Methods of the working processes modelling of an internal combustion engine by an ANSYS IC Engine module

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Abstract. This article deals with developed methods of the working processes modelling in the combustion chamber of an internal combustion engine (ICE). Methods includes description of the preparation of a combustion chamber 3-d model, setting of the finite-element mesh, boundary condition setting and solution customization. Aircraft radial engine M-14 was selected for modelling. The cycle of cold blowdown in the ANSYS IC Engine software was carried out. The obtained data were compared to results of known calculation methods. A method of engine’s induction port improvement was suggested.

1. Introduction
Matters of the working processes modelling in ICE were previously considered in articles [1-8]. A special attention was paid to features of the 3-d model designing of the ICE combustion chamber and creation of the finite-element mesh in the ICE combustion chamber for the dynamic modelling of working processes [1, 8]. It is necessary to spend a significant amount of time to prepare a 3-d model of the ICE combustion chamber to processes modelling in the ANSYS Fluent software, because all settings and customization were made manually. All customization can be divided into three stages. The first stage deals with the modelling of the head of the cylinder block (HCB) for one cylinder with input and output ducts as well as input and output valves in the graphic editor (SolidWorks for example). Then, this model is exported to ANSYS Gambit and the combustion chamber is created by Boolean operations with input and output ducts and cut valves. In ANSYS Gambit, the model was divided by auxiliary surfaces into 16 volumes according to the developed scheme. Then, conditions of penetration for contacted surfaces (Interfaces) between the volumes were set. Boundary conditions of inlet pressure in the input valve and outlet pressure in the output valve were set. The purpose of this operations is preparation of the model to a second stage. The created volume gives an opportunity to create a dynamic rectangular mesh in valve motion zones with the layering motion method and a tetragonal mesh with remeshing during the motion [1-3,8].

At the second stage, every volume in the model is divided into two parts in ANSYS Gambit. Surfaces which connect halves are meshed. A quadrilateral mesh with a mesh size equal to 0.5 mm with the Pave creation type is created in the cylindrical volume. If the surface seizures the ring volume with a trapezium and parallelogram profile, it is meshed with a mesh size equal to 0.3 mm and the Map creation type. The size is selected taking into account the fact that the given volumes contact each other and contain the area of a valve gap, and an undersized mesh is required for correct calculation in ANSYS Fluent. The map type is selected due to the volumes form, because it allows obtaining an optimal form of the mesh units of the surface. A mesh with an element size equal to 1 mm is created by the Cooper tool and the surface mesh as a source.
A triangular mesh is created in the combustion chamber volume with an element size equal to 2 mm, which is enough for gas-dynamic calculation in a first approximation. Volumes of input and output valves are meshed by the triangular mesh with an element size equal to 2 mm because these areas are static and do not require a small element size. The finite-element mesh with a prismatic form is created in the head-end. Such mesh allows obtaining high quality results of gas-dynamics and heat calculations of ICE main parameters [4-6].

The third stage is setting boundary conditions including the application of the motion equation to a moving boundaries, which is described in detail in [7].

2. Results and Discussion

An IC Engine – a special system for modelling processes in the combustion chamber of ICE in the Fluent software with a simplified procedure of combustion chamber 3-d model preparation. Parts of input and output ducts are also included in the model. This system allows a significant decrease in the time for 3-d model preparation by means of the fact that all stages are executed in a semi-automatic mode except for boundary conditions. This stage is simplified by the fact that all necessary settings are emphasized in a separate window.

In the beginning, a crank radius, a shaft length, distortion of the crank axis in relation to the cylinder axis, a minimal gap between the valve and the saddle are set. The program automatically creates a piston motion equation according the input data. Valve motion equations are also loaded.

Then, the 3-d model, which consists of a unified model of the combustion chamber internal part and two separated models of input and output valves, is imported in Design Modeler. Surfaces of input and output ducts, the surface of the cylinder, the input and output valves, their saddles are noted in this 3-d model. Valve motion equations are applied to corresponding valves. A certain crank angle can be set as an initial value or it can be chosen from the options suggested by the program. In a given case, the combustion chamber with parts of input and output ducts is divided into 21 volumes. Ducts are both divided into 9 volumes and the combustion chamber is divided into 3 volumes (figure 1). Two of these volumes (head-end and the upper part of the combustion chamber) are then meshed by tetrahedral finite elements and the volume between them is meshed by volumes in the form of a triangular prism. It is necessary for the elements to remesh around the valve during calculation and layering of the mesh during the piston motion. If the cylinder wall is quite small during piston top positionining in the upper dead center, the program probably will not separate the combustion chamber into three volumes. In this case, it is necessary to point two planes which will separate the combustion chamber.

![Figure 1. The combustion chamber](image)

The display of the piston top and the valves motion animation start before model separation into the volumes to check the accuracy of settings. After it, the setting program separates the model into
volumes. Every volume has its own mesh settings in the ANSYS Meshing module, which are optimal for the given non-stationary task.

There are two standard regimes of model separation into finite elements: coarse and fine. They are chosen during mesh automatic settings. These settings are parameterized in relation to a valve diameter. If standard settings are not appropriate, there is a possibility to change both common settings and settings for every element which was created during separation.

This program allows one to visually check which model is separated into finite elements, for example, in the valve symmetry plane (figure 2) created automatically or in any other plane created by a user.

![Figure 2. The mesh model in a section of the valve symmetry plane](image)

Solution parameters settings follow after mesh creation. In a given system, all settings required for calculation are extracted from the Fluent software and executed as a separate paragraph. The last stage is loading of the model into the Fluent module where calculation has started. The accomplished calculation shows imperfection of the input duct of the researched engine. The area of the vortex flow occurs due to a small radius of the duct turn, which decreases the fuel-air mixture flow through the duct. The geometry of the input duct was changed as a corrective action, and calculation was repeated. Results of the calculation before and after modernization are presented in figures 3 and 4.

![Figure 3. The velocity distribution field in a section of the input valve before modernization](image)
3. Conclusion
After a cycle of ICE cold blowdown calculation by the ANSYS IC Engine software and a comparison of the obtained results, a conclusion can be made that the suggested option of the engine input duct improvement allows increasing the fuel-air mixture flow through the duct. Volumetric efficiency increases by 5%, which positively influences engine characteristics.

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