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Performance simulation of electronically controlled cooling system for automotive engines

Jiao Hongtao[1]

Abstract. The past engine cooling system is limited by the drive mode, and the fan speed depends on the engine speed, which is difficult to automatically adjust the temperature through the engine. However, the movement condition of the car is constantly changing, which will lead to engine cooling difficulties or excessive cooling, and at the same time, it will also cause the engine to stop working, increase the fuel consumption. Based on this, in this paper, the performance simulation of the electronically controlled cooling system for automotive engines was researched. Firstly, the design process of intelligent control system of cooling system was introduced briefly; secondly, relevant researches on the control of electronically controlled cooling system based on automotive engines were carried out; thirdly, the software design research of electric cooling system based on automotive engines was conducted, and the actual inspection was carried out. The results showed that the critical ratio K_s was decreasing and the simulation results were in accordance with the actual requirements.

Key words. Automobile engine, cooling system, electromechanical control, performance simulation.

1. Introduction

At present, the vast majority of automotive engines adopt the forced circulating water cooling treatment system. Engine cylinder head and cylinder block have the water jacket. Then, the pump inhales water from the outside of the machine, and generates pressure, makes the cool water flow in the water jacket, eliminates the heat of the adjacent parts. After the heating of the cooling water, the water's temperature is increased, and then it enters into the front of the radiator. With the progress of the car and the suction of the fan, the cold air outside puts the radiator cooling water into the atmosphere through the radiator. When the cooling water in the radiator is cooled down, it can enter into the water jacket circulation again under the action of the pump. In view of this situation, in the text, the

[1]Zhengzhou Railway Vocational & Technical College, Henan, Zhengzhou, 450052, China

Y80-based automotive engine electronically controlled cooling system was studied deeply. The intelligent control system of cooling system is an important foundation of the research. Therefore, this paper first studies relevant design standards and types of the cooling system intelligent control system. Then, the control planning of electronically controlled cooling system for automotive engines is analyzed, and some results are gained. Finally, the software design of electronic controlled cooling system based on automotive engine is studied in detail, and the experiment is carried out. The experimental results show that the oscillation period and the critical scale factor K_s of the system are determined by using the proportional adjustment link. The proportional coefficient K_p is automatically controlled by the microcontroller system, then, it increases gradually. This shows that the actual needs can be satisfied, and the simulation of the engine can be accurately achieved, which has a very good application prospect.

2. State of the art

The most commonly used clutch fan in the wind speed adjustment technology is the silicone oil clutch fan, in the design, the viscous liquid drive is applied, and then, the liquid viscous shear can be cut by the dynamic viscosity of the force and the shear film, its rate is proportional to the oil film and inversely proportional to the thickness, that is, as long as the thickness of the oil film is small enough, the oil film area is large enough to pass through large forces [1]. In the course of work, according to keep the same role of the shear film thickness, the role of the fan speed adjustment can be achieved by cutting the area. The clutch fan can control the engine operating temperature in the range of 80–90 °C, compared with the traditional fan, it has significant energy saving effect, besides, the clutch is small and easy to install, at present, this kind of fan is widely used in vehicles [2], and it is very popular in the silicone clutch vehicles at home and abroad [3]. In 1980s, there were electric cooling fans. The fan is no longer powered by the engine, while the electric fans are adopted, the fan can achieve changes in operating speed, avoid the fan power loss caused by the engine drive cooling, shorten the engine warm-up time, and reduce heat in accordance with the engine temperature and load conditions [4]. Electric adjustment technology is the hot spot in recent years. The earliest car electric cooling fan appeared in the patent document in March, 1981, the patent first proposed to replace the engine crankshaft with an electric cooling fan through a V-type drive cooling fan [5]. The heat system can control the temperature of the coolant and the temperature of the air conditioning condenser by ECU [6]. The system can control the fan speed according to the cooling water temperature and the operating conditions of the air conditioning system separately. On the basis of that the domestic car manufacturers are absorbing new advanced cooling systems abroad, the new cooling systems are developed [7]. In addition, research institutions also research and develop actively. Shandong Agricultural University has been engaged in the study of engine cooling control. In 2000, a new electronic thermostat was developed, and then, the single-chip control engine cooling theory was put forward, that was, the fan could work under the static, low and high speed conditions [8].

3. Methodology

3.1. Design of intelligent control system for cooling system

Cooling system can use the pump as a driving force, so that the cooling liquid in the body can conduct the forced circulation. The pump is installed in front of the cylinder and the coolant is placed in the water jacket of the cylinder, and then into the cylinder head. Finally, the thermostat is taken out from the outlet pipe of the cylinder head to complete the coolant cycle [9]. When the coolant temperature is below 66 °C, the coolant is pumped back from the outlet pipe through the pump and pumped into the body for an hour. When the outlet temperature reaches 76 °C, the thermostatic control valve is fully opened, and the cooling liquid enters the radiator for heating through the thermostat, this is a long cycle [10]. Figure 1 is a schematic diagram of an automotive engine.

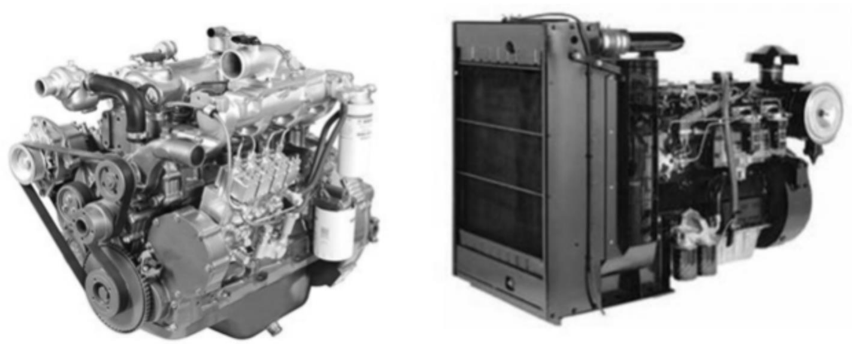

Fig. 1. Sketch map of automotive engines

As can be seen from Fig. 1, the cooling system consists of a radiator, a fan, a water pump and a thermostat, as well as consisting of a closed system including a flow path in a pipe and cylinder [11]. In a conventional cooling system, the fan is driven by the crankshaft of the engine, so the speed is relatively fixed. The problem of the traditional axial fan to the DC motor fan is driven by the pump to the DC motor [12]. In addition, compared with the conventional control system, the intelligent control system also adds microcontrollers and temperature sensors, and the speed of the fan motor is controlled by the microcontroller according to the coolant at different temperatures [13]. This paper focuses on micro control device system. The system is mainly composed of signal acquisition, clock circuit, temperature setting, LED temperature display, power supply circuit, motor drive, buzzer alarm and other components, and the specific composition is shown in Fig. 2.

3.2. Control of electronically controlled cooling system based on automotive engines

The temperature value of the electronically controlled cooling system for automotive engines is set as the setting value of the whole system. Then, the actual temperature detected by the NTC temperature sensor is compared with the set value [14]. And the comparison result is input to the PID temperature controller. In order to control the deviation between the two PWI output signals, the controller changes the fan and adjusts the measured parameters, so it always changes the direction of the set value. Figure 3 is the system's control schematic diagram.

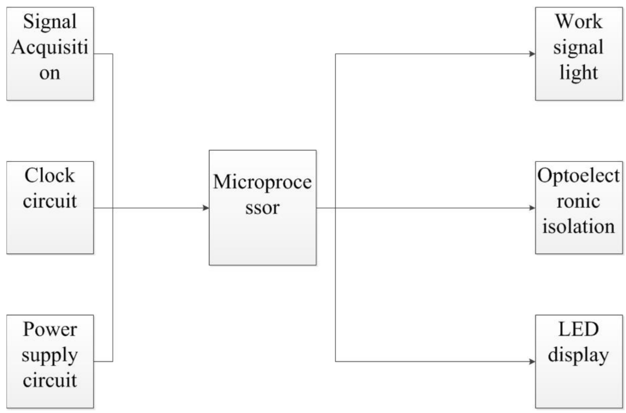

Fig. 2. Composition of intelligent control system

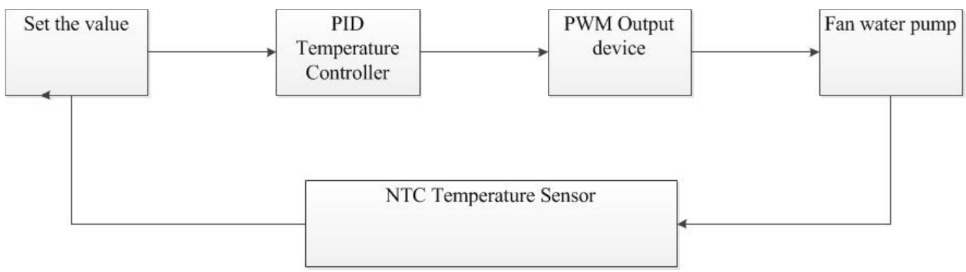

Fig. 3. Composition of intelligent control system

As the NTC temperature sensor conducts the real-time monitoring on water's temperature changes, and feedback back to the controller for the real-time comparison, so that the set temperature and the actual water temperature can be closely linked, therefore, the system constitutes a negative feedback closed-loop control system [15]. This method can not only change the controlled parameters quickly, but also conduct the corresponding adjustment, combines the PID control algorithm and PWM output mode, so as to improve the control accuracy, and the temperature control system adopts a wider control method. In a variety of electromechanical systems, the DC motor has good start, braking and speed control performances. Besides, the DC speed control technology has been widely used in in all aspects of the industry, aerospace fields. The most commonly used direct current speed control technology is pulse width modulation (PWM) DC speed control technology, which has high precision, fast response, wide speed range, wear and other characteristics. Through the pulse width modulation (PWM) control motor armature voltage, DC motor speed expression is

$$n = \frac{U - IR}{K\Phi}, \tag{1}$$

where n denotes the revolutions per time, U is the voltage, I denotes the current, R stands for the resistance, Φ is the magnetic flux and K is a constant.

The vast majority of DC motors use the switch drive mode. The switch drive mode allows the semiconductor power device to be in a switching state, then, the motor armature voltage is controlled by pulse width modulation (PWM), so as to achieve the required speed.

3.3. Software design of electronically controlled cooling system based on automotive engines

The control software of the electrically controlled system of the automotive engine adopts the modular structure design, and each function block is independent, which needs to be expanded in accordance with needs. In the structure, the software is composed of the main program, interrupt procedures and multiple subroutines. The first order subroutine is: interrupt service subroutine, A/D sampling subroutine, digital filter subroutine. The second order subroutine is: temperature setting subroutine, table conversion subroutine and operation subroutine. The third subroutine is voltage checklist subroutine, checklist subroutine, delay subroutine. The specific features are shown in Table 1.

Table 1. Modular structural design components

First order subroutine	Interrupt service subroutine, A/D sampling subroutine, digital filter subroutine, digital Pm regulator subroutine, PWM output subroutine, alarm subroutine
Second order subroutine	Temperature setting subroutine, table conversion subroutine, operation subroutine, BCD code conversion subroutine, display subroutine
Third order subroutine	Voltage checklist subroutine, temperature checklist subroutine, LED checklist subroutine, delay subroutine

In the real-time control of the system, the microprocessor is calibrated at regular intervals, and the interval is called the sampling period. In each sampling period, the controller performs sampling and coding of continuous signals and digital operations according to the control law, and then, it enters into a continuous signal by converting the results of the output register into a decoder digital signal (that is, PWM conversion process). Through the NTC sensor and temperature acquisition circuit, the temperature signal converts the physical signals into electrical signals, and then, converts them into digital by A/D. The voltage signal is converted to a temperature value by scale. Besides, the AD-CMP-CON operation is used to define analog input pins and digital I/O pins. Then, the ADPD bit that is 1 is set to start sampling; turn on or off is based on needs; ADR is set to start AD conversion; and the conversion result is read from ADDATA; the interrupt flag bit ADIF is cleaned up, and before the next sampling, two time intervals need to be waited at least.

For analog signals, especially flow, pressure, component content and other processes, there should be a better digital filter. For example, in winter, the engine's cooling water temperature is higher, while the cooling water temperature in summer is lower. The system provides a possible support for the user to set the cooling water temperature. The keyboard interrupt is the highest priority, which is the need for real-time man-machine exchange. When the key is pressed, the system executes the critical interrupt subroutine from the currently executing program. Delaying 10 seconds is to get rid of the tremble, so as to avoid the wrong operation of the button. This is a commonly used switch signal software anti-jamming measures. If the key is pressed, the INTO interrupt subroutine is executed. Pressing the button once displays the currently set temperature value and flash. Pressing the button again, the circulation can be set accordingly at the same time of setting the value and the flash next time. When the key is pressed for 3 seconds, the flashing temperature value is stored in the program and the target value of the system is considered. At the same time, returning to the main program interrupts, before continuing to interrupt the program, the digital tube at this time can display the current measured temperature value.

4. Result analysis and discussion

According to the parameters obtained, the operation was carried out in the speed control system, and the control effect was observed. If the control effect could not meet the control requirements, based on the following principles, the parameters could be adjusted according to the following rules. Increasing the scale coefficient K_{p} would speed up the system's response speed, but the system would produce a large overshoot, or even produce oscillation. Then, increasing the integration time T_{i} was conducive to reducing overshoot, reducing oscillation and making the system more stable; however, the system transition time was also increased. In addition, increasing the differential time constant T was helpful to speed up the response of the system, so that the overshoot was reduced and the stability was increased. However, the system's ability to suppress the disturbance was weakened and the response to the disturbance was more sensitive. The calculated KI values were placed in the simulation model, as shown in Fig. 4.

In the transfer function of the zero-order holder, T was the sampling period. Based on the above principle, in the PID control system model, the target value of $80\,^{\circ}\mathrm{C}$ and the simulation time of 2000 seconds were input, then, the PID parameters were gradually adjusted, particularly $T = 3.36\,\mathrm{s}$, $K_{\mathrm{p}} = 1\,\mathrm{s}$, setting 002, $KI = 0.008\,\mathrm{s}$. The digital PID control parameter adjustment task was to determine the parameters of the digital PID. For simple control systems, these parameters could be determined by using theoretical calculations. However, due to the complexity of the speed control system of automotive engines, the mathematical model was not very accurate. In this paper, the extended critical grading method was used to adjust the parameters, and the final PID parameters were obtained by combinatorial empirical method.

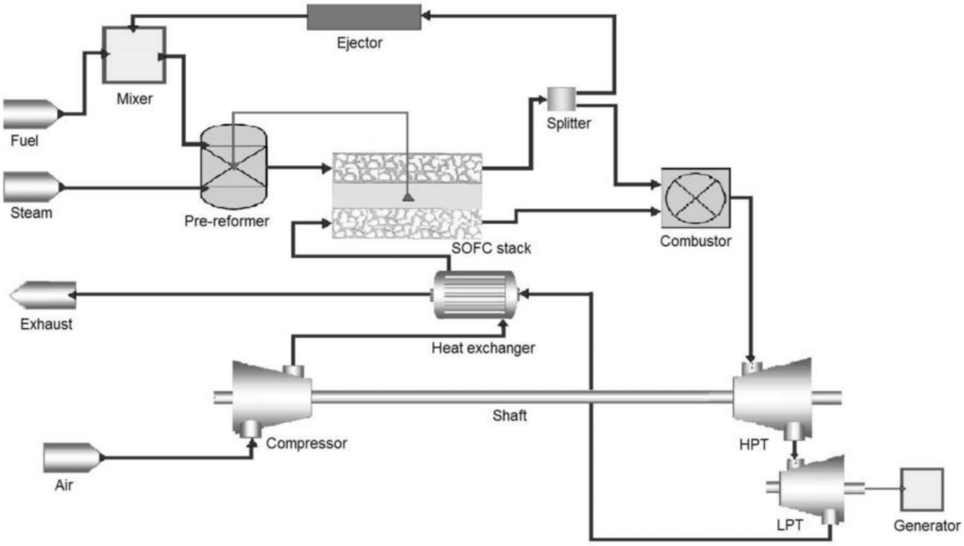

Fig. 4. Simulation model diagram of PID control system

In the digital control system, the sampling period was a more important factor, and the selected sampling period should be considered with the PID parameters. Firstly, the sampling period was selected to meet the following requirements: far less than the object disturbance cycle; much smaller than the time constant; try to shorten the sampling period, improve the quality of supervision. In this system, the PID regulation control process was completed in a periodic interrupt state, so the size of the sampling period must ensure that the interrupt service routine operated normally. Without affecting the operation of the interrupt program, the sampling period $T = 0$ (T being the vehicle engine's pure delay time) was adopted.

Determination of the critical oscillation period: when the digital PID parameters were initially determined, the differential control function and integral control function of the digital controller in the PID control circuit of the speed control system were eliminated, and the condition was the sampling period. The oscillation period and the critical scale factor K_{s} of the system were determined by using a proportional adjustment link (shown in Fig. 5). The proportional coefficient K_{p} was automatically controlled by the microcontroller system and it gradually increased.

It could be seen from Fig. 5 that the critical ratio K_{s} was decreasing, and finally, it tended to zero illimitably. Control degree was based on analog adjusters, then, the quantitative measurement of digital control systems and analog adjusters could achieve the synthesis of control effects of the same object. Control effect was to use a certain integral criteria, and then, the response was conducted in accordance with the system specified input. As mentioned before, the length of the sampling period would affect the control quality of the system, both the two were best tuning, while the quality of the digital control system was lower than the control quality of the simulation system. In other words, the control degree parameter was always

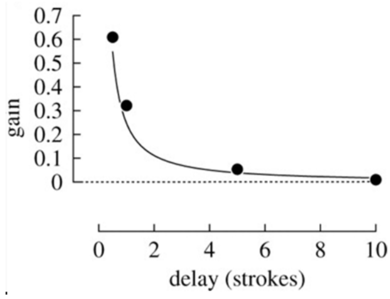

Fig. 5. Parameter change curve

greater than 1, and the greater the control degree was, the worse the quality of the corresponding digital control system was.

5. Conclusion

Conventional cooling systems often cause the phenomenon of the temperature imbalance in the cold start of the engine. In this paper, in view of the existing shortcomings of the automobile engine cooling system, the microcomputer and advanced control method were proposed to control. According to research the cooling system, it is proposed to use electromechanical control method for control. Then, through the test, research, design and simulation of the control system, the operation system based on the electrically controlled cooling for automotive engines was successfully designed. Firstly, the purpose and significance of the research were discussed, and the significance of controlling the engine coolant was described. Then, the research status of the engine cooling system at home and abroad was introduced, the problems in this field were analyzed, next, the factors affecting the cooling system were analyzed, the overall structure and hardware circuit of the cooling system were devised. This article can provide some relevant theoretical basis for motor engineers of the automobiles. Due to the limitation of time and my personal ability, there are still some shortcomings in this paper. For example, the computer in this control system is independent, which neither communicates with the engine and chassis control computer, nor conducts the centralized control on the system and other control systems of the vehicle by using the computer.

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