Original Research Article

The influence of computer aided internal combustion engine fuel injection strategy on exhaust gas

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Abstract: Automotive exhaust contains harmful components such as nitrogen compounds and hydrocarbons. This study employs computer-aided methods to analyze the relationship between fuel injection strategies and emissions in internal combustion engines. Experimental results indicate that delaying fuel injection timing during the compression stroke reduces cylinder combustion temperature and NOx emissions, while optimizing injection parameters (e. g., timing at 280 ms) decreases overall exhaust concentrations but increases NOx.

Keywords: Computer aided; Internal combustion engine fuel; Injection strategy; Exhaust gas changes

1. Introduction

The automotive industry faces challenges in balancing engine performance with emission regulations. There are many theoretical results on the related research of internal combustion engine fuel injection. For example, Liu Yuxin said that the internal combustion engine is a product of China's technological development and one of the main machinery widely used in various industries. With the continuous development of computer technology, it is of great significance to promote the advancement of internal combustion engine design based on computer technology[1]. HouXianjun examined the changes in engine economy and particulate emissions after adopting single injection and secondary injection strategies under different operating conditions. When the secondary injection strategy is applied to a supercharged direct injection engine, properly optimizing the secondary injection ratio and the secondary injection phase can effectively reduce fuel consumption and particulate emissions[2]. Zhang Qingpeng carried out an experiment on the influence of fuel injection parameters on particle emissions, and analyzed the influence of fuel injection time, fuel injection pressure and EGR rate on the particle size distribution of particle emissions[3]. Therefore, this paper also intends to use computer-aided research to study the influence of fuel injection strategy on exhaust gas.

This paper integrates computer-aided technology to optimize injection timing and pressure, aiming to improve combustion efficiency and mitigate emissions.

2. The influence of computer-Aided internal combustion engine fuel injection strategy on exhaust gas

2.1. The development history of fuel injection strategy

Evolution of Fuel Injection Technology

Fuel injection systems evolved from traditional nozzles to electronically controlled mechanisms. Early systems focused on combustion efficiency, while modern strategies integrate electromagnetic regulation and multi-dimensional simulations to optimize fuel-air mixing[4-8].

2.2. The requirements of internal combustion engine fuel injection strategy for exhaust emissions

Meeting emission standards requires precise control of injection timing, pressure, and air-fuel ratios. Delayed injection during compression lower combustion temperature, reducing NOx but increasing soot due to incomplete mixing[9-11].

2.3. Selection of fuel injection strategy

Optimal strategies balance injection timing, pressure, and load conditions. Secondary injection strategies under high load reduce particulate emissions by 15–20%[2], while single-injection optimization at medium load enhances fuel economy.

3. Test System and research plan

3.1. Optical engine bench and test system

The direct-injection gasoline engine used in the test is a spray-guided optical single-cylinder engine with a central porous injector. Its main parameters include:

Bore diameter/mm: 70
Piston stroke/mm: 81.8
Compression ratio: 8
Number of valves: 4 (VVT)
Direct injection type: spray-guided type

The piston of the optical single-cylinder engine is flat-topped and shallow-pit-shaped. The non-uniform and symmetrical 6-hole injector is arranged close to the cylinder axis and slightly inclined to the side of the intake valve, and the spark plug is arranged obliquely on the side of the exhaust valve. And close to the injector. The construction of the test bench is based on a complete set of AVL performance benches. The measurement and control system of the test bench is AVL PUMA. The engine speed and load are controlled by a DC electric dynamometer. The intake air conditioning system can control the intake air temperature, humidity and intake pressure of the single-cylinder engine. A wide-area oxygen sensor and an ETAS 630 air-fuel ratio analyzer arranged at the exit of the exhaust duct are used to monitor the excess air coefficient. The AVL independent cylinder pressure sensor is used to collect the cylinder pressure signal, and the data is processed and analyzed by the AVL Indicom combustion analyzer. Use HORIBAR MEXA-1600D emission analyzer to collect and analyze conventional gas emissions in engine exhaust, and use micro-smoke meter to collect and analyze soot emissions in engine exhaust.

Perform a three-dimensional simulation calculation model on it. The fuel injection and combustion in the engine cylinder are complex reaction processes and have strong instantaneous variability. The traditional single simulation model has certain limitations, and the accuracy of describing the internal reaction process of the engine is limited. With the advancement of technology, the application of multi-dimensional engine combustion models in practice has become more and more extensive. During the fuel injection process, it is inevitable that there will be collisions and interactions, aggregation and breakage again. The frequency of collision adopts the probability density method of Poisson distribution, and the formula is as follows:

$$\mathrm{s} = \frac{M_2}{s}\frac{\mu}{4}(c_1 + c_2)^2 \left| o_1 - o_2 \right| \tag{1}$$

Among them, S is the frequency of particle collisions. And o_1 false and o_2 false are the speeds of the examples respectively. And c_1 false and c_2 false are the diameters of the examples respectively.

During the experiment, in order to describe the interaction between the particles, the particles are arranged in advance, so the calculation takes less time.

3.2. Experimental research plan and boundary condition control

When performing each test point, after the optical single-cylinder machine runs stably for 3 minutes, start the high-speed video test and record the test data. Combustion and emissions data are the average of 100 cycles. In addition, in order to reduce the influence of boundary conditions and other factors, the air intake temperature, coolant temperature, and oil temperature after intercooling were maintained at 31°C, 61°C, and 61°C, respectively, during the test.

The specific experimental research plan can be divided into the following two parts:

(1) Under the condition of medium speed and medium load, set different injection time and pressure of single injection, combine high-speed camera images and bench test data, explore the effect of single injection strategy on spray-guided direct injection gasoline engine Influence of combustion and emission characteristics.

(2) Under the condition of medium speed and high load, adopt the two injection strategy, set the time of the first injection in the early intake stroke, change the different second injection time and different injection ratio, and explore the two The influence of the injection strategy of the second injection on the combustion and emission characteristics of the spray-guided direct-injection gasoline engine.

4. Analysis of survey results

4.1. Influence of fuel injection timing on emission characteristics

According to the experimental test results, it is found that with the delay of the fuel injection timing, the CO emissions in the engine exhaust and the total unburned hydrocarbon THC emissions have a similar trend, and the overall trend is gradually increasing. The specific data is shown in **Table 1**:

Table 1. Effect of oil injection time on emission characteristics.

Temperate	CO	THC	NOx	Soot
300	0.8	500	1100	9
280	0.6	545	1300	6
260	0.5	570	1000	10
240	0.4	600	950	14
220	0.3	575	900	9
200	0.7	580	1050	8

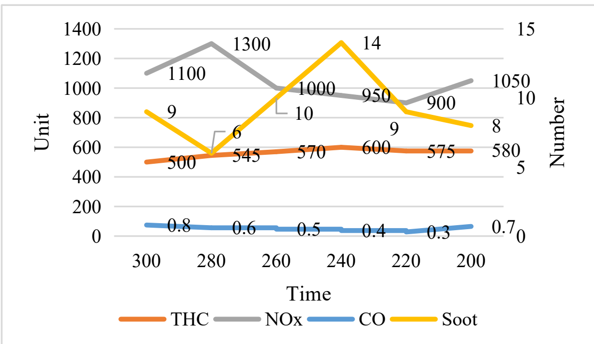

Figure 1. Effect of oil injection time on emission characteristics.

As shown in Figure 1, under the test conditions, with the delay of the fuel injection timing, the NOx emissions in the exhaust gas showed a gradual decrease as a whole, and it was greatly affected by the combustion temperature in the cylinder. The soot emission in the exhaust gas showed a gradually increasing trend as a whole. The main reason for this trend may be that the shortening of oil and gas mixing time makes the oil and gas mixing insufficient and increases in local over-concentrated areas.

5. Conclusion

The oil and gas mixing process is an important part of the engine. Researching and controlling it can not only improve the efficiency of internal combustion engines, reduce energy consumption and emission levels, but also improve vehicle exhaust performance. In this paper, computer-aided technology is used to optimize the parameters of various operating conditions in the gasoline engine injection system to achieve the goal of small changes in the fuel-air ratio and large changes in nozzle pressure. According to the experimental investigation results in this article, it is found that the timing of fuel injection has a certain impact on exhaust emissions.

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