

Developing the Model of Fuel Injection Process Efficiency Analysis for Injector for Diesel Engines

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Abstract. The article proposes an assessment option for analysing the quality of fuel injection by the injector constituting the development of calculation blocks in a common injector model within LMS Imagine.Lab AMESim. The parameters of the injector model in the article correspond to the serial injector Common Rail-type with solenoid. The possibilities of this approach are demonstrated with providing the results using the example of modelling the modified injector. Following the research results, the advantages of the proposed approach to analysing assessing the fuel injection quality were detected.

1. Introduction

The injection performance and fuel atomization depend on the injector design: geometric characteristics of atomized fuel jets, fuel spray structure, fuel atomization fineness, and a number of other parameters of the fuel delivery process [1, 2]. To ensure high-efficiency combustion of fuel and, consequently, obtain high technical and economic indicators of the diesel engine, it is necessary to organize a rational injection. The quality of fuel atomization is characterized by its fineness and uniformity. The process of jet disintegration shall be organized so as to obtain high quality of spraying at all stages of injection, including the initial and the final stage, when there is a low fuel pressure upstream the injector.

Presently, three-dimensional modelling of fuel delivery units and systems of diesel engines is being actively employed [3]. However, three-dimensional calculation is a complex and labor-consuming task. Therefore, its application in the calculation of injectors is limited to and concentrated on the analysis of fuel atomization and spray geometry. In some researches, a rapid evaluation of fuel delivery characteristics is required, as well as a study of the dynamics and qualitative characteristics of fuel atomization, for example, to verify or compare different types of injectors.

In solving some tasks of estimating the compared options by their quality of fuel atomization, flow diagrams are not always possible to be used. Also, to improve the injection process, it is necessary to increase the injection pressure, which is accompanied by an increase in the flow rate of the fuel through the atomizing orifices (resulting in the flow turbulence) and the spreading velocity of the fuel jets in the CC. The disintegration of the fuel jet begins immediately at the atomizing orifice. These factors lead to the improved quality of fuel atomization, which indicates the need to study the



dynamics of atomizers. Thus, there is a challenge in qualitative and quantitative estimation of fuel dispersion, which is presently a labor-intensive and an energy-consuming task. It is not possible to obtain accurate fuel atomization characteristics without performing three-dimensional modeling, which requires a high and an advanced level of knowledge of the calculation packages.

2. Determining the cycle dose along the pressure spectrum

In solving some tasks of estimating the compared options by their quality of fuel atomization, flow diagrams or pressure diagrams upstream the atomizing orifices may be sufficient. For example, the assessment of the influence of the electrohydraulic injector (EHI) parameters may be performed using the value of cycle supply and the moments of the injection beginning and end of with the same control signal. The option of the injector with a higher cycle delivery rate, provided the equal delay of the moments of the injection beginning and end relative to the moment of the control signal beginning and end, is faster, and, as a consequence, more preferable, since it is known in advance that the fuel delivery quality improves with increasing EHI operating speed. However, in most cases, there is no information on the correlation between the modelling output parameters and the fuel atomization quality, which requires changing the approach to forecasting it.

As one of the tools for assessing the fuel atomization quality based on modeling the dynamics of atomizers, the distribution of the cycle dose over the pressure spectrum upstream the atomization orifices is used. Due to such a tool we are capable of qualitatively assessing the process of fuel injection into the CC. By knowing the pressure at which the fuel dose is injected, we can assess the atomization quality. Also, another advantage of this tool is the possibility of performing a detailed analysis of the fuel delivery process and its features, deriving the effect caused on it by particular parameters of the fuel delivery system elements. The tool model in the LMS Imagine.Lab AMESim [4, 5] software package is represented in fig. 1.

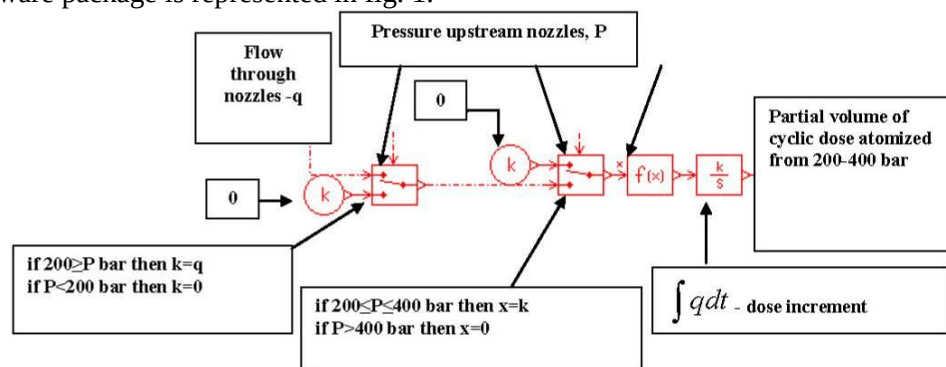


Figure 1. The model of the tool for cycle dose distribution according to the pressure spectrum (from 200 to 400 bar) upstream the outlet nozzles in LMS Imagine.Lab AMESim

If it is necessary to assess the process of injection according to the criteria for the emergence of the fuel ignition conditions in the combustion chamber, it is possible to use the incremental time-volume diagrams for the cycle doses atomized at the pressures of the assigned spectral ranges. When using the same modelling block, this tool is able to demonstrate the pressure, time, and portion of fuel, which is injected to the CC. The obtained dependence is also able to show the nature of ignition, since the pressure at which a portion of fuel enters the cylinder at the time of the injection beginning, is very important.

2.1 Changes in the mean pressure values upstream the orifices in the injector atomizer

To study the various fuel atomization processes, it is necessary to obtain the numbers or integral components serving as the basis for an assessment, as well as an analysis of the regularities of various parameters. Therefore a tool was developed within the LMS Imagine.Lab AMESim package allowing to study change of the mean pressure value upstream the orifices in the injector atomizer.

A particular feature in determining the mean pressure upstream the nozzles is the necessity to consider the features of different injection modes, in which the needle can not only oscillate, but also set in the seat, and therefore the time of non-zero flow through the atomizer orifices may not coincide with the cycle time. Therefore, the mean pressure is proposed to be calculated by dividing the integral from the pressure upstream of the orifices of the atomizer in time by the time integral corresponding to a non-zero flow through the orifices of the atomizer (1).

$$P_{cp} = \frac{\int P dt}{\int dt} \quad (1)$$

The package LMS Imagine.Lab AMESim is capable of representing the model results in the form of the curve of calculated values versus time. Therefore, it is possible to select several parameters to be used for comparison of the systems' options and building regression models based on the analysis of the mean pressure variation upstream the orifices as full injection cycle characteristics, for example:

- a finite or a maximum mean pressure value upstream the nozzles;
- the time for reaching the maximum mean pressure value upstream the nozzles

Building these curves depending on the parameters varying through the modelling process extends the result analysis possibilities to the design stage. The tool model in the LMS Imagine.Lab AMESim software package is represented in fig. 2.

General view of the injector with the above blocks is given in fig. 3

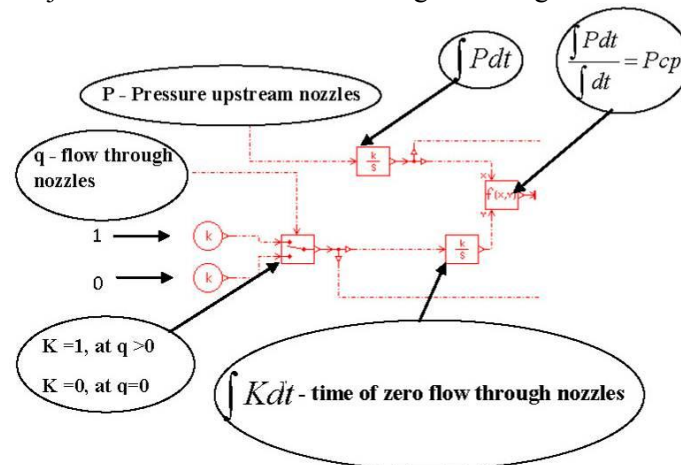


Figure 2. The calculation block for delivery ratio and mean pressure of the injection cycle

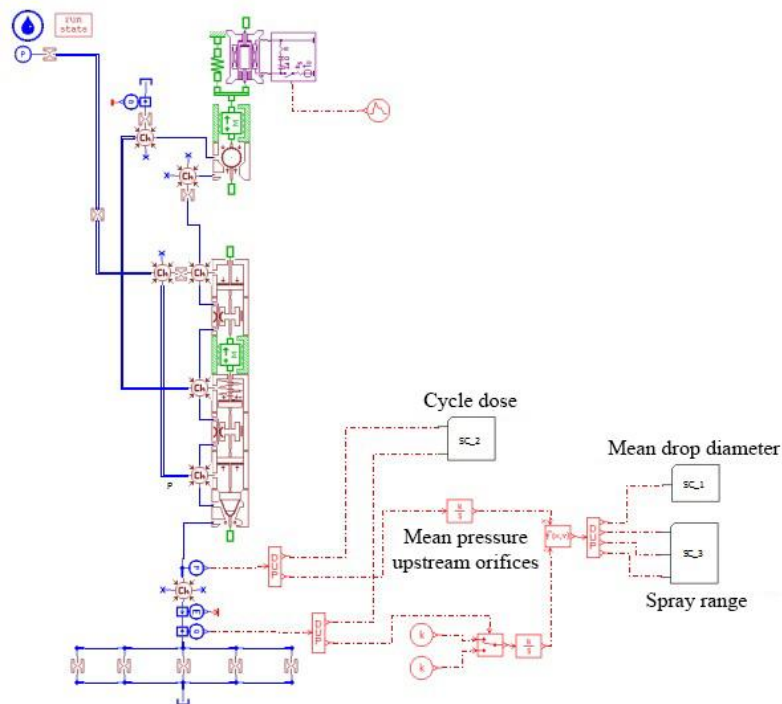


Figure 3. General view of the model with analysis blocks

2.2 Determining Sauter mean drop diameter and jet range

The fuel atomizing quality is directly related to the geometry of the fuel spray, the nature of the jet disintegration and the diameter of the drops. Because of disintegration, the fuel jet is transformed into a fuel spray with a certain drop size distribution. Furthermore, the drop diameter is a random continuous quantity, i.e. it can take any value in the interval of its definition. In this regard, the fuel spray should be considered not only as an accumulation or a set of drops, but as a static aggregate of drops of various sizes.

According to the distribution laws considered, at least two parameters are required to study the drop size spectrum of the atomized fuel: the average drop diameter and the jet distribution characteristics (dispersion, range).

A Sauter mean drop diameter method was selected. It represents a ratio of the total volume of all the drops to their total surface.

Fuel atomization depends on the Weber number, which is a dimensionless quantity establishing a relationship between three parameters that influence the fineness of liquid atomization and found from the expression (2):

$$We = \Delta P d_c / \sigma ; \quad (2)$$

ΔP - Pressure drop, H/m^2 between the nozzle orifice and medium to which the injection is performed
 d_c - nozzle orifice diameter, m ; σ – fuel surface tension, N/m

One of the basic laws of capillary phenomena influencing the fineness of atomization is the Laplace law. A dimensionless criterion links four parameters that influence the fineness of fuel atomization (3):

$$L_p = (\rho_T d_c \sigma) / \mu_T ; \quad (3)$$

ρ_T - fuel density kg/m^3 between the nozzle orifice and medium to which the injection is performed; d_c - nozzle orifice diameter, m ; σ – fuel surface tension, N/m, μ_T – fuel dynamic viscosity, Ns/m^2

A significant effect on the fuel atomization is caused by the rate at which the liquid flows out of the nozzle orifice. The rate of flowing out fuel at which the disintegration begins immediately at the nozzle orifice depends on a number of factors (4):

$$\vartheta_T = f(\rho_T; \rho_b; \mu_T; \mu_b; \sigma; d_c); \quad (4)$$

where ρ_T and ρ_b – are density of fuel and air respectively μ_T and μ_b – fuel and air dynamic viscosity; σ – fuel surface tension; d_c - nozzle orifice diameter.

Therefore, the formula takes the form (5):

$$\vartheta_T = \sqrt{2 \cdot \Delta P / \rho_T}; \quad (5)$$

ΔP - mean pressure upstream the orifices, Pa, ρ_T - fuel density, kg/m³

To determine Sauter mean drop diameter the formula is used (6):

$$d_{32} = d_c \cdot 1.68 \cdot (\rho_k \cdot We)^{-0.266} \cdot L_p^{-0.073}; \quad (6)$$

Based on the selected method, a model was simulated in the LMS Imagine.Lab AMESim software package with the diagram represented in figure 4.

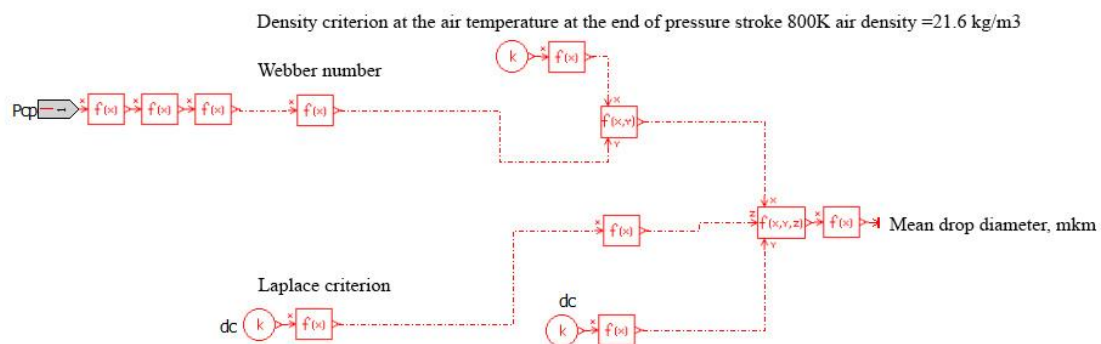


Figure 4. Calculation block of the Sauter mean drop diameter in LMS Imagine.Lab AMESim.

Also during the injection process, it is important to aim at the formation of small fuel drops with simultaneously ensuring the ability of drops to penetrate deeply in all directions in the compressed air medium in the combustion chamber. Penetration of drops into the compressed air medium depends on the range of the fuel jet. With the reduced range of the jet, the fuel drops may not penetrate into the remotest parts of the combustion chamber, incomplete combustion occurs, the specific fuel consumption increases, the engine power decreases.

The range of the spray from the nozzle orifice may be determined from expression (7):

$$L_F = \frac{d_c}{1.2} \left(\frac{\vartheta_D \cdot \tau}{d_c} \right)^{0.5} \cdot \frac{We^{0.105} \cdot M_x^{0.08}}{1.7 \cdot \rho_k^{0.5}}; \quad (7)$$

d_c - Nozzle orifice diameter, m; ϑ_D – actual fuel discharge rate m/s; τ – time of spray movement from the injector s; We – Weber criterion; M_x - Mach criterion (ratio of the fluid flow rate to the sound velocity; ρ_k - density criterion (ration of the air density to the fuel density)).

This method for determining the spray range was also modeled in the LMS Imagine.Lab AMESim software package, whose flowchart is given in fig. 5

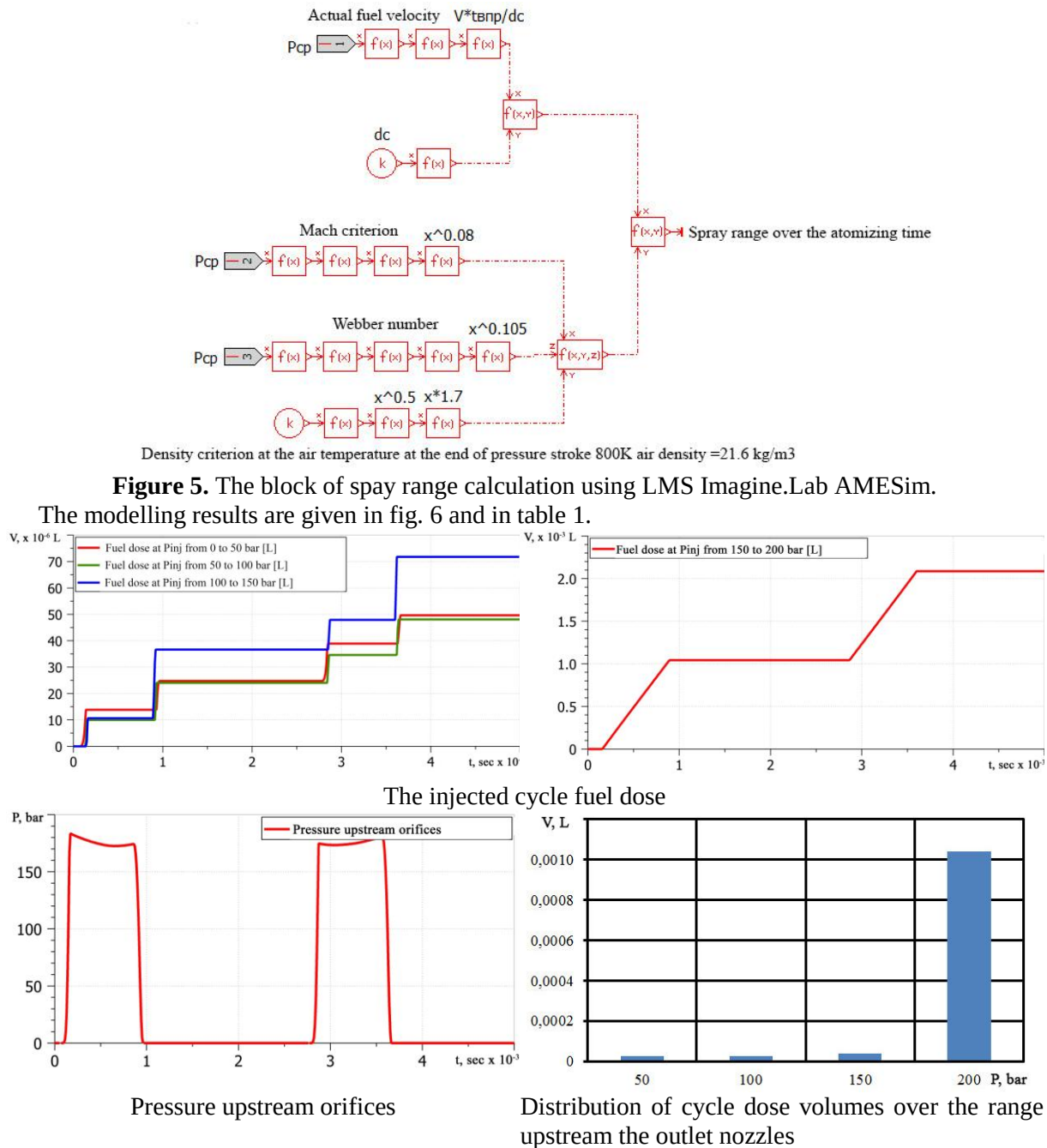
**Figure 6.** Modeling results

Table 1. Numeric values of the parameters obtained	
Mean pressure upstream the orifices, bar	158.7
Mean drop diameter, micron	97.29
Spray range, m	0.03616
Injector inlet pressure, bar	1000

3. Conclusions

1. It has been demonstrated that when modeling diesel injectors in the ICE in LMS Imagine.Lab AMESim it is possible to preliminarily assess the quality of fuel atomization following the results of the analysis of processes in these systems without three-dimensional modeling of fuel spray formation processes.

2. The following design characteristics are proposed as the tools for analyzing the effect of processes in fuel systems caused on the fuel atomizing quality of the injector:

- distribution of the shares of cycle delivery over the pressure spectrum upstream the injector nozzles;

- change of the mean pressure values upstream the injector nozzles.

3. The blocks for calculating the mean diameter of drops and the range of the spray were modeled as the tools for preliminary assessment of fuel atomization quality.

4. The represented tools allow avoiding the use of labor-intensive three-dimensional calculation and analysing the fuel atomization quality based on modelling the dynamics of atomizers.

Based on the simulation results, it can be concluded that it is necessary to increase the injection pressure to reduce the drop mean diameter and increase the spray range. In this connection, the research shall be continued with respect to the rest of the factors and optimization of their values to obtain the maximum high fuel injection quality.

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