

Modeling a VR-type piston engine as the power plant

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Abstract. This article describes existing methods of internal combustion engine calculation. The developed algorithm of diesel engine modeling in 'AVL FIRE ESE DIESEL' and 'LMS Imagine.Lab AMESim' software is presented. The algorithm includes description of model preparation, boundary condition setting and calculation execution. Obtained results of the modeling show significant enhancement in accuracy in contrast with analytical calculation. The difference between results obtained in different software is caused by a simplified combustion model in 'LMS Imagine.Lab AMESim' and a lack of a submodel describing a refrigeration system.

1. Introduction

Methods of the internal combustion engine in systems of automatized designing are described in [1-8]. Articles [9-15] deal with engine heat calculation in the 'AVL FIRE ESE DIESEL' software. They also deal with different approaches to boundary conditions setting and engine calculation settings. Data on the R-type and V-type piston engine 'LMS Imagine.Lab AMESim' simulation are presented in [16-20]. In the same time, information about designing of VR-type engine, which is a combination of V-type and R-type engines, was not found. This article deals with the modeling algorithm of VR-type piston engine. The engine, which is described in the given work, represents a four-cylinder, four-strokes, VR-type diesel engine with the V-angle equal to 15°, developed on the basis of the Volkswagen AAA VR-6 engine.

2. Problem to be solved

The first stage of the given research deals with heat calculation of the piston diesel internal combustion engine in the 'AVL FIRE ESE DIESEL' software [21]. Combustion chamber setting and calculation were carried out in the 'AVL FIRE ESE DIESEL' software. The type of the engine (Vee engine, which is a mark for V-type engine), the number of cylinders, the piston diameter (85 mm) and the compression ratio (18) were set in the menu 'General engine parameters'. Data about the crank radius (42.5 mm), the shaft length (150 mm) and cylinder axis displacement from the axis of the crankshaft (0 mm) were introduced in the menu 'Piston movement specification'. Models of the piston and the fuel sprayer were created in the 'Sketcher' window with parameters of the designed engine. Geometric parameters of the combustion chamber and the injector sprayer are represented in figure 1.

The next stage is creation of the mesh model of the combustion chamber by the integrated mesh generator. To check the mesh operation ability, it is displayed in different positions in relation to the crankshaft angle. The angle of calculation start (560°) and finish (900°), as well as the crankshaft frequency (3000 rounds per minute) are set in the 'Simulation parameters' chapter after mesh model



generation. The next step is the choice of the boundary conditions in the corresponding menu. Air was chosen as a working fluid, and common boundary conditions were set: pressure (101325 Pa) and temperature (380 K). Turbulence model constants are also chosen at this stage. Then, the type of fuel is selected. Diesel fuel was chosen in the list of the 'Type of hydrocarbon fuel' tab. Equations for the process of burning and a 'k-zeta-f' turbulence model are selected in the 'Activate equations' tab. This model has a more suitable representation of the equation for elliptic functions and for boundary conditions near the wall and is also less sensitive to a wall non-uniformity. Advantages of this model are very important in the area of the nozzle sprayer where boundary conditions have a significant impact.

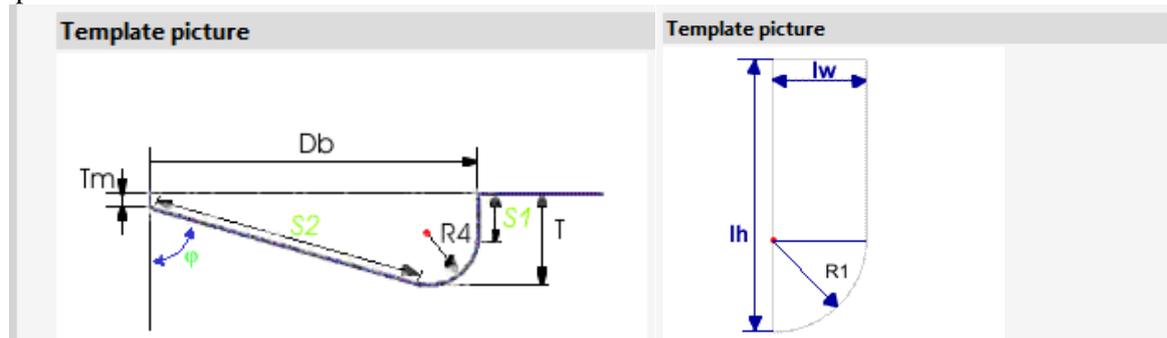


Figure 1. Geometric parameters of the combustion chamber and the nozzle sprayer

The combustion model 'Coherent Flame Model' was chosen in the 'Combustion models' chapter. This model is able to model burning of both uniform and non-uniform mixtures of air and fuel which is typical of diesel engines.

Nozzle parameters are also taken into account during the calculation due to the nozzle presence in the fuel-support system. The initial time, duration and the amount of fuel, injected in the combustion chamber, are selected in the 'Nozzles' chapter along with the nozzle geometry. The fuel injection duration is equal to 1.7 ms and the cyclic dose is equal to 24 mg.

A cycle of calculation with the initial time of injection of the varied parameter was carried out to determine an optimal variant of the engine operation. The variant with injection start on the crank angle equal to 703° was selected as optimal because maximal values of power and momentum were obtained in this regime without an increase of gas loads on engine details. The indicator diagram was plotted as a result of the calculation, and it is presented in figure 2. Maximal pressure reaches 9.4 MPa. Characteristics for the single cylinder are obtained: power is equal to 11.23 kW, and momentum — 35.75 N•m.

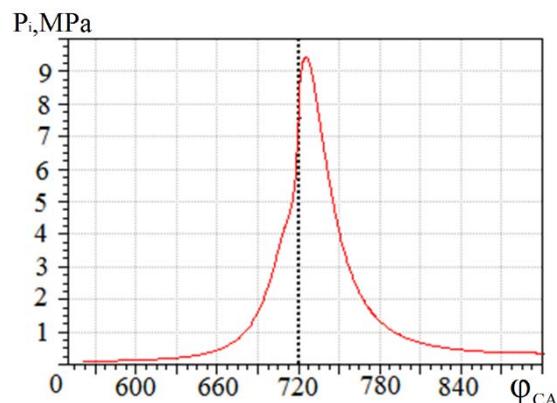


Figure 2. The indicator diagram

Pictures with fields of parameters distributions along the volume of the combustion chamber (figure 3) were generated in the 'Report generator' chapter.

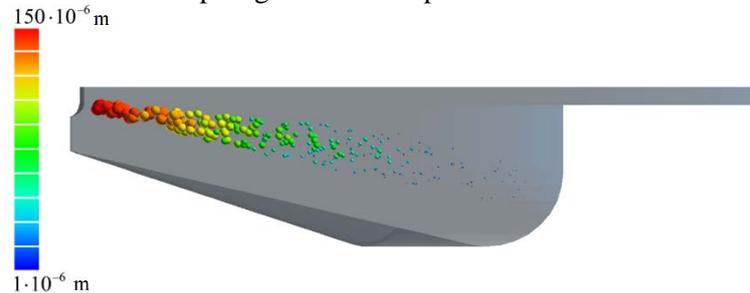


Figure 3. Distribution of the drops diameter in the torch in the combustion chamber (720°)

Figure 3 shows that given parameters of the nozzle provide acceptable distribution of the diameters of the drops in torch without their ricochet from the combustion chamber surface.

Data, which was obtained during the heat calculation, is differ from results of the numerical modelling. This is caused by the fact that polynomial equations, used during heat calculation were derived by the authors in the experimental and statistical way for a limited number of engines which decreases the accuracy of calculation during designing of modern engines.

Heat, kinematic and dynamic calculation of the piston diesel engine were carried out in the 'LMS Imagine.Lab AMESim' software at the second stage [22].

The engine model was composed in this program in the Sketch mode from separate submodels (figure 4), stored in the program libraries.

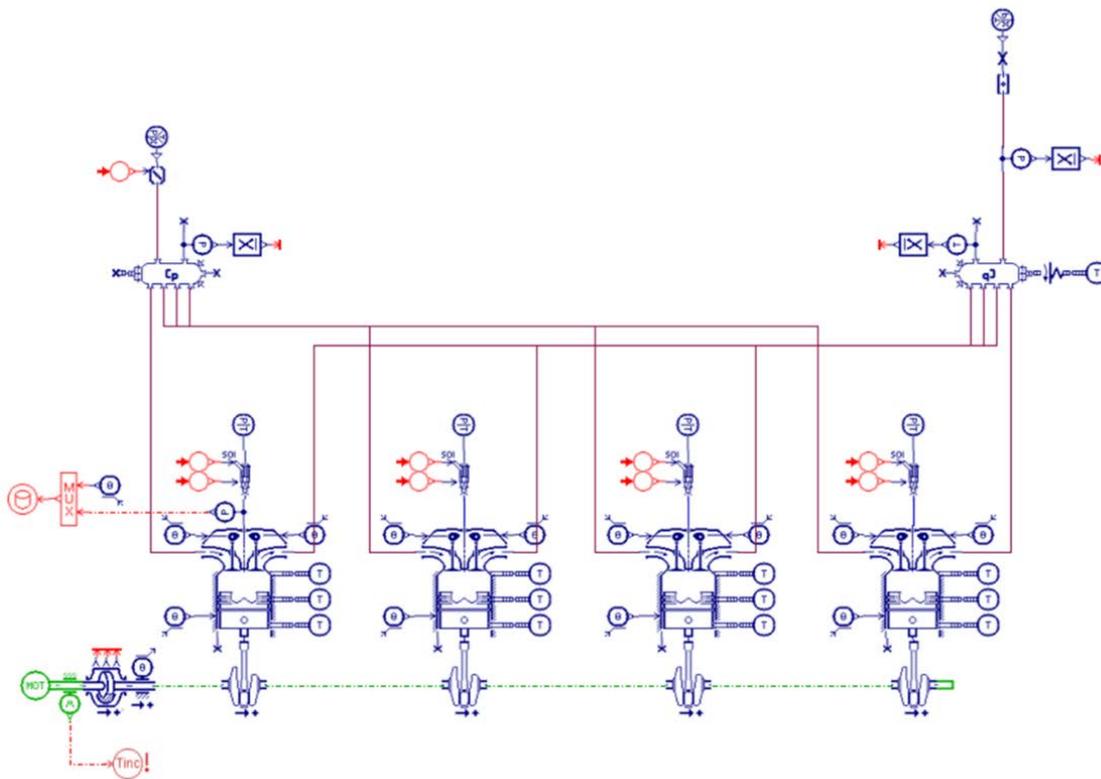


Figure 4. The ICE model

Submodel parameters were set in the parameter mode. There are two options of parameter setting in 'LMS Imagine.Lab AMESim': for every submodel separately and for several models simultaneously through the chapter 'Global parameters'.

Then, main data about the engine were inserted in the 'engine definition' chapter: engine architecture (V), the number of cylinders (4), the V-angle (5), the type of a crank-shaft mechanism (simple), the piston area of heat transfer (7032 mm²), the firing sequence (1-3-4-2), the heat exchange model (Annand). The chosen model (Annand) allows one to determine the heat transfer coefficient for constant mean gas velocity equal to mean piston velocity. The given model is simpler in comparison with other models which take into account the increase of the velocity in the cylinder.

Geometric parameters of the crank-shaft mechanism, the compression ratio (18), the advance angle of input valve opening (12°) and the delay angle of output valve closing (10°), the ICE operation regime, injection duration (1.7 ms), the injection advance angle (17 before the top dead centre), fuel supply pressure created by the low-pressure fuel pump and the type of the fuel are stated in the 'Global parameters' chapter. Geometric dimensions of valves, their number (1 input and 1 output ones), angles of the angular position countdown during the start of the rise (31,5°) and the fall (224°) of the valve are set in the "Gas distribution mechanism" chapter.

Conditions of the entrance and of the exit of the engine are also set: air pressure (0.124 MPa), air temperature (642 K), volumes of input and output ducts (2.545·10⁻³ m³).

Pressure distribution in the cylinder along the cycle was obtained as a result of the calculation and is represented in figure 5. Maximal effective pressure in the cylinder is equal to 9.51 MPa.

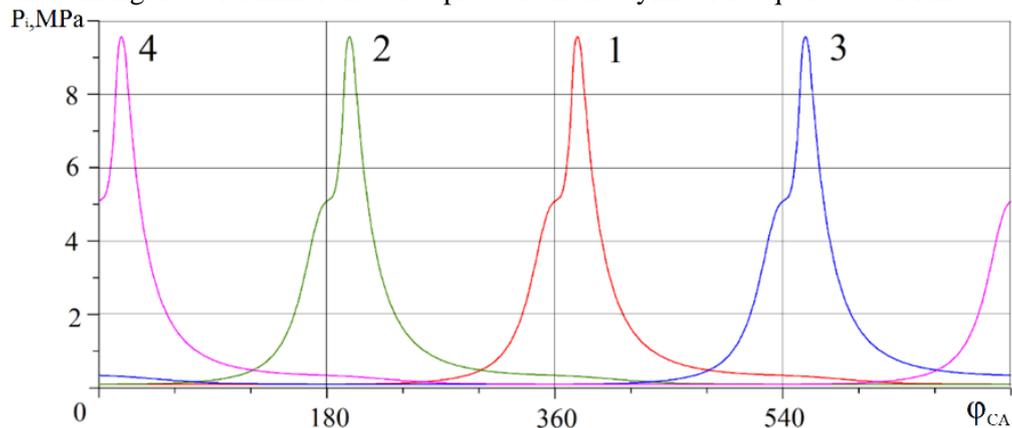


Figure 5. The pressure diagram in all cylinders

The feature of this calculation of the diesel engine in 'LMS Imagine.Lab AMESim' is the fact that engines submodels do not take into account heat exchange; therefore, there is no refrigeration system in this model. However, 'LMS Imagine.Lab AMESim' has an opportunity to model this type of system.

3. Results and Discussion

This chapter deals with results of analytical calculation of the diesel internal combustion engine and two types of numerical calculations: in 'AVL FIRE ESE DIESEL' and in 'LMS Imagine.Lab AMESim' software. The comparison of calculation results is represented in figure 6 in form of indicator diagrams.

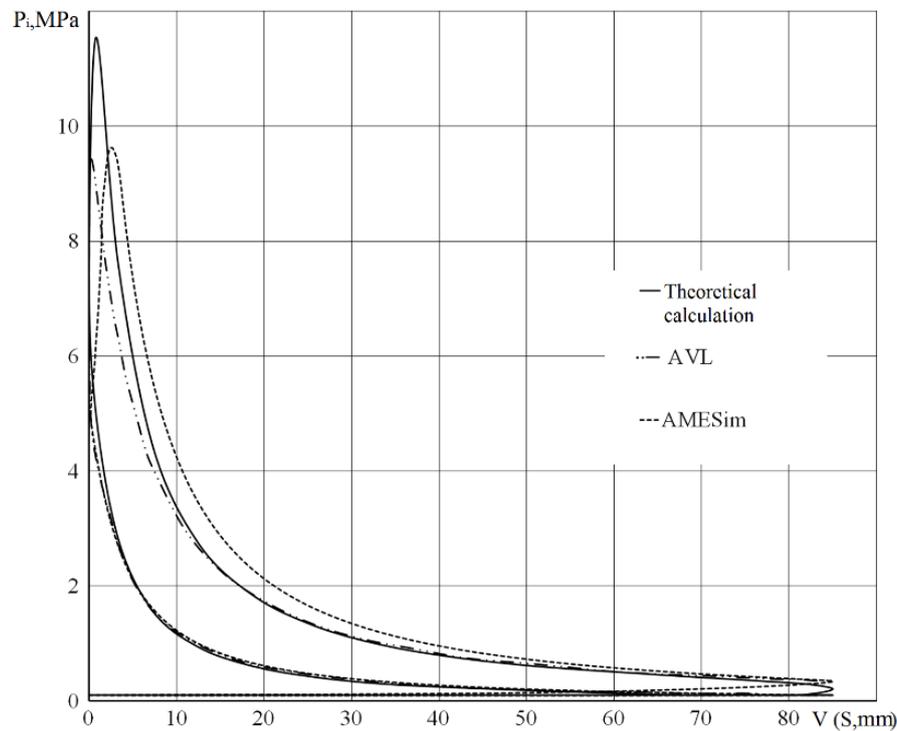


Figure 6. Indicator diagrams of every type of calculation

The values of indicator power and momentum are provided in table 1 for comparison of results of calculation by aforementioned methods. Data obtained from calculations in ‘AVL’ and ‘AMESim’ software differ from the analytical one. It is caused by the fact that polynomial equations, used during heat calculations, do not provide enough accuracy. Also, the ‘AMESim’ software does not consider heat transfer, so there is no refrigeration system.

Table 1. Comparison of calculation results

Calculation method	Power N_i (kW)	Momentum M_i (N·m)
Theoretical calculation	48,0	152,8
‘AVL FIRE ESE DIESEL’	44.9 (-6.5 %)	143.0 (-6.5 %)
‘LMS IMAGINE.LAB AMESIM’	41.5 (-13.5 %)	132.2 (-13.5 %)

4. Conclusion

A method for modeling of working processes in a VR-type engine in ‘AVL FIRE ESE DIESEL’ and ‘LMS Imagine.Lab AMESim’ is developed. The developed models allows one to calculate indicator parameters of working processes, which was compared to the results of the analytical research as a verification. ‘AVL FIRE ESE DIESEL’ allows modelling an injection from the nozzles to obtain a mixing and spraying quality in the cylinder. ‘LMS Imagine.Lab AMESim’ allows one to add different modules to the existing model such as a refrigeration system and external load to model the real behavior of the engine. Results deviations between numerical and analytical research varies from 5% to 10% which means that these models are suitable for engine designing.

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