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CFD Modeling of Complete Thermal Cycle of SI Engine

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Summary. The results of the modeling of thermal cycle of spark ignition internal combustion engine are presented. The modeling was carried out in the AVL Fire. The authors undertook an effort to generate a complete mesh for the test engine, including the intake and exhaust ports and the valves. This involved four computational domains generating. The number of computational cells of engine geometry was optimized. There was included a local and temporary thickening of the mesh which has contributed to more accurate solutions and shortening of computing time and, consequently, the engine cycle calculations.

Key words: engine, simulation, modeling, combustion.

INTRODUCTION

Engines are designed to maximize power and economy while minimizing exhaust emissions. This is due to growing concern for decreasing energy resources and environmental protection. For this reason, there is still carried out intensive research and development in internal combustion engines. An engine should operate with the greatest efficiency with the least toxic compound emissions. Researches on how to improve the combustion process, introduce a new fuel such as hydrogen, and optimize engine parameters are still carried out. Maximizing the performance of the engine (BMEP) usually causes the occurrence of the so-called knock combustion. Therefore, intensive researches and development in internal combustion engines are being conducted.

Researches based on numerical simulations using advanced mathematical models have recently been developed very intensively. The development of numerical modeling is heightened by increasing computational power that allows modeling not only of flow processes but also combustion in 3D [1,2,3]. One of more advanced numerical models used for combustion process in internal combustion engines modeling is AVL FIRE [4]. In 2009 Institute of Internal Combustion Engines and Control Engineering of Czestochowa University of Technology began University Partnership Program with AVL Company. This allowed the use of the Fire software to IC engine thermal cycle modeling [5,6,7]. The AVL FIRE software belongs to programs which are used to modeling of thermal cycle of internal combustion engines. FIRE allows the modeling of flows and thermal processes occuring in the intake and exhaust manifold and in combustion chamber of internal combustion engine. This program allows modeling of the transport phenomena, mixing, ignition and turbulent combustion in internal combustion engine. Homogeneous and inhomogeneous combustion mixtures in spark ignition and compression ignition engine can be modeled using this software as well. Kinetics of chemical reactions phenomena is described by combustion models which take oxidation processes in high temperature into consideration. Several models apply to auto ignition processes. AVL FIRE allows modeling knock process which occurs in combustion chamber of IC engine. This program allows to create three-dimensional computational mesh, to describe boundary conditions of surfaces and initial conditions of simulation, as well.

NUMERICAL MODEL

The test engine was constructed on the basis of a four-stroke compression-ignition engine 1HC102 manufactured by "ANDORIA" Diesel Engine Manufacturers of Andrychow. After some constructional changes, this engine was redesigned for the combustion of gasoline as a spark-ignition engine. For this reason, the engine was equipped with a new fuel supply system and an ignition installation. As a result of modernization the shape of the combustion chamber and the compression ratio was reduced from 17 to 8.5. This is a stationary engine, equipped with two valves with horizontal cylinder configuration. The engine is equipped with a cooling system based on the evaporation of liquid.

Figure 1 shows the modernized combustion chamber with spark plug location of the test engine. On the basis of the test engine geometry the computational mesh was created (Fig. 3). Valve lifts curves were determined by measuring the engine cams. The modeling takes into account only the intake and exhaust channels located in the engine head.

Tab. 1. Main engine parameters

bore cylinder	100 mm
stroke piston	120 mm
connecting rod length	216 mm
direction of cylinders	horizontal
squish	11 mm
compression ratio	8.5
engine speed	1500 rpm
number of cylinders	1

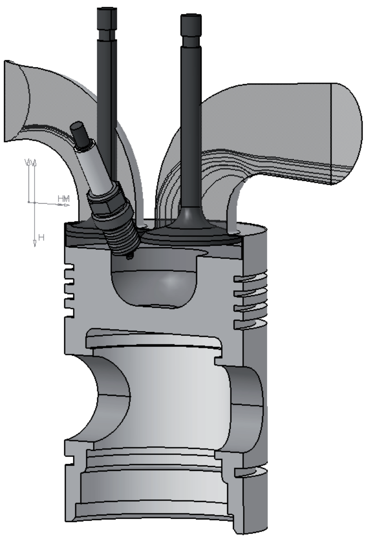


Fig. 1. Experimental engine

The computational mesh can be obtained as surface or volume discretization. In AVL Fire the Finite Volume Method (FVM) is used to calculate the heat flows. For four-stroke engine four computational domains are required. The first domain includes the intake stroke until closure of the intake valves. The second domain is used since the closure of the inlet valve until the exhaust valve timing, at a time when the valves are closed. The third domain is used since the opening of the exhaust valve to the end of the exhaust stroke. And finally the fourth domain is required for the whole engine cycle. The division cycle of three domains eliminates the problem of return flows in the crevices between the valve train and valve seat.

The first step is to draw the engine workspace (Fig. 2). Due to software, valves must be slightly open. This geometry is loaded into the preprocessor of Fire program. On the basis of this geometry the computational moving mesh is generated (Fig. 3).

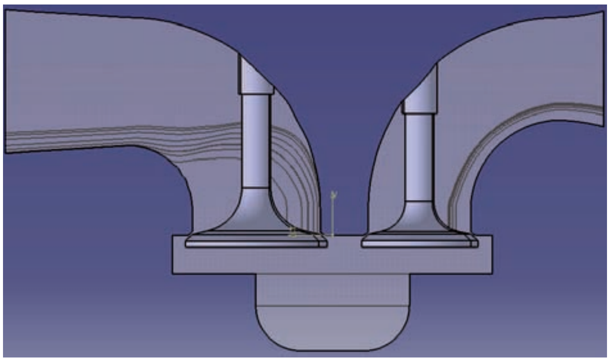
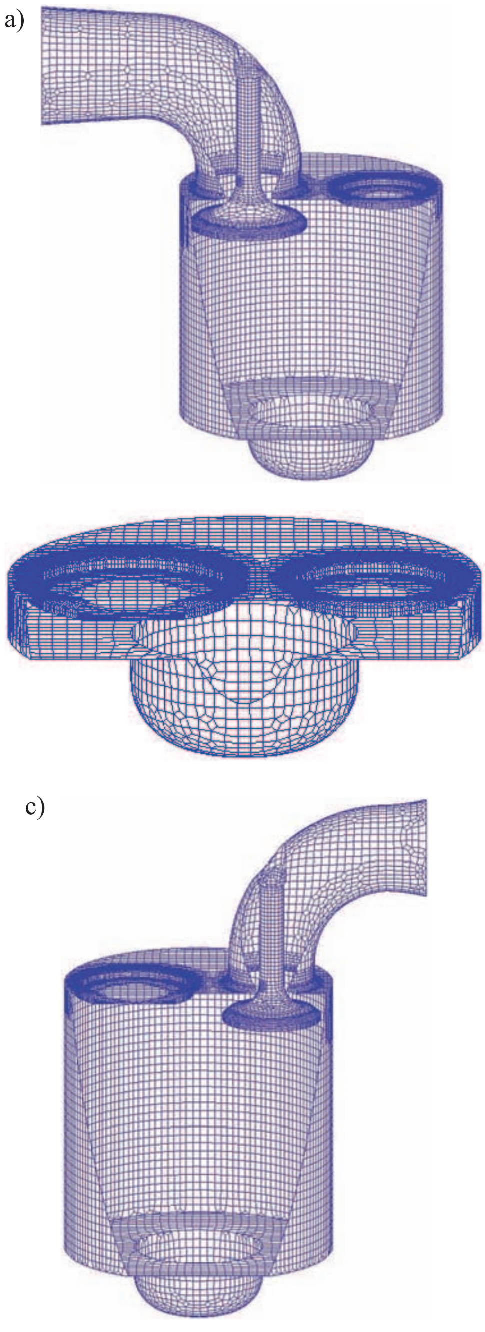


Fig. 2. Geometry of engine in CAD

a)

b)

c)



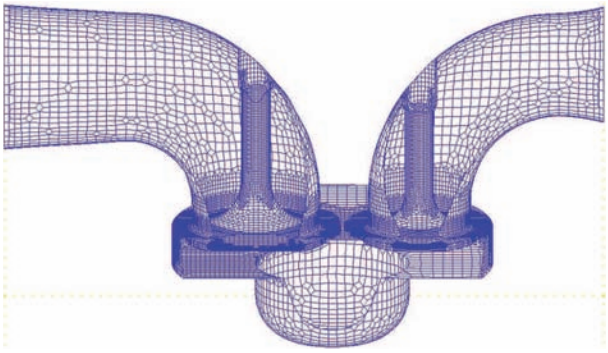


Fig. 3. Computational mesh of engine, a) intake, b) compression, c) exhaust, d) complete mesh

The computational mesh around valves was concentrated to obtain more accurate results. Fire gives the possibility of temporary thickening of the grid.

Modelling of the thermal cycle of the test spark ignition engine in the AVL FIRE [4] software was carried out. Modelling of combustion process was carried out using an advanced combustion model. ECFM (Extended Coherent Flame Model) model was used based on the basis of turbulent mixing zone of air, fuel and exhaust. The ECFM was developed in order to describe combustion in spark ignition engines. This model allows the modelling of the combustion process of air-fuel mixtures with EGR effect and NO formation. The model is based on the description of unburnt and burnt zones of the gas. The concept of combustion model is based on a laminar flamelet idea, whose velocity and thickness are mean values, integrated along the flame front. The thickness of the flame front layer depends on the pressure, temperature and content of unburnt fuel in the fresh zone. In addition, it is assumed that reaction takes place within relatively thin layers that separate the fresh unburned gas from the fully burnt gas. This model uses a 2-step chemistry mechanism for the fuel conversion. Unburnt gas phase consists of 5 main unburnt species: fuel, O_2, N, CO_2 and H_2O. After the burnt gas phase it is assumed that no fuel remains. The burnt gas is composed of 11 species, such as O, O_2, N, N_2, H, H_2, CO, CO_2, H_2O, OH and NO.

Tab. 2. The main input parameters

ignition advance angle	12 deg
fuel	gasoline
fuel temperature	320 K
initial pressure	0.085 MPa
initial temperature	365 K
excess air factor	1.0
density	1.19 kg/m^3

RESULTS

As a result of numerical analysis a number of characteristic quantities of combustion process in the engine were obtained such as: pressure, temperature, parameters of flow field, turbulence, heat transfer, species, toxic parameters and others.

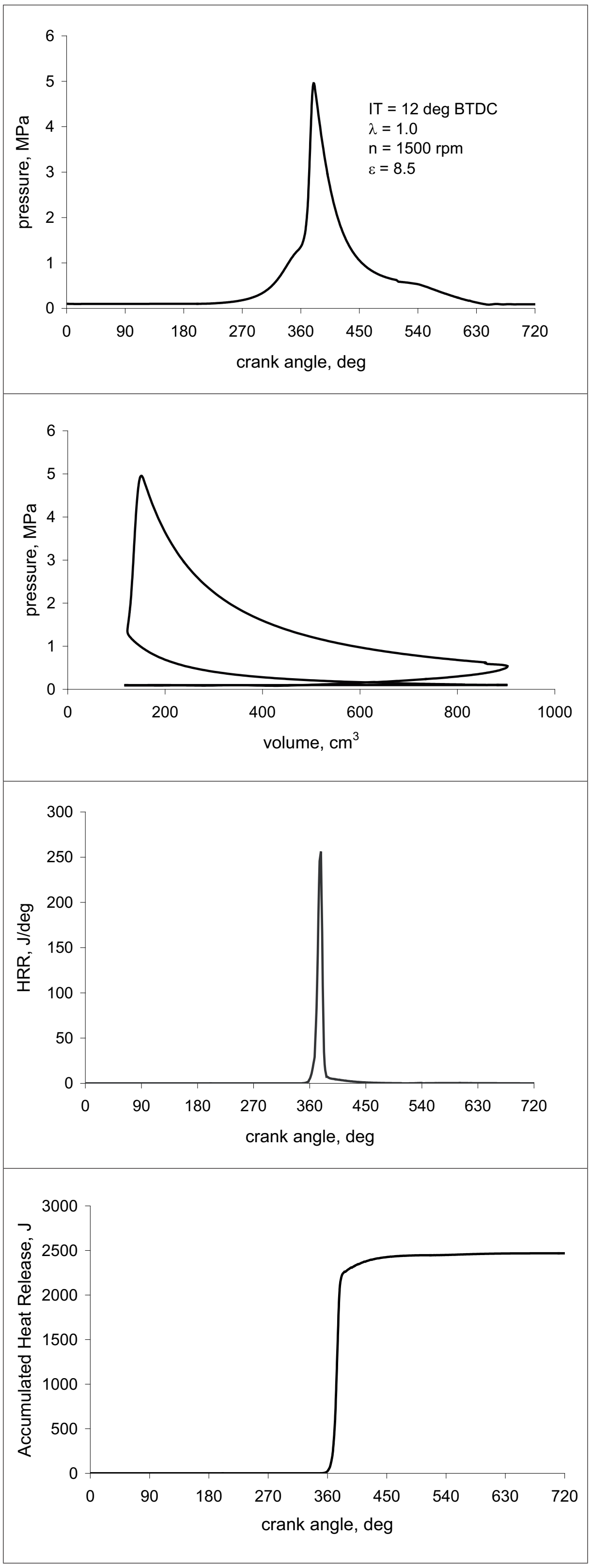


Fig. 4. Pressure, heat release rate and accumulated heat release courses

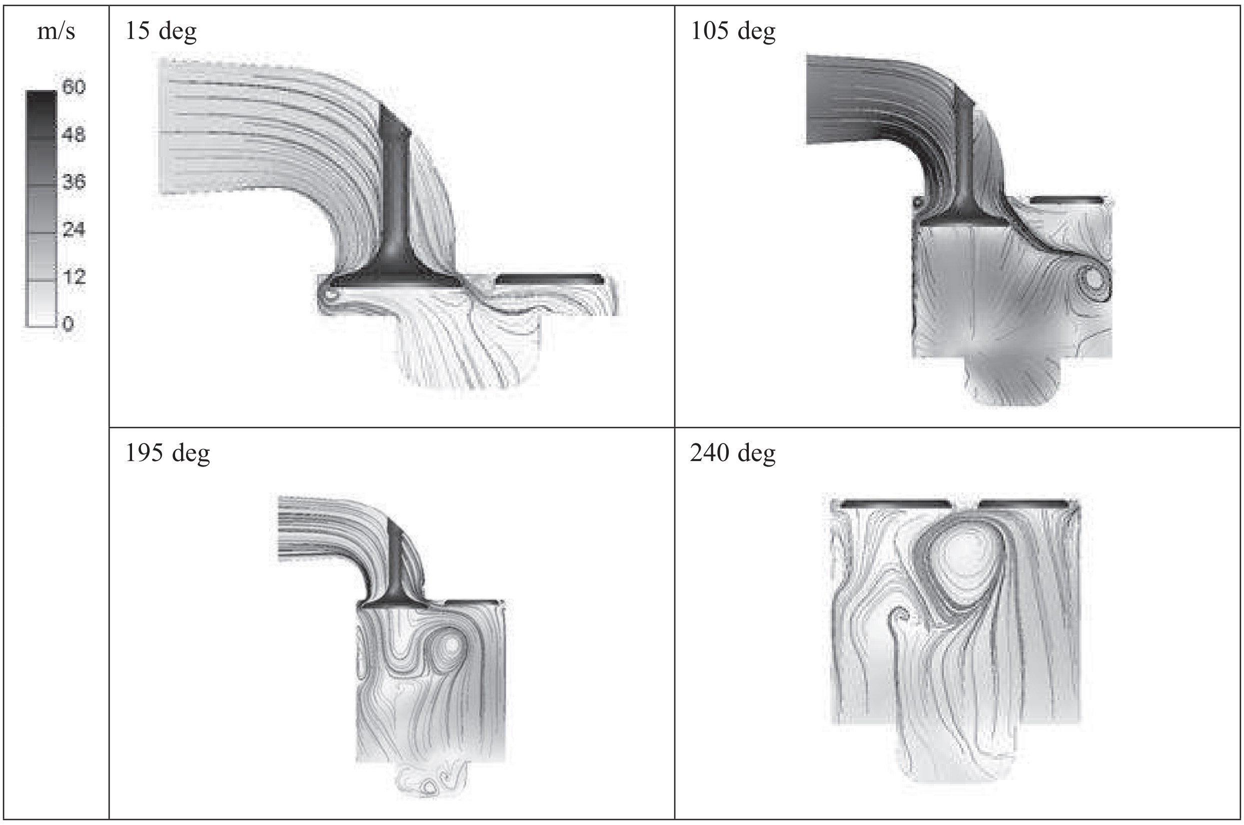


Fig. 5. Cross sections of the engine cylinder during intake stroke - velocity field with streamlines

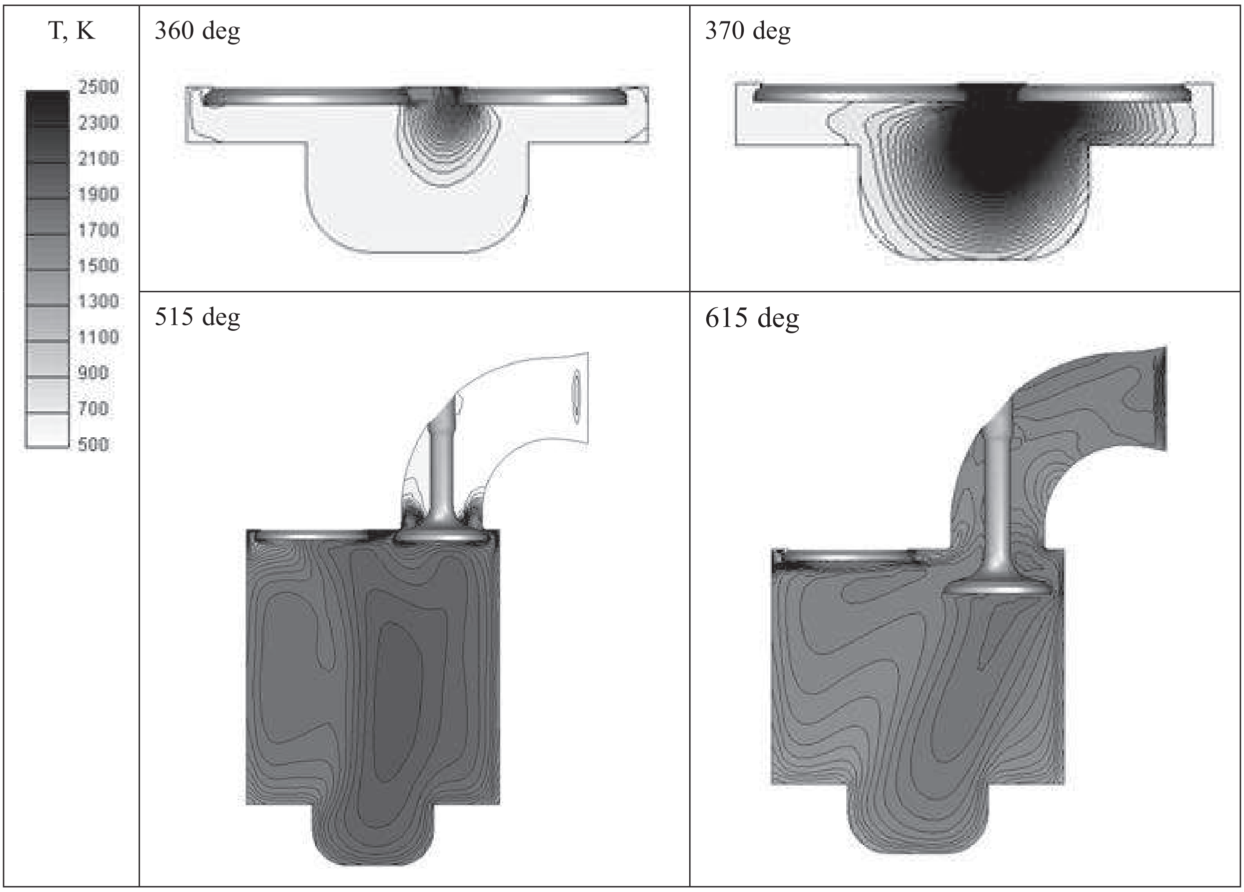


Fig. 6. Cross sections of the engine cylinder at the beginning of combustion and during exhaust stroke - temperature

Figure 4 shows pressure and heat release rate, and accumulated heat release courses. The values of these parameters are realistic, and these are close to parameters obtained by real engine indications. The publication does not present the analysis results of the engine thermal cycle, and is only capable of modeling a complete engine cycle. The results of the analysis will be presented in subsequent publications of the authors.

In Figure 5 the flow field in the modeled engine during intake stroke is presented. The main swirl process by the streamlines is underlined. There, the so-called tumble swirl is visible. This swirl is responsible for flame kernel direction propagation.

Figure 6 shows the cross sections of the engine cylinder where the temperature field is presented. The first two pictures show flame propagation in the combustion chamber. The direction of flame propagation is determined by fluid flows generated during intake stroke (Fig. 4). In Figure 4 the tumble flow is highly visible. The second two pictures show the exhaust stroke when the exhaust valve starts to open and when it is full open.

CONCLUSIONS

AVL FIRE program is a research tool that can be successfully used to model the thermal cycle of the internal combustion engine. The AVL FIRE up-to-date numerical code used during research made possible to generate 3D geometric mesh of combustion chambers of the test engine and allowed to perform numerical calculations of processes occurring in this engine. Simulations of combustion process have delivered information concerning spatial and time-dependent pressure and temperature distribution in combustion chamber. This information would be extremely difficult to obtain by experimental methods. It allows analyzing not only the combustion chamber but also the intake and exhaust process.

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MODELOWANIE PEŁNEGO CYKLU CIEPLNEGO SILNIKA ZI

Streszczenie. W pracy przedstawiono wyniki modelowania obiegu cieplnego tłokowego silnika spalinowego o zapłonie iskrowym. Modelowanie przeprowadzono w programie AVL Fire. Autorzy pojęli trud wygenerowania kompletnej siatki dla posiadanego silnika spalinowego, z uwzględnieniem kanałów dolotowych wraz z zaworami. Wymagało to wygenerowania czterech domen obliczeniowych. Dokonano optymalizacji ilości komórek obliczeniowych siatki geometrii silnika. Uwzględniono miejscowe i chwilowe zagęszczanie siatki, co przyczyniło się do uzyskania dokładniejszych rozwiązań oraz skrócenia i tak długiego czasu obliczeń cyklu silnika.

Słowa kluczowe: silnik, symulacja, modelowanie, spalanie.