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Test on High Pressure Leakage of Diesel Needle Valve Coupler Based on Artificial Intelligence Algorithm

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Abstract: Needle valve coupling is a device used to monitor and control fluid medium leakage, which has been widely used in petroleum, chemical and other fields. At present, the leakage detection methods for needle valve couplings mainly include simulation test method and intelligent analysis technology. Because the working environment of diesel engine is relatively bad, and its harm to the environment is also great, it is necessary to avoid high-pressure leakage as much as possible. The purpose of this paper is to improve the test accuracy of the high-pressure leakage of the needle valve coupling parts of diesel engines. This paper mainly uses the test plan design to detect the high-pressure leakage of the diesel engine needle valve coupling parts, and then analyzes the leakage rate of the thermal fluid solid coupling and one-way fluid solid coupling needle valve coupling parts through the comparison method. The experimental data shows that when the pressure reaches 105, the leakage rate of the needle valve coupling reaches 0.053ml/s. Compared with the static experimental results, the thermal fluid solid coupling error and the unidirectional fluid solid coupling error are larger. Therefore, the elastic deformation and thermal deformation of needle valve coupling can not be ignored under high pressure.

1. Introduction

High pressure leakage of needle valve coupling is a very important but critical problem in the test system. The neural network method is used to model and analyze by simulating the causal relationship in the human brain. It is a mathematical model that decomposes a complex system into simple functions and can process information quickly and identify and classify. This paper will establish the neural network model of the needle valve coupling system of diesel engine, simulate it, and explore the relationship between its response characteristics and fault state under different

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parameters and working conditions.

Through research, it is found that there are many theoretical achievements based on artificial intelligence and the theory of high-pressure leakage of diesel needle valve coupling parts. For example, some scholars put forward that with the continuous tightening of diesel engine emission regulations, the injection pressure of diesel engine is getting higher and higher, and the fuel leakage of the fitting clearance of high-pressure injection pressure bearing coupling will have an impact on the injection process [1-2]. Some scholars also pointed out that in order to further improve the working condition of fuel injection atomization, the test of increasing the opening pressure of the injection needle valve pair should be carried out [3-4]. In addition, some scholars said that the needle valve coupling of diesel engine injector is one of the key components in diesel locomotives, and its quality is directly related to the normal use of diesel locomotives [5-6]. Therefore, this paper is a new attempt to study the high-pressure leakage of the diesel needle valve coupling combined with the artificial intelligence algorithm, which has the significance of the times.

This paper first studies the working characteristics of high-pressure common rail injector, and describes the function, response and needle valve movement of the injector. Secondly, for the sealing mechanism of needle valve coupling, it is proposed that there is a close relationship between needle valve coupling and high pressure leakage. Then the swarm intelligence optimization neural network algorithm is described, and it is found that it can play a role in pattern recognition of diesel engine under complex working conditions. Finally, relevant data and conclusions are obtained through the leakage test of needle valve coupling.

2. High Pressure Leakage of Diesel Needle Valve Coupling Parts Based on Artificial Intelligence Algorithm

2.1. Operating Characteristics of High-Pressure Common Rail Injector

When the high-pressure common rail fuel injection system is working, the functions of the injector can be divided into the following four stages: the needle valve is closed, the needle valve starts to rise, the maximum lift of the needle valve and the needle valve is closed. The good motion pattern of the solenoid valve is conducive to the working performance of the engine. In the study of the motion equation of the needle valve of the injector, the moving part of the needle valve composed of the needle valve and the control plunger is regarded as a whole, and it is considered that both of them reciprocate simultaneously, with the same acceleration, speed, maximum lift and displacement. The motion law of the needle valve directly affects the injection law of the fuel injector. When the fuel pressure is constant, the duration of needle valve opening determines the amount of fuel injection. The quick opening and closing of the needle valve is the basis for accurate measurement of fuel injection. The movement of the needle valve always lags behind the movement of the solenoid valve, because the solenoid valve does not directly open the needle valve, but indirectly controls the needle valve through the transmission of hydraulic pressure. The motion curve of needle valve in the opening and closing stages is close to the motion curve of uniform acceleration and deceleration [7-8].

The high-pressure common rail injector operates in two ways. One is to directly contact with the air to atomize the liquid at a higher pressure within a certain temperature range. The other is to atomize the liquid into gas by changing the liquid level height. The main structure of fuel injector is high-pressure common rail injection system and pump. The working principle of the fuel injector is that under the action of high-pressure common rail injection fluid, due to pressure, kinetic energy and other factors, the liquid or gas is compressed to form a complex mixture layer. The system is internally equipped with pumps, valves and corresponding accessories, which are connected to each other to form a complete system, so as to realize the function of regulating and controlling the high pressure. At the same time, the valve control unit can also be used to complete the data collection of the specified values on the circuit board and the change of flow size [9-10].

2.2. Sealing Mechanism of Needle Valve Coupling

The pairing clearance of needle valve coupling parts is very small, generally 1~4 μ m. During the actual operation of needle valve coupling, due to the high pressure of fuel, and the relative movement and deformation between the coupling parts, fluid lubrication between the coupling parts is formed. The needle valve coupling adopts the diesel self-lubricating method. The high-pressure diesel oil leaks and flows, forming an oil film in the matching gap of the needle valve coupling, avoiding the direct contact of the oil film sealing surface [11-12].

The two ends of the sealing cone are the high-pressure fuel from the oil sump and the cylinder pressure connected with the nozzle, which are the sealing surfaces that directly control the fuel injection. As the needle valve squeezes the valve body seating surface, a small contact zone is formed between the needle valve sealing cone and the needle valve body sealing cone. The needle valve lift is shown in Figure 1:

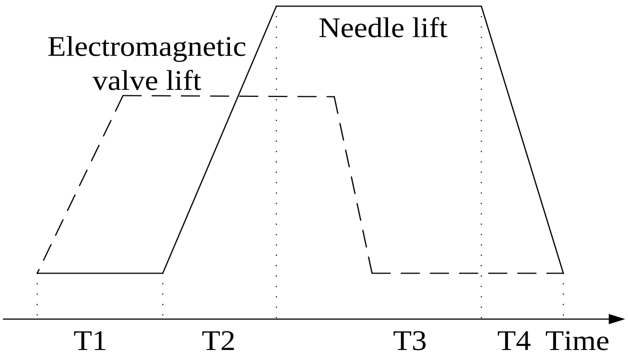

Figure 1. Needle valve lift curve

Needle valve coupling is one of the three precision couplings of diesel fuel injection system. It is often worn by high-speed, high-pressure and foreign particles in the fuel during operation, resulting in poor sealing performance. The sealing state of needle valve coupling is closely related to its wear degree, and the wear degree of needle valve coupling is generally qualitatively analyzed through indirect measurement. The wear of the sealing cone of the needle valve coupling parts will lead to poor sealing of the nozzle and fuel leakage, resulting in black smoke, carbon deposition, cylinder knocking, insufficient power and other problems, as well as the change of the needle valve lift. Because the injection quantity control of high-pressure common rail injection system is pressure time type, the change of needle valve lift directly leads to the change of injection time, which leads to the change of injection quantity. When the nozzle of needle valve coupling is worn, the fuel atomization becomes worse, the phenomenon of insufficient combustion intensifies, and the emissions of carbon deposits and particles increase [13-14].

With the increase of fuel pressure in the fuel supply system, the high pressure fuel in the oil sump and the clearance between the needle valve and the coupling parts makes the needle valve and the coupling parts subject to heavy load. This kind of load not only directly affects the sealing characteristics of the oil film in the clearance of the needle valve coupling, but also makes the needle valve coupling deform and increases the radial clearance thickness of the needle valve coupling.

2.3. Group Intelligent Optimization Neural Network Algorithm

Artificial neural network is an important part of intelligent science, with its powerful computing learning ability, approximation ability to any continuous mapping and dynamic network stability analysis ability. Compared with other types of optimization methods, swarm intelligence optimization algorithm is simpler, more efficient and has faster convergence speed [15-16].

Artificial neural network is an important part of intelligent science. Feedforward neural network is a typical hierarchical structure. BP neural network can approximate a highly nonlinear function with arbitrary accuracy. Compared with BP neural network, RBF neural network can better complete difficult function approximation, with fast operation speed, simple single hidden layer network structure, strong nonlinear mapping ability, and is not easy to fall into local minima. When using PSO to optimize BP neural network, three aspects are generally studied: the first is to optimize the weights and thresholds of the network. Second, optimize the network structure. Third, it optimize both. This paper uses swarm intelligence algorithm to optimize the threshold value of BP neural network weight [17-18].

The leakage test of needle valve coupling parts in this paper is carried out on the cylinder head of diesel engine. The test method is autoregressive algorithm. Firstly, the temperature distribution on the contact surface of the needle valve element is determined. Then we use a simple calculation program, that is, using swarm intelligence to optimize the neural network algorithm, to calculate the distance and pressure between each point to obtain the corresponding parameters. Finally, the leakage of needle valve coupling can be obtained by changing the response frequency of position sensors in the device to the surface roughness of cylinder block, piston ring, cylinder liner and other parts.

3. Research on Leakage Test of Needle Valve Coupling

3.1. Design of Needle Valve Coupling Leakage test

During the test, the clearance fuel leakage rate is used to measure the sealing characteristics of the needle valve coupling. The greater the leakage rate, the worse the sealing performance of the needle valve coupling. On the contrary, the better the sealing performance of the needle valve coupling. Through the change of the leakage, the sealing characteristics of the needle valve coupling can be evaluated macroscopically. The test design includes the debugging and refitting of the basic test bench, the design of the test plan, and the processing of the test device.

In this paper, CR4000A high pressure common rail fuel supply test-bed is used to test the fuel supply characteristics of BOSCH electronic injector and fuel injection pump. This paper uses the high-pressure common rail fuel supply test bed to test the leakage of the needle valve coupling. By establishing different rail pressures in the high-pressure fuel pipe, ECU adjusts the injection pulse width, injection frequency and other parameters to study the sealing characteristics of the needle valve coupling.

3.2. Test Scheme Design

The electronic injector has two pairs of plunger and needle valve, which seal the internal oil circuit. The leaked fuel returns to the fuel tank through the low-pressure oil circuit. When the needle valve coupling rotates 180 degrees, the leaking oil outlet hole of the needle valve coupling is blocked by using the plane seal between the needle valve body and the injector body. At this time, the flow of the small hole is the leakage of the plunger coupling P_m^1. When the needle valve is closed, the differential pressure at both ends of the plunger coupling and the needle valve coupling is the same, regardless of the change of diesel viscosity. In static state, it is a pure differential pressure leak, and the ratio of the two leakage amounts is:

$$\frac{P_m^1}{P_n^2} = \frac{c_1 \partial_1^3 h_2}{c_2 \partial_2^3 h_1} \tag{1}$$

When the injector works normally, the dynamic leakage of the plunger coupling and the needle valve coupling is set to P_c^1 and P_c^2 respectively to meet the following requirements:

$$P_c^1 + P_c^2 = P_c \tag{2}$$

The leakage caused by shear flow can be obtained by subtracting the static leakage from the dynamic leakage. The clearance oil film thickness of needle valve coupling and plunger coupling has the same movement rule.

3.3. Processing of Test Device

Due to the high material hardness and precise matching of the electronic fuel injector, it is difficult to process and easy to damage the injector. Therefore, EDM is adopted. According to the internal structure of the fuel injector, a round through-hole with a diameter of 2mm is machined on the fuel injector body. When the fuel injector is working, the fuel leakage of the valve coupling and plunger coupling flows back to the fuel tank through the low-pressure fuel channel of the injector. In order to avoid the influence of the fuel return in the plunger control room on the test, the outlet of the low-pressure fuel channel of the injector body is blocked during the test. During the test, the measurement shall be started when the oil flow is stable. Because the leakage rate is small, in order to shorten the test time and reduce the measurement error, the metering unit of the high-pressure common rail fuel supply system is not used, but the leaked fuel is introduced into a small range cylinder for direct measurement.

4. Test Measurement and Analysis

Punch holes on the fuel injector body, close the outlet of the low-pressure fuel circuit, and check whether the working performance of the fuel injector is normal on the high-pressure common rail fuel supply test bench after the refitting. Measure the fuel leakage of the fuel injector when the fuel injector is normal. In order to reduce the measurement error, the measurement shall not be started until the small hole flow is stable during the test.

4.1. Measurement of Static Leakage

The pulse width is 0 μs, the frequency is 16Hz, and the static leakage measurement value of the injector is different under different fuel pressures. Subtract the leakage rate of the plunger coupling from the total leakage rate to obtain the leakage rate of the needle valve coupling under static conditions, as shown in Table 1. In order to reduce the measurement error, the metering time is adjusted according to the flow rate of the small hole.

Table 1. Leakage rate of the static lower pin valve coupling

	Total leakage rate	Pin-valve coupling leakage rate	Pger coupling leakage rate
65	0.034	0.021	0.013
75	0.045	0.027	0.018
85	0.056	0.036	0.020
95	0.071	0.044	0.027
105	0.084	0.053	0.031

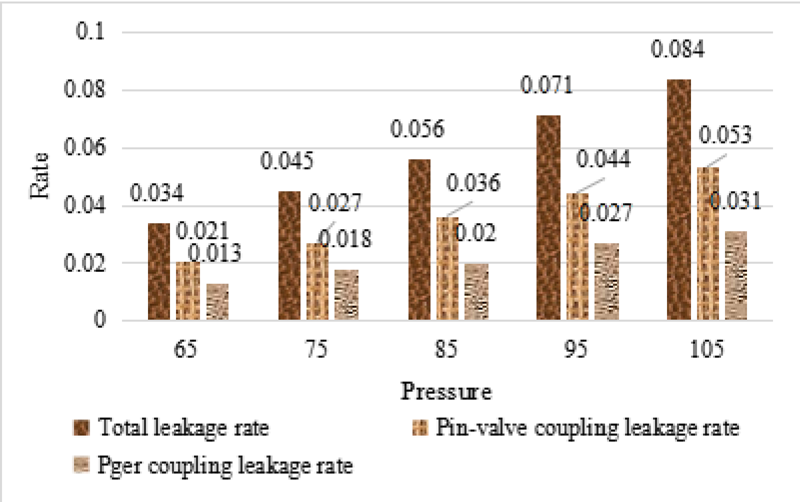

Figure 2. Leakage rate of the static lower pin valve coupling

As shown in Figure 2, we can see that under different pressure conditions, the leakage rate of plunger coupling is lower than that of needle valve coupling. And with the increase of the pressure, the static leakage is also increasing. This shows that the change of pressure will affect the coupling in different degrees.

4.2. Analysis and Comparison of Leakage Rate of Needle Valve Coupling

The leakage rate of the needle valve coupling measured in the test is compared with the the simulation results when the needle valve is concentric. The influence of the fluid pressure field and temperature field on the oil film in the clearance between the needle valve coupling parts is considered in the thermal fluid structure coupling calculation. The leakage rate results of solid coupling needle valve coupling parts are shown in Table 2:

Table 2. Comparison of the leakage rate of needle valve coupling parts

	One-way flow-solid coupling	Heat flow solid coupling	Static test
65	0.016	0.023	0.021
75	0.019	0.029	0.027
85	0.021	0.038	0.036
95	0.023	0.049	0.044
105	0.026	0.059	0.053

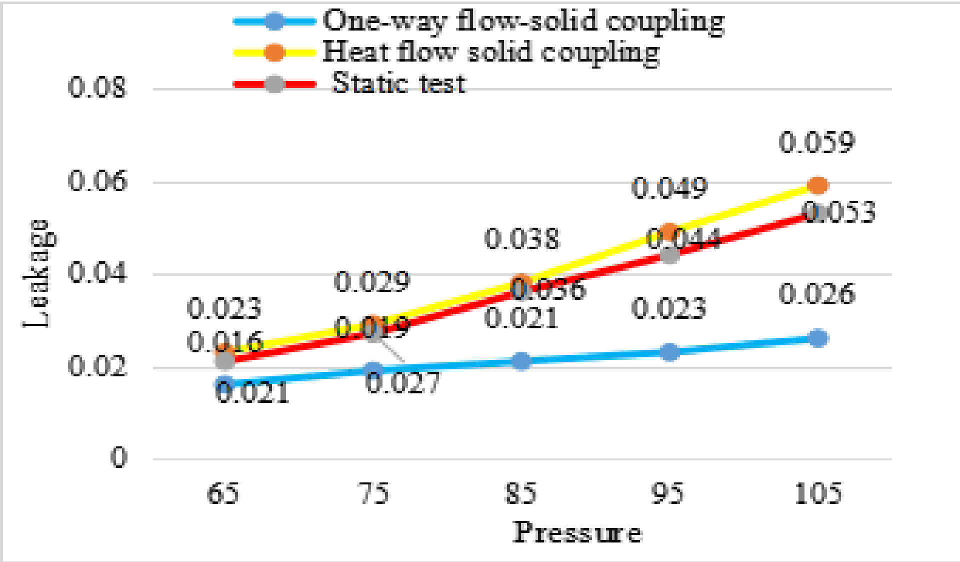

Figure 3. Comparison of the leakage rate of needle valve coupling parts

As shown in Figure 3, the results of static test, thermal fluid solid coupling simulation and one-way fluid solid coupling simulation show that the change trends of the three are basically consistent. With the increase of fuel pressure, the leakage rate of the oil film in the clearance between needle valve pairs increases. The change rate of leakage rate corresponding to unidirectional fluid structure coupling remains unchanged, while the change rate of leakage rate corresponding to thermal fluid structure coupling calculation and static test increases gradually with the increase of pressure, that is, the sealing characteristics of needle valve coupling parts deteriorate rapidly.

5. Conclusion

The traditional diesel engine injection system can no longer meet the increasingly stringent emission regulations. The performance of the needle valve coupling directly affects the running state of the important parts in the diesel engine system, such as the power plant, electrical components and the whole unit. High pressure leakage of needle valve coupling will cause a series of problems. Therefore, it is necessary to strictly control the leakage of the diesel engine. Therefore, this paper puts forward the application of artificial intelligence algorithm in testing the leakage of needle valve pairs. This paper will further study the influence of temperature and other factors on the leakage detection technology, and consider how to avoid errors to the greatest extent in the detection process, and analyze the differences and shortcomings between laboratory and field tests.

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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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