Chapter 139
Simulation Analysis on Effect of the Orifice on Injection Performance

Yu-lan Li, Xiang-bi An and Da-hai Jiang

Abstract The injector is one of the precision components for a diesel engine, and it is inevitable to wear fault during utilization. For the fault of the orifice expansion and the orifice obstruction, they are essentially changing the structure parameters. In order to analyze the effect of the orifices on injection performance, the simulation model of a certain type diesel injector was established based on AMESim. And a simulation for a whole injection cycle of this injector was performed, thus the injection characteristics and the relevant information about motion of the needle valve was obtained. The effect on the velocity of the needle valve, the flow rate and the volume of the fuel oil injection, etc. had been analyzed by changing the number, or the diameter of orifices, and setting different diameters for each orifice. The analysis would provide some references in structure design, optimization, testing data analysis and fault diagnosis.

Keywords AMESim · Diesel injector · Orifice · Simulation analysis · Working process

139.1 Introduction

The injector is one of the precision components for a diesel engine, and it is inevitable to wear fault during utilization. The orifice expansion and the orifice obstruction are two of the most common fault phenomena.

The orifice expansion is due to constant spray and erosion of high-pressure fuel oil flow on the orifices during the injector working. It drops the injection pressure,

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shortens the injection distance, which leads the diesel atomizing worse and increasing the carbon deposit in cylinder.

The orifice obstruction is due to half or complete block caused by the nozzle corrosion during long-term storage for the diesel engine, or some solid impurity particles mixing into the fuel oil, or the carbon deposit caused by bad combustion accumulating around the orifices and making the orifices be in half blocking state (Jin 2008).

These two kinds of fault phenomena are essentially changing the structure parameters of the orifice, from the point of view of the physical mechanism. It is difficult to record the parameter variable in real time during the working process of the injector. So simulation is the common method for analysis on the injector (Lv et al. 2009).A hole-type injector model is built based on AMESim to simulate an injection cycle, and to analyze the effect of the orifices on the injection performance, which can provide some references in structure design, optimization, test data analysis and fault diagnosis.

139.2 Phenomena Analysis on Effection of the Orifices on Injection Performance

The combustion process of the traditional diesel engine is mainly diffusion combustion, and its combustion heat release rules and its fuel economy depends on the fuel injection spray and the spread mix. So it is a high requirement for the spray quality (Zhou 2011). The fuel injection spray process is very complex. As the fuel spraying into the cylinder, the processes of fuel bunch rupturing, the fuel droplets colliding and polymerizing, the fuel droplets running up against the cylinder wall, and the fuel droplets evaporating spread, all accomplish in tiny space and time scale (Xie 2005). The diameter and number are important parameters for the fuel injection system in the diameter. The diameter of orifice has a great influence on the fuel injection column shape, spray quality, fuel and air mixing state (Ma et al. 2008).

It is in favor of the fuel mixture formation to decrease the orifice diameter, but it will also prolong the injection duration, in condition of the same cam lift and the same injector open pressure. The average diameter and the heterogeneity of the fuel oil droplets increase, the injection flow rate increases, and the fuel oil injection duration is shorten, with the increasing of the orifice diameter (Jia et al. 2003). However, smaller orifice diameter improves the low speed performance, meanwhile leads worse emission of NO_X (Zhang et al. 2008). Therefore, the smaller injector orifice diameter is more advantageous to forming the injection rectangle. And the larger orifice diameter is benefit for reducing the diesel engine noise, vibration index and emission levels, with being in line with the ideal fuel injection law requirements of continuous acceleration injection until the quick broken fuel oil injection process at the end (Wang et al. 2012).

It is inclined to cause the fuel oil mist adhering to the cylinder wall and producing more soot with too few orifices. It causes higher temperature inner the cylinder and it is inclined to cause interference and overlap of the fuel oil bunch, thus producing more NO_X and soot, with too many orifices (Zhou et al. 2008; Ding et al. 2008; Wu et al. 2010; Zhou et al. 2008).

139.3 Simulation Model and Injection Process Analysis

LMS Imagine.Lab AMESim offers a complete simulation suite to model and analyze multi-domain, intelligent systems and to predict their multi-disciplinary performance. The software creates a physics based model of the system, which doesn't require a full 3D geometer representation. AMESim can be used to study the system or the components of steady state and dynamic characteristics. It adopts top-down modeling method to achieve the complex system being modularized and the abstract system being materialized. Now AMESim has been used to analyze the fuel oil injection performance for the injector in practice (Boudy and Seers 2009; Wen and Zhang 2010; Zeng et al. 2008).

The simulation model including physical model of mechanical motion and fluid movement is built according to the working principle of the injector. The model can mainly be divided into the volume unit, the movement unit and the leakage unit, in order to be convenient for analysis.

The concentrated volume of the injector is mainly in the nozzle, which is a pressure chamber formed by clearance between the needle valve and the valve body. In AMESim, the model of a conical poppet valve shown as in Fig. 139.1a is used to signify the needle valve, and simulate certain valve by setting corresponding structure parameters.

The movement unit of the injector points to the movement parts includes the valve body and the mandril. In AMESim, the models are as shown in Fig. 139.1b and c are used to signify the two components separately.

In order to signify the fuel oil leakage during the working process for the injector, a model shown as Fig. 139.1d is used in AMESim.

The model of diesel injector composed of the three units above and other necessary auxiliary components, which are as shown in Fig. 139.2. The model

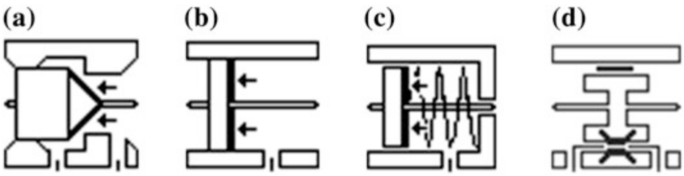


Fig. 139.1 Main model units of the injector. **a** Model of conical poppet valve; **b** Model of mandril; **c** Model of valve body; **d** Model of leakage unit

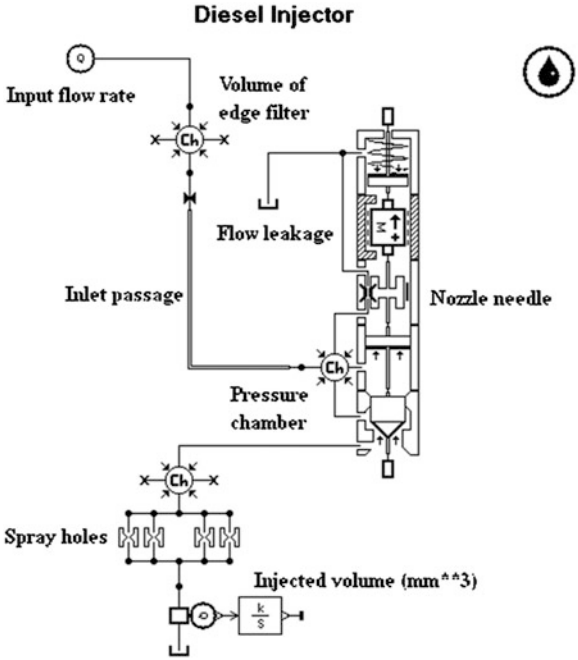


Fig. 139.2 Model of diesel injector

simulates with the hypothesis that the fuel oil in the inlet passage is to motionless at the beginning of the injection, because of stickiness force. That is the pressure in the whole injector and the density of the fuel oil to be equivalent. The simulation process computes a whole injection cycle, including the needle valve opening time, the fuel oil injection duration tine and the needle valve closing time.

The basic parameters are four orifices with the same diameter of 0.28 mm. Each parameter is set to basic parameter except the control parameter. In order to analyze how the orifices affect the injection performance, the model batch runs taking different parameter as control parameter respectively.

139.3.1 Analysis on the Injection Performance with Different Number of Orifices

Setting model with 7, 6, 5, 4 or 3 orifices respectively, the curves of each performance with different number of orifices are draw in the same graph.

The orifice number does not affect the injection time, but the injected volume is slightly more with more orifices. It exerts great influence on the change process of the injected volume. Usually, it takes shorter time to reach the maximum injected volume and finish the injection process with more orifices. However, the influence weakens after the orifice number increasing some value. The results are as shown in Fig. 139.3.

Fig. 139.3 Curves of injected volume with different number of orifices

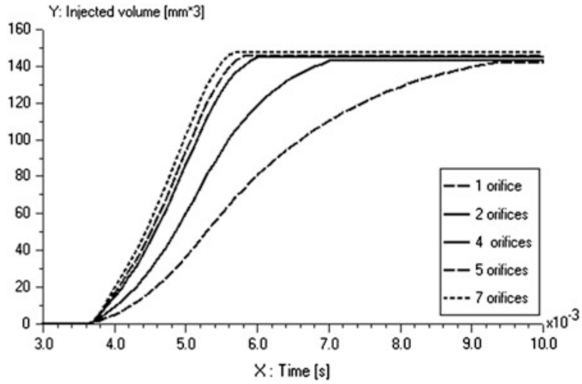
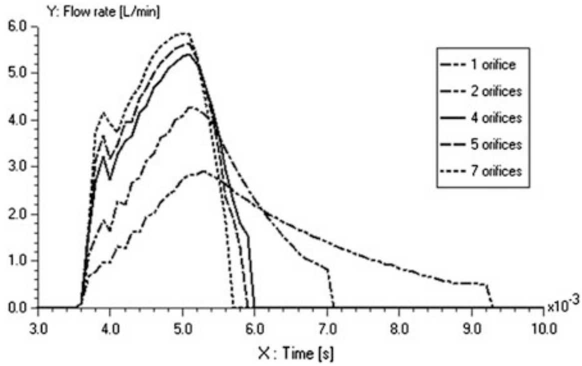


Fig. 139.4 Curves of flow rate with different number of orifices



The fuel oil flow rate reaches maximum rapidly and then drops to zero quickly with advisable orifice number, which closes to the ideal fuel oil flow rate curve. Meanwhile, too few orifices leads to increase slowly after the injection, keep short at the maximum flow rate, and take too long dropping to zero, which does not conform to the requirements that begins and stops supplying fuel oil to the combustion chamber quickly. The results are as shown in Fig. 139.4.

The needle valve rises following the law of slow first and then rapid, which also being an ideal state of the injector. The needle valve rises rapidly at start time and stays long at the maximum displacement. The results are as shown in Fig. 139.5.

139.3.2 Analysis on the Injection Performance with Different Needle Valve Diameter

Shown as the curves in Fig. 139.6, the beginning injection time is brought forward and the injection during time is longer with increasing of the needle valve diameter. That is because the pressure-bearing surface area of the needle valve increases with

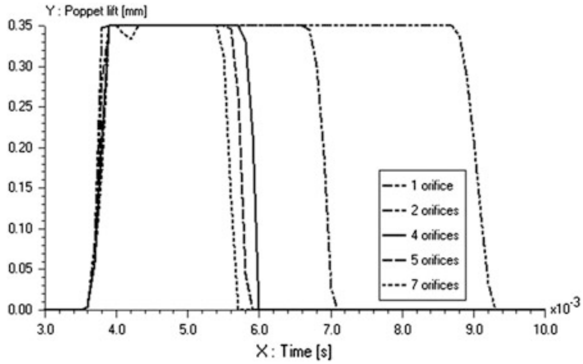


Fig. 139.5 Curves of the needle valve lift with different number of orifices

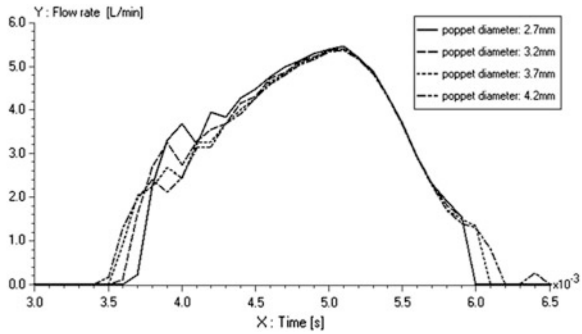


Fig. 139.6 Curves of flow rate with different needle valve diameter

the increasing of the needle valve diameter, which makes the volume in the pressure chamber decrease correspondingly. So the pressure in the chamber increases fast, and the needle valve opens earlier. The pressure falls slowly after the needle valve opening which makes the needle valve keep the maximum displacement for longer. At the end of the injection, the needle valve takes its seat quickly under the force of the spring preload, and the injection flow rate falls to zero rapidly. But too large needle valve diameter can make the pressure in the chamber fall slowly and produce pressure wave that exceeding the needle valve opening pressure at the time of the needle valve taking its seat, compelling the needle valve go up again as a result to generate a twice-injection. However, too small poppet diameter can intensify the volatility at the beginning injection time.

139.3.3 Relation Between Different Parameters

The effect of the orifice on injection performance is relevant to the orifice number and orifice diameter. With different diameter for each orifice, the injected volume and the injection flow rate computes as equivalent to convert the corresponding number of diameter of the same orifices in the model.

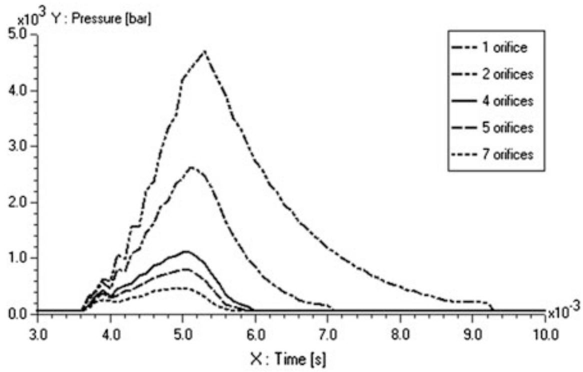


Fig. 139.7 Curves of the pressure at the orifices with different needle valve diameter

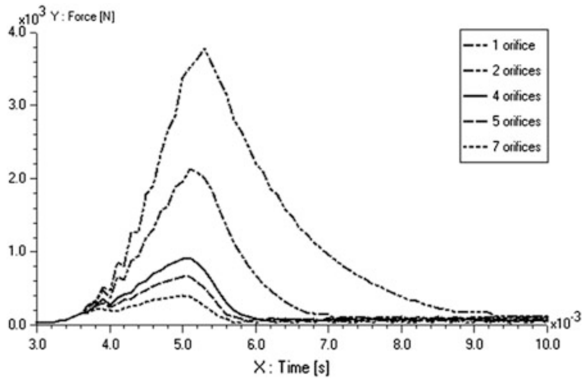


Fig. 139.8 Curves of the force on top of the needle valve with different needle valve diameter

Shown as the curves in Fig. 139.7 and 139.8, it is exactly the same form for the curves of the pressure at the orifices and the curves of the force on top of the needle valve. In other words, it will get same value with normalizing the corresponding data.

139.4 Conclusion

The simulation model of a traditional diesel hole-type injector is built up based on AMESim. By simulating an injection cycle with different needle valve parameters, and analyzing the effect of the orifice on the injection working process, the conclusions are given below:

(1) It computes fast and accurately by simulating the injection performance based on AMESim for the injector. And it offers important references for well matching with the engine, designing and optimizing the injector.
(2) The parameters such as the flow rate, the injected volume, the velocity and the lift of the needle valve, which character the injection performance. The

parameters are not mutually independent but have inherence relations with each other. And they are coincident to each other. It is to examine how each parameter satisfies the diesel engine features in certain aspect that analyzes the curves of each parameter independently.

(3) The orifice number affects the duration of the injection process, especially with too few orifices to meet the requirement. The injection flow rate increases slowly at first, and drops to zero taking quite a long time after reaching the maximum value, which does not accord with the requirement of the instantaneous injection, shown as the movement of the needle valve that it residences too long at the maximal displacement, going against the throughout distance and the spray column cone angle meeting required values.

(4) The orifice diameter has little effect at the beginning of the needle valve opening, while has great effect on stopping supply fuel oil during later of the injection process.

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