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Detailed dynamic modeling of common rail piezo injector

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Abstract

A mathematical model of Bosch 3rd generation Common Rail fuel injection system with piezoelectric injector has been created. The numerical calculations for third different accumulator pressures (30, 80 and 160 MPa) and third energizing times ET (0.5, 1 and 2 ms) have been carried out. The results of calculations of total injected mass per cycle have been compared with the experiment with good agreement. The maximum error for ET=0.5 ms is 10.4% and for ET≥1 ms is less than 5 %.

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Keywords: Fuel injection system; Common rail; Piezo injector; Mathematical model.

1. Introduction

Modern diesel fuel injection systems (FIS) are characterized by complex dynamic hydromechanical processes. Also, an electromagnetic processes on drives of injector's control valves significant influence on fuel injection process.

Optimization of developed fuel injection system design has an important role [1], then, an adequate mathematical modeling, that allows fast and flexible change of varying parameters and get simulation results in optimization criteria form, is very actual.

Now, one of the most perfect of FIS is common rail fuel injection system with piezoelectric indirect-acting injector.

This paper is devoted to modeling of common rail piezo injector from Bosch.

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2. Mathematical modeling

2.1. Bosch Common Rail piezo injector

The design of a piezoelectric injector essentially differs from hydraulic injectors of the previous generations besides that the electromagnetic operating valve has been replaced with the piezoelectric. Developers have refused the locking piston, thereby having excluded the mechanical forces operating on a needle and having reduced moving weights. The management chamber is directly over a needle that, in a compartment with speed of operation of a piezoelement and reduction of moving weights, allows to lower a delay of lifting of a needle to 0,15 ms [2]. The principle of the injector working described in detail in [2-7].

2.2. Mathematical model

For modeling of hydromechanical processes the Astakhov-Golubkov method was used [8,9]. This method consists of a solution of unsteady fuel flow in high pressure line problem by D'Alembert method with boundary conditions in form of volume or mass balance.

The simulation scheme of piezo injector is presented in Fig. 1.

Mass balance equation (for control chamber as an example):

$$\frac{dp_3(t)}{dt} = B_3 \frac{\frac{\sigma_{13}}{\rho_3} G_{13} - \frac{\sigma_{34}}{\rho_3} G_{34} + A_3 \frac{dx_n(t)}{dt}}{V_3 - A_3 x_n(t)}, \tag{1}$$

where t - time; p_3 - pressure in chamber 3 (control chamber) (see Fig. 1); B - bulk modulus of fuel с учетом деформации стенок камеры [10]; ρ_3 - current fuel density in chamber 3; V_3 - initial volume of chamber 3; A_3 - geometrical area of area 3; x_n - current lift of needle; σ_{13}=sign(p_1- p_3); σ_{34}=sign(p_3- p_4); G - fuel mass flow through orifice, for example:

$$G_{13} = C_{d13} A_{13} \sqrt{\rho_1 \left(p_1 - p_3\right)}, \tag{2}$$

where C_{d13} - discharge coefficient of orifice 13; A_{13} - cross-sectional area of orifice 13.

For solution of unsteady fuel flow in high pressure line problem D'Alembert method was used [8,9]. For example, equations for line 1 is written as:

- for inlet:

$$\begin{cases} p_0 + F_1(t) - W_1(t) \cdot e^{-k_1 \frac{L_{line1}}{a}} = P_A; \\ \frac{1}{a\rho} \left[F_1(t) + W_1(t) \cdot e^{-k_1 \frac{L_{line1}}{a}} \right] = u_{1in}; \end{cases} \tag{3}$$

- *for outlet:*