the author into KIVA-3V code).

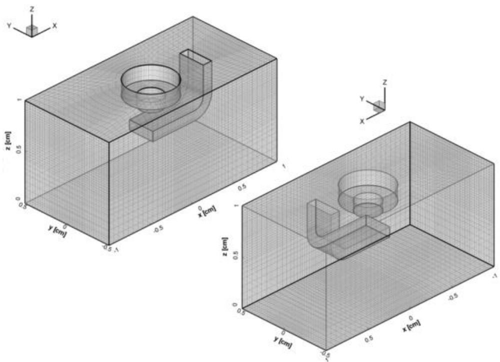

Fig. 2. Hexahedral mesh of computational domain

The value of resultant air-fuel mixture flow velocity measured with the use of anemometer located in the place of spark plug in S320 engine at the piston position corresponding to ignition moment measured in [18],[19] was determined to be at the level of 10 m/s. Therefore constant and uniform flow field of above mentioned velocity value was declared as boundary condition at the borders of computational domain coplanar to YZ plane. However the geometry of spark plug induces disturbances dependent on the ground electrode location regarding flow direction. The unsteady flow exists for approximately 1 ms and after that time the flow stabilizes.

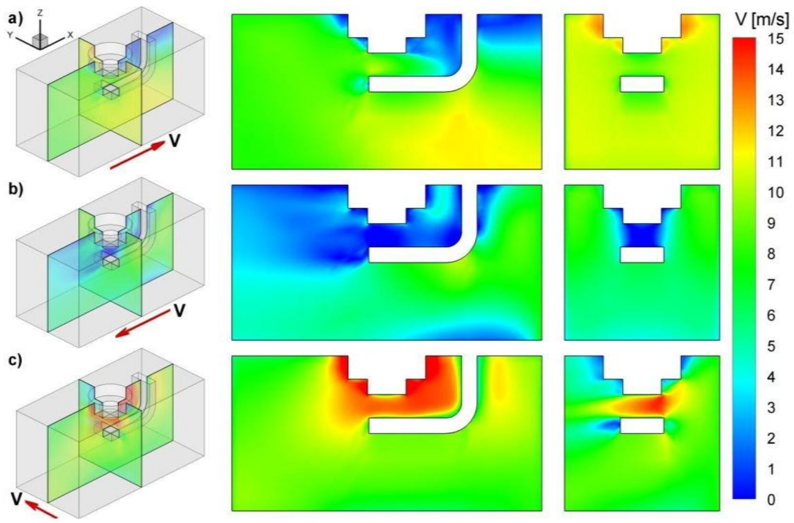

Fig. 3. Distribution of mixture velocity for different ground electrode location (flow direction marked by arrows)

The velocity magnitude in the ignition region depends strongly on the ground electrode location [5],[6]. The velocity mean value equals:

- 7,3 m/s – flow through YZ plane along X axis (Fig. 3a),
- 6,9 m/s - flow through YZ plane opposite X axis (Fig. 3b),
- 11,8 m/s - flow through XZ plane along Y axis (Fig. 3c).

KIVA-3V package

Numerical research was conducted using KIVA-3V package. The engine work cycle model in the code is based on system of mass, momentum and energy conservation equations describing three dimensional, unsteady flow field with combustion. The code solves three dimensional Navier-Stokes equation for the mixture of compressible liquids, which enables taking into account creation and development of shock wave in gas [1]. Periodic boundary conditions and walls (with turbulent wall law, free slide and without slide, with adiabatic wall and with diversified temperature distribution on the wall) are used as boundary conditions in the KIVA-3V. Three turbulence models are implemented: k-ε, RNG k-ε and SGS (Sub-Grid Scale).

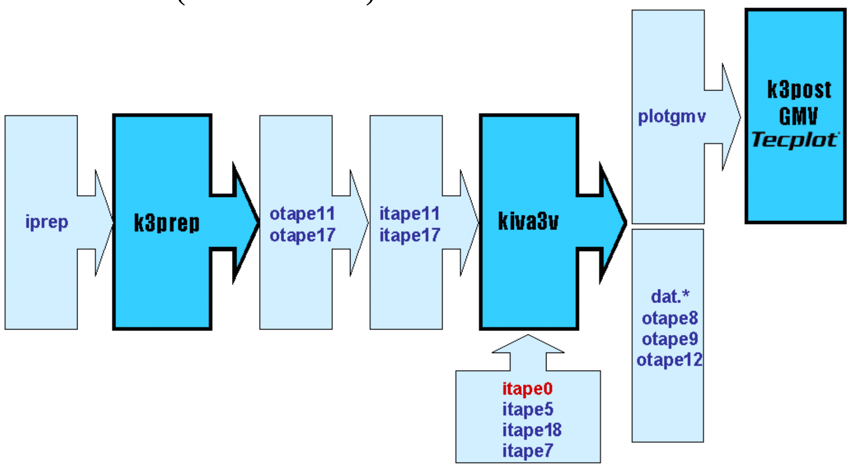

Fig. 4. Schematic diagram of data processing during computations in KIVA-3V package

The KIVA-3V package consists of three separate executables:

- k3prep – preprocessor,
- kiva3v – solver,
- k3post – postprocessor.

Schematic diagram of data processing in KIVA-3V package is depicted in Fig. 4. The preprocessor input data (geometric mesh) is prepared in file called *iprep*. The preprocessor generates *otape11* and *otape17* files which are input data to the solver after renaming respectively to *itape11* and *itape17*. Another input data to the solver is written in *itape5*, *itape8* and *itape7* files. The main program generates *plotgmv* files and data concerning in-cylinder conditions. The *plotgmv* files serve as input data for visualization in postprocessor. Additional data needed by the newly developed, advanced ignition model to calculate the path of electric arc is delivered in modified *itape5* and *itape0* files.

Standard and advanced ignition model

The ignition modelled in KIVA-3V is accomplished by delivering specific amount of energy to a cell or prism shaped block of cells. It is also possible to define two ignition regions. The energy is supplied in fixed manner. The start of ignition (energy supply) is set in *itape5* input file and lasts for crank angle specified in the same file. There is also possibility to define the ignition window on the basis of time in spite of crank angle. The energy flux delivered to the mixture during ignition can be modified by changing the value of *xignit* parameter but it is not possible to modify the energy flux during individual phases of spark discharge. The energy supply to the specified region is terminated if the temperature of the region exceeds 1600K before the end of ignition window. The front of the flame is assumed to have enough energy to sustain its development and the addition of external energy is no longer needed after exceeding the above mentioned temperature[15], [16].

Table 1. Ignition models comparison

	Standard model	**Advanced model**
Influence of flow field between spark plug electrodes on discharge arc geometry	✗	✓
Influence of pressure in the combustion chamber on discharge arc geometry	✗	✓
Influence of spark plugs electrodes design on discharge arc geometry	✗	✓
Arc quenching caused by too intensive flow between spark plug electrodes	✗	✓
Arc creeping on the surface of spark plug electrodes	✗	✓
Electric arc convection with the flow	✗	✓
Analysis of mesh element sizes	✗	✓
Automatic arc diameter adaptation in case of too coarse mesh	✗	✓
Different values of energy delivered to mixture during subsequent phases of spark discharge	✗	✗
Electrodynamic phenomenon	✗	✗

✗ - not taken into account in the model, ✓ - taken into account in the model

The advanced ignition model has been developed and implemented into KIVA-3V solver in order to achieve better conformity of numerical and experimental research concerning combustion in SI engine. The model describes ignition induced by spark discharge between spark plug electrodes. It takes into account the influence of spark plug geometry on local flow velocity of mixture in the ignition region. It also analyzes local flow velocity and its impact on spark discharge process. The model also takes into account the variation of electric arc path and variation of discharge region volume caused by mixture convection however the electrodynamic phenomenon is neglected[17].

Fig. 5 and Fig. 6 depict the electric arc path calculated with the use of standard and advanced ignition model. In the case of standard ignition model it is only possible to set the dimensions of prism-shaped ignition region arbitrary. The advanced ignition model calculates the electric arc path on the basis of flow parameters as well as pressure and temperature in the combustion chamber one computational time step before the ignition (Table 1).

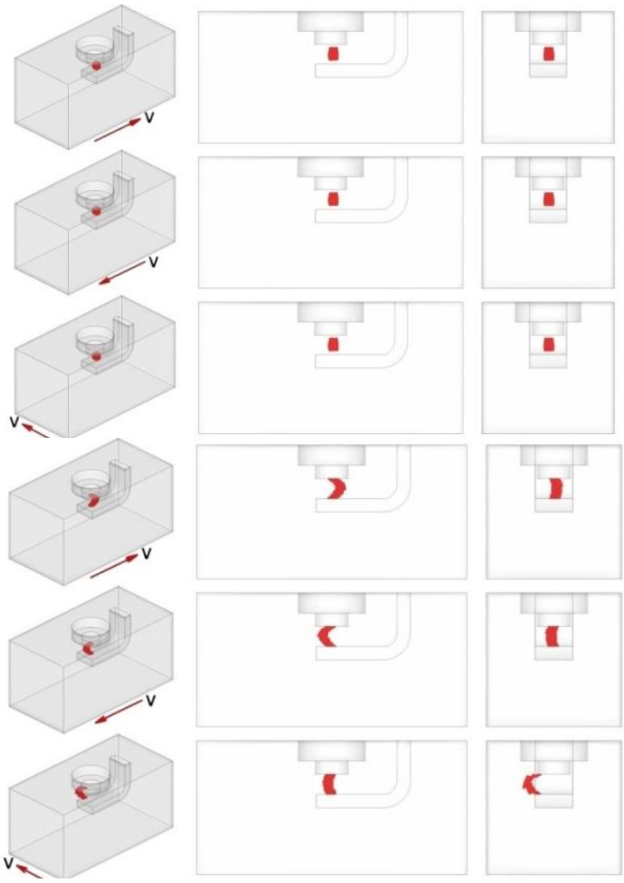

Fig. 5. Electric arc path calculated by standard (left) and advanced (right) ignition model regarding mixture flow direction marked by arrows

Results

Fig. 6 and Fig. 7 show numerical modelling results of early flame propagation in analysed domain 1 ms after the beginning of spark discharge for two analysed ignition models and air excess factor equal 1,4.

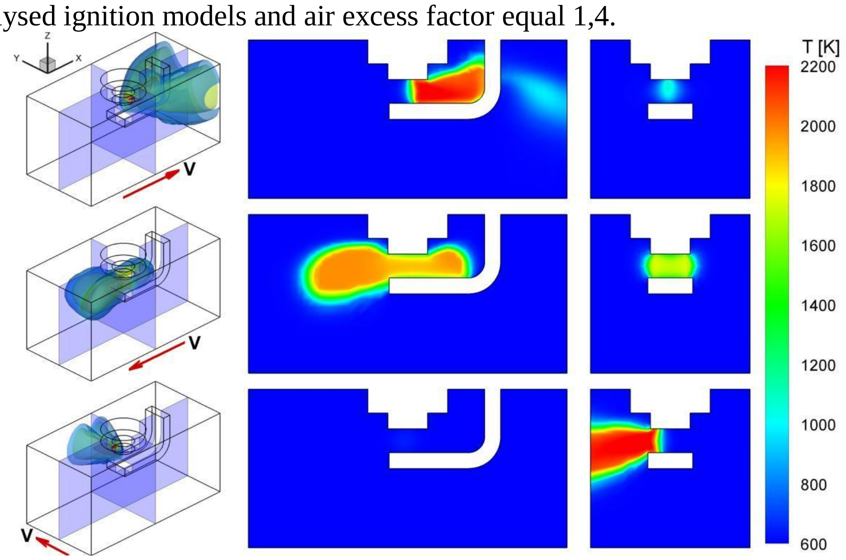

Fig. 6. Temperature distribution in computational domain for λ=1.4 (standard ignition model)

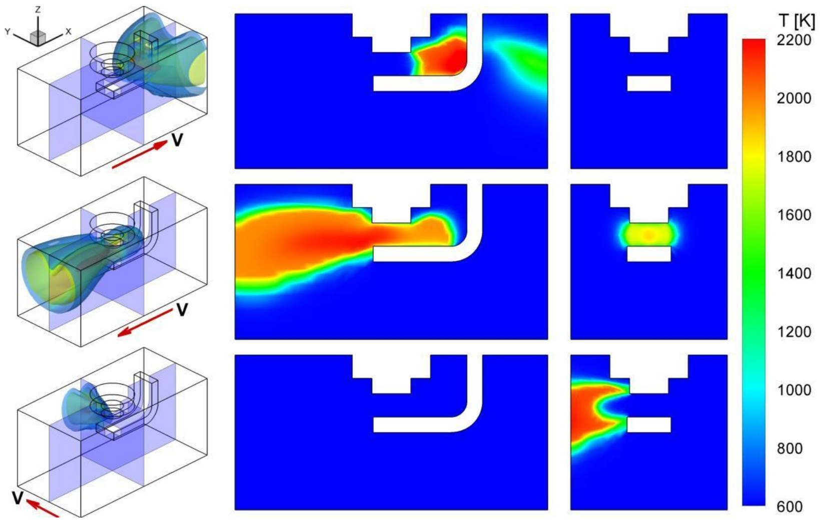

Fig. 7. Temperature distribution in computational domain for λ=1.4 (advanced ignition model)

Conclusions

It has been shown that the location of spark plug ground electrode regarding resultant mixture flow velocity direction significantly influences the processes of flame front formation and grow.

It has been proved that spark plug geometry should be described in geometric mesh of combustion chamber in order to obtain reliable results of piston engine work cycle numerical modelling because its influence on research results is important.

The attempt to estimate the correlation between spark plug ground electrode location regarding flow direction is also purposeful as above mentioned factors directly influence the flame kernel propagation in combustion chamber.

In terms of flame development, the most favourable flow direction regarding ground electrode location is the one directed oppositely to X axis as in such configuration the flame kernel propagation from the area between spark plug electrodes is the most effective.

Obtained results show, that proper value of local flow velocity favourably influences the processes prior to mixture ignition (charge preparation and its distribution in combustion chamber) as well as early flame front propagation.

The advanced ignition model is capable to reflect the processes occurring during ignition and flame development more precisely than standard model due to taking into account greater number of phenomenon, which occur in real engine at the time of ignition.

The differences in results obtained with the use of analysed models justify the purposefulness of working on the development of ignition model as this factor strongly influences the overall combustion and therefore toxic components concentration in exhaust gases.

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MODEL ZAPŁONU I JEGO WPŁYW NA FORMOWANIE JĄDRA PŁOMIENIA W SILNIKU ZI

Streszczenie

Zaprezentowano analizę wpływu geometrii świecy zapłonowej, pola prędkości mieszanki między elektrodami świecy oraz ciśnienia na proces spalania w silniki ZI. Badano trzy konfiguracje lokalizacji elektrody masowej względem wypadkowego wektora prędkości przepływu mieszanki homogenicznej w komorze spalania o stałej objętości. Zaprezentowano wyniki symulacji formowania jądra płomienia dla dwóch modeli zapłonu.