Scholar Publishing Group
Kinetic Mechanical Engineering
https://doi.org/10.38007/KME.2022.030205
ISSN 2790-2676 Vol. 3, Issue 2: 37-45

Optimization Design of Injection Pump Cam of Single Cylinder Direct Injection Diesel Engine Combined with Artificial Intelligence Algorithm

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Keywords: Artificial Intelligence Algorithm, Single Cylinder Direct Injection Diesel Engine, Injection Pump Cam, Design Optimization

Abstract: Most models of low-power off-road diesel engines in China are single-cylinder diesel engines. The production, use and export of single-cylinder diesel engines are one of the characteristics of internal combustion engine industry in China. As the emission standards of off-road diesel engines are becoming stricter in China, it is of academic significance and engineering application value to study the low emission mechanism and optimization of low emission technical scheme of single-cylinder diesel engines. The purpose of this paper is to study the optimal design of injection pump cam of single cylinder direct injection diesel engine combined with artificial intelligence algorithm. The problems existing in the fuel injection system of domestic large bore single cylinder diesel engine are analyzed. The measures to improve the injection pressure of single cylinder engine are put forward. The basic principle and method of oil pump cam design are given. The artificial intelligence technology is used to simulate and model the new oil pump cam. According to the calculation, the cam design of single-cylinder engine fuel injection pump has its own characteristics. In the design, not only the general technology of the cam design of fuel injection pump, but also the special requirements of the installation and adjustment of single-cylinder engine should be considered to meet the needs of the overall layout of diesel engine. Based on the optimization scheme, the influence of key parameters changes on diesel engine emissions in the simulated production process is studied. The calculation results show that in order to ensure the effective control of emissions, performance and production consistency, it is necessary to reduce the change range of key parameters in the production process. The calculation and analysis show that the fuel supply advance angle, compression clearance and injector extension height are controlled within ±0.5℃A, ±0.08mm and ±0.1mm respectively. The increase percentage of NOx emission is within 9.8%, and the increase percentage of Soot emission is within 8.4%. The calculation results can guide the control of parameters and dimensional tolerance of parts in diesel engine production.

1. Introduction

As agricultural transport vehicles, water pumps, generators and other road auxiliary products, single-cylinder diesel engines have been widely used all over the world, especially in the third world countries. With the continuous improvement of economy, the increasing urbanization rate, the increasing demand for power from technical construction, agricultural machinery and families, and the advantages of single-cylinder diesel engines such as compact structure, high cost performance and convenient use and maintenance, the use of single-cylinder diesel engines will be further expanded at home and abroad [1-2].

In the research of optimization design of injection pump cam of single-cylinder direct injection diesel engine combined with artificial intelligence algorithm, many scholars have made research on it, and achieved good results. For example, Leng J took a small off-road single-cylinder direct injection diesel engine as the research object, comprehensively applied CAE and CFD optimization design technology, and started with multi-parameter optimization matching of combustion system and improved design of mechanical system, developed a small off-road diesel engine with high performance and low emission [3]. Al-Haidari H S J et al. think that the electronically controlled unit pump fuel system is an EFI system with high injection pressure, which can freely and flexibly adjust the injection quantity and timing [4].

In this paper, a test system of fuel pump is constructed, and the relationship between piston speed and oil pressure in piston cavity when the control valve of single cylinder pump is stopped is analyzed by using artificial intelligence technology. Then, using this test system, the low-speed fuel delivery characteristics of single-cylinder pump fuel system are studied. The results show that under the low-speed working condition, after the system is installed, the oil pressure of the system fluctuates obviously, and the needle valve cannot keep a stable open state during the fuel injection process. Using neural network, the specific position of the valve stem movement of control valve under high pressure is studied. It is noticed that the valve stem will jump backwards when it is fully opened and closed, and the valve stem of control valve will close in the opening process under some operating conditions.

2. Research on the Optimal Design of Injection Pump Cam of Single Cylinder Direct Injection Diesel Engine Combined with Artificial Intelligence Algorithm

2.1. Calculation and Analysis of Changing Cam Design Parameters

The main measures to increase the injection pressure are to increase the piston diameter, increase the injection pressure, increase the piston diameter, increase the injection pressure and increase the injection pressure. The effective oil flow cross-section of the camshaft and the reduced cross-section of the injection hole flow, etc. As the single-cylinder diesel engine has been used to analyze the parameters of the fuel injection pump, increase the fuel injection pressure and increase the fuel injection pressure. The lift of the camshaft is feasible, which can not only increase the effective injection cross section of the fuel injection pump, but also increase the speed of the fuel injection pump. Besides increasing the piston speed, it also increases the processing pressure of oil. In addition, increasing the piston speed can also improve the dynamic pressure seal in the oil pressing process, thus further increasing the injection pressure. If the injection system of a single-cylinder engine is significantly changed, the installation size must be adjusted. Some adjustments are necessary. Because the fuel injection pump camshaft and the intake and exhaust camshaft are integrated in a single cylinder engine, it is necessary to replace the fuel injection pump camshaft and the intake and exhaust camshaft [5-6].

If the fuel injection pump camshaft and the intake and exhaust camshafts are integrated, the

installation dimensions of the fuel injection pump camshaft and the intake and exhaust camshafts must be changed. Changing the installation size of the injection system will lead to major adjustments to many parts of the engine, which makes serial production very difficult. From a structural analysis, it is shown that it is possible to reach 10.5 mm while keeping the installation size unchanged. Appropriately reducing the diameter of the base circle of the camshaft can ensure that the camshaft can be used in a wide range of applications. The proper reduction of the pitch diameter of camshaft ensures the installation requirements of timing gear. In addition, the operation of the tangential cam with transition section when the cam profile is changed to tangential can further improve the working characteristics, reliability and service life of the cam [7-8]. The scope of travel can be expanded. After increasing the cam lift, it is necessary to adjust the height of the fuel injection pump cylinder assembly in the following ways to increase the pre-stroke, thus increasing the effective fuel delivery. The actual design intention is to adjust the height of the cylinder assembly of the fuel injection pump to increase the pre-passage, so that the effective fuel supply can run at high speed [9-10].

2.2. Basic Requirements of Diesel Engine for Fuel Injection System

As the core system of diesel engine, the fuel injection system has always been called the "heart" of diesel engine. Its function is to inject atomized fuel into the combustion chamber regularly, quantitatively and qualitatively, and mix it with air to form a combustible mixture, so as to ensure the requirements of diesel engine combustion and work. Therefore, diesel engine has the following basic requirements for fuel injection system[11-12]: (1) Provide the diesel engine with the fuel quantity suitable for its working conditions, and ensure the fuel quantity of each cylinder. (2) The fuel supplied for diesel engine should enter the cylinder in a good mist, and the spray distribution in the cylinder should be consistent with the shape of the combustion chamber and evenly distributed. (3) The moment when the atomized fuel provided for the diesel engine is injected into the cylinder should be accurate and appropriate, and the injection should be finished promptly and simply. (4) The fuel injection law (including fuel injection rate) should meet the requirements of diesel engine indexes, especially the highest explosion pressure, fuel consumption rate and emission. (5) The fuel injection system must have high reliability.

2.3. Ways to Improve the Design of Fuel Injection Pump

Due to the development of diesel engines in the direction of high pressure, high injection rate and low emission, coupled with the worldwide energy crisis, in order to prolong the life cycle of manufactured diesel engines and reduce energy consumption, shipowners generally adopt the way of burning heavy oil and strengthening power to improve their competitiveness. In order to meet the development requirements of this kind of diesel engine, its fuel injection system must be improved according to the needs of diesel engines. The restriction conditions for the improved design of this kind of fuel injection system are as follows [13-14]: (1) The installation and connection dimensions of fuel injection pump are generally not allowed to be changed; (2) The starting point of fuel injection pump cannot be changed; (3) The inner cavity size of the transmission device (guide piston or lead cylinder hole) cannot be changed; (4) Generally, the overall height of the fuel injection pump cannot be changed. In view of the above constraints, in order to meet the needs of power increase and injection pressure increase, the following three ways are generally adopted: (1) increasing the plunger diameter; (2) increasing the cam lift; (3) Increase the plunger diameter and cam lift. From the above, it can be seen that the design of the oil supply cam mechanism is particularly important.

2.4. Application of Artificial Intelligence Technology in the Optimal Design of Injection Pump Cam of Single Cylinder Direct Injection Diesel Engine

BP model can realize the idea of multi-layer network learning. When an input mode of the network is given, it is transmitted from the input layer unit to the hidden layer unit, which is processed by the hidden layer unit one by one and then transmitted to the output layer unit, and the output layer unit processes it to produce an output mode. This is a process of updating the state layer by layer, which is called forward propagation. In this paper, bp model is used to analyze the cam of injection pump of single cylinder direct injection diesel engine. Through data simulation, through continuous bp network training, the best parameters are obtained, and the injection pump cam is optimally designed [15-16].

The structure of BP neural network is hierarchical. According to the function of neurons, it is divided into three layers: input layer, hidden layer and output layer, which are connected in sequence. The mathematical relationship between layers of BP neural network is as follows:

For the output layer:

$$o_k = f(net_k) = f\left(\sum_{j=1}^{m} \omega_{jk} y_j\right), k = 1,2,\Lambda\ ,m; \tag{1}$$

For hidden layers:

$$y_j = f(net_j) = f\left(\sum_{i=1}^{1} v_{ij} x_i\right), j = 1,2,\Lambda\ ,m, i = 1,2,\Lambda\ ,l \tag{2}$$

3. Research and Design Experiment on the Optimal Design of Injection Pump Cam of Single Cylinder Direct Injection Diesel Engine Combined with Artificial Intelligence Algorithm

3.1. Design Process

The design process of fuel supply cam profile is shown in Figure 1, and its implementation steps are as follows: (1) According to the requirements of fuel injection pump plunger pre-stroke, fuel supply starting point speed and cam and roller tracking, the design of pre-stroke section is determined. (2) According to the maximum oil supply of plunger, tracking of cam and roller, and design requirements of pump chamber pressure, determine the design of effective oil supply section. (3) According to the need of cam and roller tracking, determine the design of oil return section. (4) According to the design gallery and related design data, determine the design of cam base circle diameter. (5) According to the design gallery, preliminarily determine the design of cam width. (6) According to the allowable contact stress of the material, calculate the contact strength; if it is reasonable, proceed to the next step; if it is unqualified, return to the corresponding design stage. (7) Finally, determine the material and heat treatment requirements of the cam [17-18].

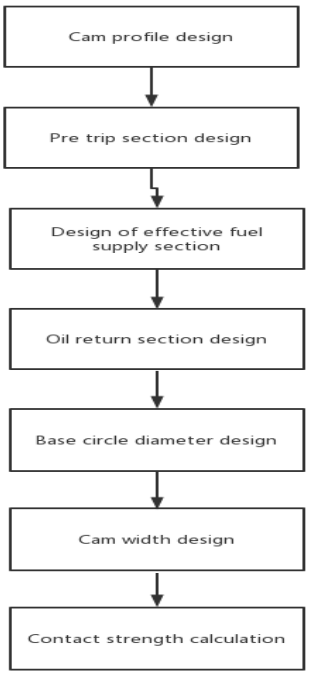

Figure 1. Flow chart of oil supply cam profile design

3.2. Experimental Design

In this paper, based on artificial intelligence algorithm, the optimal design experiment of injection pump cam of single cylinder direct injection diesel engine is carried out. Firstly, the cam angle is tested, and the results of simulated oil pressure and experimental oil pressure are compared under different angles. Secondly, the improved design of cam profile is tested, mainly by analyzing the oil pressure in different injection durations.

4. Research and Experimental Analysis on the Optimal Design of Injection Pump Cam of Single Cylinder Direct Injection Diesel Engine Combined with Artificial Intelligence Algorithm

4.1. Cam Angle

In this paper, firstly, the cam rotation speed of 1000rpm and the injection duration of 15 cam rotation angle are calibrated, and the model parameters matching the test results are determined. Then, the working conditions with different durations of the cam rotating speed of 1000rpm are calibrated, and the model parameters matching the rotating speed are further determined. Finally, the working conditions of 17 cam angle with different rotational speed and duration of injection control signal are calibrated. The established model is used to calibrate the cam rotation speed of 1000rpm and the duration of injection signal control of 15 cam rotation angle. The comparison between the simulation oil pressure results and the test oil pressure results is shown in Table 1.

Table 1. Simulation oil pressure results and test oil pressure results

	-20	-15	-10	-5	0	five	10
experimental result	50	100	600	900	600	50	0
simulation result	55	100	585	eight hundred	600	forty-nine	0

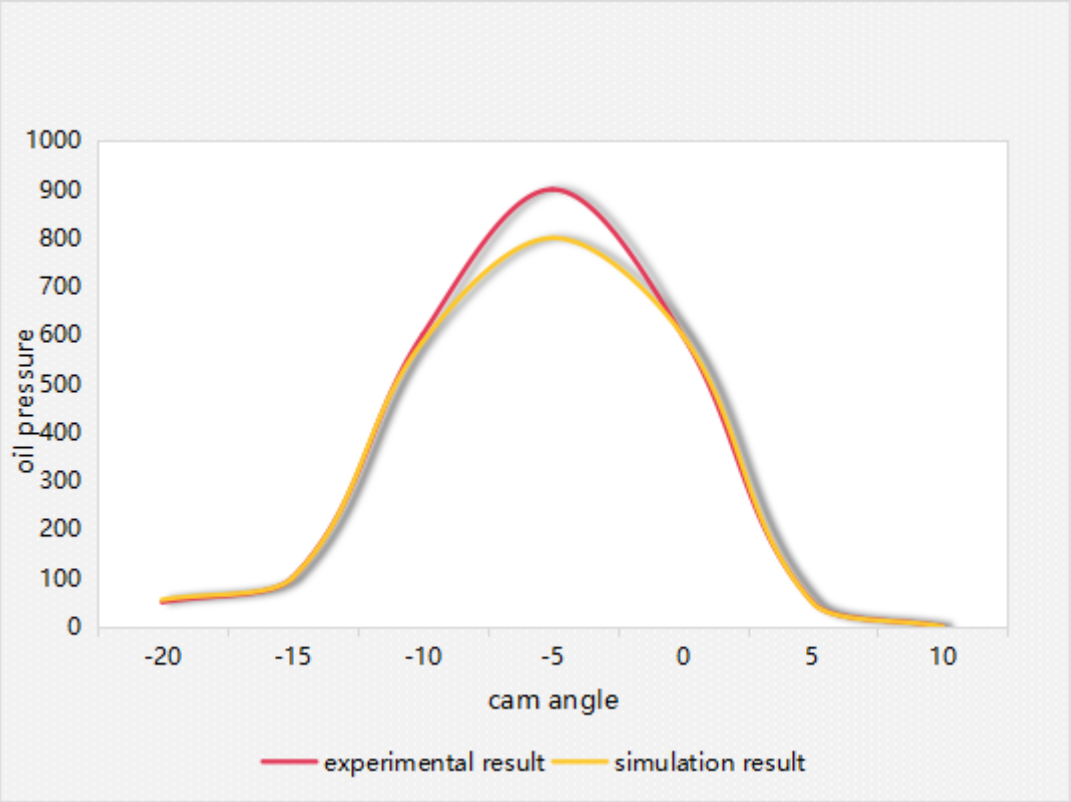

Figure. 2 Comparison between 1000 rpm 15 °simulated oil pressure and test oil pressure

As can be seen from Figure 2, when the cam speed is 1000rpm and the duration of the injection control signal is 15, the experimental waveform of the oil pressure at the pump end is in good agreement with the simulation waveform.

4.2. Improved Design of Cam Profile

When isobaric injection occurs, the oil pressure will not change obviously with the increase of injection duration. The injection duration is too small, so the isobaric injection can't be realized. The duration is too long, which may exceed the working range of the profile. Therefore, it is first necessary to determine the appropriate injection duration that can reflect the isobaric injection. Under the same working condition, the oil pressure with large duration will cover the oil pressure

with small duration, so long as the injection duration does not exceed the working range. The oil pressures with different injection durations are shown in Table 2.

Table 2. Oil pressure in different durations

	-15	-5	five	15	25
17	100	1000	500	50	0
20	100	1050	2000	50	0
25	100	1055	2010	500	0
30	100	1060	2010	2000	0
35	100	1070	2010	2020	300

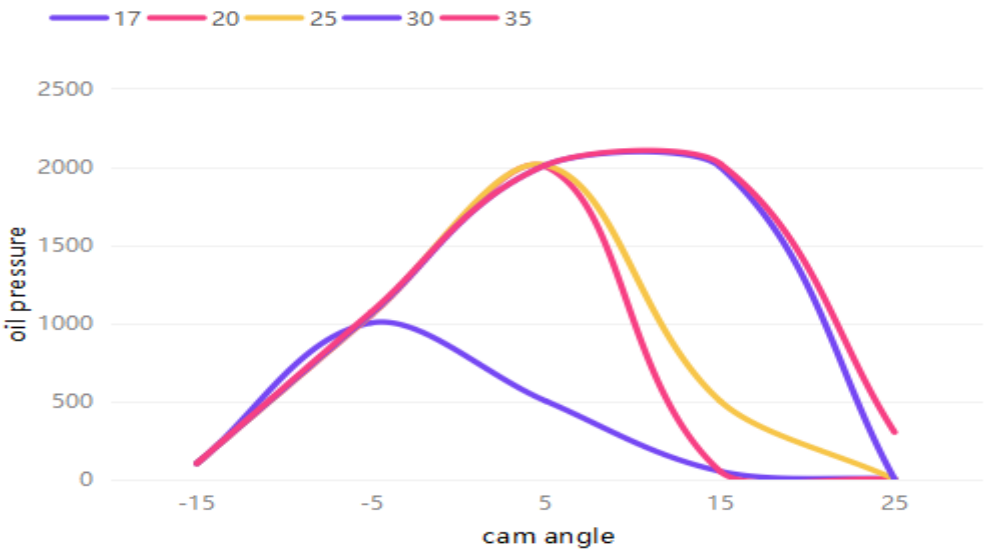

Figure 3. Comparison of oil pressure changes in different durations

It can be seen from fig. 3 that, when the cam-matched BIT single pump is preliminarily designed with reference to the relevant parameters of concave arc cam, even though the isobaric injection can be realized, the oil pressure level during isobaric injection is very high. This will increase the load on the cam and reduce the reliability of the cam. Therefore, it is necessary to further improve the design and reduce the oil pressure level during isobaric injection. In order to obtain the required profile, it is also necessary to reasonably match the relevant design parameters. According to the mathematical model of the profile established in the previous chapter and the research on the influence of various parameters on the movement characteristics and oil pressure of the tappet, in order to ensure that the maximum acceleration Amax does not exceed the limit, this paper mainly

achieves the purpose of isobaric injection by adjusting Aa.

5. Conclusion

The main results and conclusions of this paper are summarized as follows: A calibration method of fuel injection characteristics of single-cylinder pump fuel system based on oil pipe pressure is proposed. Combined with the known pre-stroke of cam, the synchronization of oil pump platform camshaft and engine camshaft is completed, and then the corresponding engine compression top dead center phase on the oil pump platform is determined. On this basis, the single-cylinder pump on the oil pump platform runs in the working section of cam, and the experimental study of fuel injection characteristics of single-cylinder pump is carried out. When the single cylinder pump is powered on, the peak phase of oil pressure lags behind with the increase of rotating speed; On the oil pump test-bed, the accurate phase of the peak plunger speed corresponds to the peak oil pressure phase when the electric power and rotational speed of the single-cylinder pump section infinitely tend to zero. Based on artificial intelligence technology, the bp neural network model of single pump fuel system is established, and the calculation model is calibrated. The results show that the model has reached a reasonable precision range. And the selection range of each structural parameter is put forward. It is pointed out that the ratio of the diameter of the secondary oil inlet of the valve seat and the diameter of the inclined oil passage of the pump body to the diameter of the plunger should be at least greater than 0.1 for the single pump with the same structure and different diameters.

Funding

This article is not supported by any foundation.

Data Availability

Data sharing is not applicable to this article as no new data were created or analysed in this study.

Conflict of Interest

The author states that this article has no conflict of interest.

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