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Research and Structural Optimization of Heat Dissipation Performance of Plate-Fin Heat Exchanger

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Abstract

Aiming at the problem of high oil temperature in a certain engineering machinery transmission system, a method to improve the heat dissipation performance of the heat exchanger by improving the internal structure of the heat exchanger is proposed, which makes it work in the normal temperature range. Based on the Colburn analogy equation and the fluid force balance equation, the influence factors of the heat dissipation performance of the water passage in the heat exchanger are analyzed. It can be seen that the cross-sectional area of the fluid passing through the fins is the most important factor affecting the heat dissipation performance of the heat exchanger. Comparing the heat dissipation performance before and after the improvement of the heat exchanger structure, the result shows that the heat dissipation power of the heat exchanger is increased by 18.3% ,and the oil temperature of the engineering machinery power transmission system is reduced by 19%,which effectively solves the problem.

Keywords: Heat exchanger; Colburn analogy equation; Structural optimization; Heat dissipation performance

Introduction

As a heat exchange device, heat exchangers are widely used in many fields such as automobiles, electrical and electronic equipment and engineering machinery [1-3]. The working environment of construction machinery is harsh, and its working time is very long. A good cooling system is a prerequisite for ensuring that the construction machinery works in the optimal temperature range, and the high temperature of the hydraulic oil caused by the failure of the heat exchanger is one of the factors that frequently cause the failure rate [4-5]. The heat exchanger is an important part of the cooling system in the power transmission, and its heat dissipation performance has an important influence on the oil temperature.

At present, the research on the heat dissipation performance of the heat exchanger is mainly on the external conditions and internal structure of the heat exchanger. The study of the external conditions of the heat exchanger is mainly in the aspects of atmospheric pressure, air density, fins gap and wind scooper [6-9]. In the study of the internal structure of the heat exchanger, part of the study is the analysis of the influence of internal structural factors on the heat dissipation performance [10-12], and the other part is to improve the heat dissipation performance by optimizing the internal structure [13-15].

In this paper, the oil temperature of a certain construction machinery transmission system is taken as the research object, and the internal structure is improved on the basis of the analysis of the influence factors of the plate-fin heat exchanger used. Through the improvement of the internal structure, the heat dissipation performance of the heat exchanger is improved, the oil temperature and heat balance point of the mechanical transmission system is lowered, and the problem of high oil temperature is effectively solved.

Problem and Test

When the ambient temperature is about 25**°C**, the oil temperature rises gradually after one hour of operation, and the maximum temperature exceeds 130**°C**, which is higher than the design requirement of 110**°C**. After inspection and testing, it can be known that:

1. The air flow of the water tank meets the design requirements.

2. No wear points are found between the key components, and there is no interference between the brake mechanisms.

3. The water circulation in the engine is parallel with the heat exchanger, the inlet water temperature of the heat exchanger is maintained at 90±1°C.

4. The water flow meets the requirements.

5. The inlet and outlet pressure of the torque converter meets the standard value, the internal leakage flow is less than 5L/min.

6. The temperature of other parts of the machine is not high.

Under the condition that the test conditions are consistent with the working conditions of the construction machinery, the heat dissipation performance of the heat exchanger was tested. The test is shown in Figure 1 and the data is shown in Table 1.

Figure 1: The diagram of heat dissipation performance test of the heat exchanger.

Table 1: Heat exchanger heat dissipation performance test data.

Parameter	Inlet	Outlet	Flow	Power
Water	90.36°C	93.56°C	210.69 L/min	47.19 kW
Oil	110.9°C	104.3°C	235.82 L/min	46.51 kW

According to the above data, the heat dissipation power of the heat exchanger is about 46.5kW, which is less than the theoretical design requirement of 50kW. Therefore, the heat dissipation performance of the heat exchanger needs to be improved.

Modeling and Analysis

The internal structure of the heat exchanger used in this paper is shown in Figure 2, where A is the water inlet, B is the water outlet, the side is the two oil inlet ports, the b side is the two oil outlets, and c is the partition

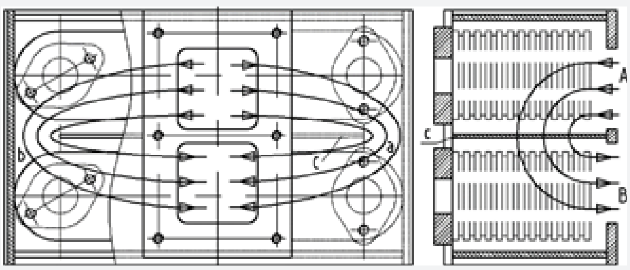

Figure 2: Heat exchanger cross-sectional structure.

There are many factors affecting the heat dissipation performance of the heat exchanger, including the number of fins and its internal structure, the overall layout of the fins, the water flow direction and the contact area between oil and water. The heat transfer coefficient equation (1) of the cold fluid passage is analyzed while maintaining the total fin structure.

$$K_c = \frac{1}{\frac{1}{h_0\eta_0} + \frac{R_0}{\eta_0} + R_w + R_i(\frac{A_0}{A_i}) + \frac{1}{h_i}(\frac{A_0}{A_i})} \quad (1)$$

Where K_c denotes the total heat transfer coefficient of the cold fluid channel, h_0 denotes the heat transfer coefficient between the cold fluid and the wall surface. hi denotes the heat transfer coefficient between the hot fluid and the wall surface, R_i denotes the thermal resistance of cold fluid fouling, R_0 denotes the thermal resistance of hot fluid fouling, R_w denotes the wall thermal conductivity, A_0 denotes the total surface area of the rib side, A_i denotes the ribless side surface area, η_0 denotes the total efficiency of the ribs.

Under the condition that the structure of the outer shell of the heat exchanger, the thermal fluid and outside the fin remain unchanged, h_i, R_i, A_0, A_i and η_0 can be regarded as constant. When R_0 is equal to 0.000176 m²•°C/W, the equation (1) can be simplified.

$$K_c = \frac{1}{\frac{1}{h_0} \times C_1 + C_2} = \frac{h_0}{C_1 + C_2 \times h_0} \quad (2)$$

Where $C_1 = 1/\eta_0$, $C_2 = 0.000176C_1 + R_w + R_i A_o/A_i + A_0/h_i A_i$.

The Colburn analogy equation is shown in equation (3):

$$St_x \times P_r^{2/3} = \frac{C_f}{2} \quad (3)$$

Where St_x denotes Stanton number, Pr denotes Prandtl number, Cf denotes the coefficient of fluid friction.

$$St_x = \frac{h}{\rho c_p \mu_\infty} \quad (4)$$

Where h denotes the heat transfer coefficient, ρ denotes the fluid density, cp denotes the fluid equal pressure specific heat capacity, and μ∞ denotes the fluid mainstream speed.

The wall shear stress equation is shown in equation (5):

$$\tau_w = C_f \frac{\rho\mu_\infty^2}{2} \quad (5)$$

Based on equations (3), (4) and (5), it is known

$$h = \frac{c_p \times \tau_w}{\mu_\infty \times P_r^{2/3}} \quad (6)$$

Taking the fluid between the fins of the heat exchanger as the research object, the force balance equation is established.

$$\tau_w \times A_w = \Delta P \times A_c \quad (7)$$

Where A_w denotes the heat dissipation area of the heat exchanger fins, △P denotes the pressure difference between the fin inlet and outlet, and A_c denotes the effective sectional area which the fluid passes between the fins.

Equation (8) is obtained by the equations (2), (6), and (7).

$$K_c = \frac{A_c}{C_1 \times \frac{A_w \times \mu_\infty \times P_r^{2/3}}{c_p \times \Delta P} + C_2 \times A_c} \quad (8)$$

When the water temperature is 90**℃**, cp is equal to 4199 and Pr is equal to 2.03. According to the structure of figure 2 and its related parameters, it is known that △P is equal to 106Pa, Aw is

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equal to 6 m^2, and h_0 is equal to h. Assuming that **μ∞** is a fixed value, equation (9) can be obtained on the premise that the heat exchanger water flow, fin structure and gap remain unchanged.

$$K_c = \frac{A_c}{C_3 + C_2 \times A_c} \quad (9)$$

Where $C_3 = C_1 A_c (\tau_w \Delta p)_r^{2/3}$ $_p$.

The relationship between K_c and A_c is shown in figure 3. According to formulas (5) and (7), A_c is proportional to $\boldsymbol{\tau}_w$, It can be seen from Figure 3 that increasing A_c can effectively improve K_c within a certain range.

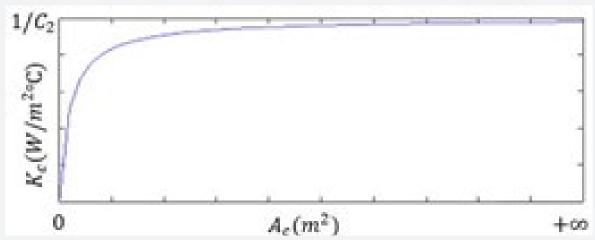

Figure 3: Relationship diagram between K_c and A_c.

Structural Improvement and Verification

The internal structure of the heat exchanger is improved while maintaining the heat exchanger outline structure, the original fin structure and the installation position unchanged. The improved structure is shown in Figure 4. It can be seen that the structure can effectively increase the effective area of fluid passage between the fins.

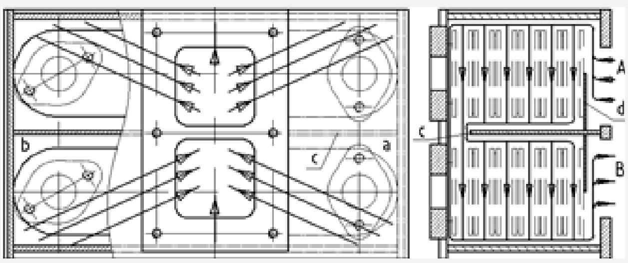

Figure 4: Improved heat exchanger cross-sectional structure.

Table 2: Improved heat exchanger heat dissipation performance test data.

Parameter	Inlet	Outlet	Flow	Power
Water	90.3℃	94.1℃	210.03 L/min	55.87 kW
Oil	110.22℃	102.4℃	235.72 L/min	55.01 kW

The experimental conditions for the performance test of the heat exchanger are the same as in section 2. The heat dissipation performance data of the improved structure is shown in Table 2. The heat dissipation power is increased from 46.51kW to 55.01kW. The heat dissipation power is increased by 18.3%, which satisfies the design requirements. At the same time, the improved heat exchanger was tested by operation, and the oil temperature of the transmission system was reduced from 130℃ to 105℃, which effectively solved the problem.

Conclusion

Based on the analysis of the influence factor of the heat transfer coefficient Kc of the cold fluid passage, it can be seen that increasing the cross-sectional area Ac of the cold fluid passage can effectively improve the heat transfer coefficient Kc of the cold fluid passage, which has engineering application value for the optimization of the heat exchanger structure.

The heat dissipation power of the improved heat exchanger is increased by 18.3%, and the oil temperature of the engineering machinery transmission system is reduced by 19%, which satisfies the use in the normal temperature range and solves the major problem.

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