Heating Analysis in Constant-pressure Hydraulic System based on Energy Analysis

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Abstract. Hydraulic systems are widely used in industrial applications, but the problem of heating has become an important reason to restrict the promotion of hydraulic technology. The high temperature, will seriously affect the operation of the hydraulic system, even cause stuck and other serious failure. Based on the analysis of the heat damage of the hydraulic system, this paper gives the reasons for this problem, and it is showed by the application that the energy analysis can accurately locate the main reasons for the heating of the hydraulic system, which can give strong practical guidance.

1. Introduction

Hydraulic system has a small size, compact structure, smooth transmission, bearing capacity and overload protection and other characteristics, so it is widely used in the industrial field. But with the increasing temperature of hydraulic oil, the hydraulic system will increase the leakage, making the control accuracy and stability affected, which has become an important reason for the restrictions of hydraulic technology[1]. Therefore, it is important to strengthen the analysis of the reasons for the heating of the hydraulic system, accurately locate the heat source and control the oil temperature in the allowable range. However, the causes of the heating of the hydraulic system are complex and difficult to exclude, which will consume a lot of time and energy. In this paper, the energy analysis method is used to analyze the reasons for the heating of the hydraulic system.

2. The damage of the heating of hydraulic system

The normal work of the hydraulic system will be seriously affected by oil temperature rise, especially exceed the allowable temperature, which perform mainly in the following areas:

2.1. Reduce the viscosity of hydraulic oil

The viscosity of hydraulic oil is very sensitive to the temperature change. The cohesion between the molecules decreases when the temperature rises, making the viscosity decreases. According to the hydraulic oil "viscosity- temperature curve", the higher the temperature is, the lower the viscosity is. A decrease in viscosity will lead to a series of problems in the hydraulic system, such as increased leakage, reduced volumetric efficiency of the pump, decreased movement speed of the actuator, reduced accuracy of the motion control and poor stability [2].

2.2. Shorten the service life of hydraulic oil

High temperature will lead to increased oxidation of hydraulic oil, making the hydraulic oil gradually generate some ketones, acids and glial, asphaltene and other substances, which can pollute hydraulic oil, resulting in deterioration of hydraulic oil. The hydraulic oil can not be used when it has been oxided to a certain extent.

2.3. Accelerated aging of rubber parts
A large number of rubber parts are used in hydraulic system, such as the seals of various types of valve and joints, and system hose. The performance of rubber parts will change when the oil temperature increases. The life of the rubber parts will be affected if they are working in high temperature for a long time, making accelerated aging or even deterioration. According to statistics, when the oil temperature is high, rubber parts life will be reduced by half if the temperature rise 10 ℃ each [3].

2.4. Failure of hydraulic component
Due to the different coefficients of thermal expansion of different hydraulic components, the oil temperature rise will lead to changes in the gap between the two components, making the gap become smaller, even causing jamming, which results in malfunction , failure action or other failures.

3. The reasons for the heating of hydraulic system
Hydraulic system provide actuators with power, which is composed of pump, reversing valve, relief valve, hydraulic cylinder, accessories, piping and other components. The fundamental reason for the rise of hydraulic oil temperature is the large power loss, because most of the power loss will translate into the form of heat, which making the oil temperature rise. The main reasons for the heating of the hydraulic system are as follows:

3.1. Power loss of pump
The pump is responsible for providing hydraulic users with oil that meets the required pressure and flow. The power loss of the pump is mainly due to the following two aspects because of the mechanical friction and volume loss:

Mechanical power loss: $W1 = P \times Q \times \frac{1-\eta}{\eta}$ （1）

Where: P-pump output pressure
Q-pump output flow
η-pump mechanical efficiency

Volumetric power loss: $W2 = P \times Q \times \frac{1-\alpha}{\alpha}$ （2）

Where: P-pump output pressure
Q-pump output flow
α-The volumetric efficiency

Power loss of pump : $W0 = W1 + W2$ (3)

It can be seen from the formulas (1), (2) and (3) that when the mechanical efficiency or volumetric efficiency of the pump decreases, the power loss will increase, resulting in the heating of the hydraulic system.

3.2. Power loss of function valve
Hydraulic system has a large number of different function valves, such as the reversing valve, throttle, check valve, etc. There is a certain pressure drop between its inlet and outlet ports due to the existence of fluid resistance of the valve. The power loss of each valve is as follows:

$W3\text{n} = \Delta P\text{n} \times Q\text{n}$ （4）

Where: $W3n$ -the power loss of the nth valve
ΔPn - The pressure drop between the inlet and outlet ports of the nth valve
Qn - the flow through the nth valve

Total power loss of hydraulic function valve: $W3n = W31 + W32 + \cdots\cdots + W3n$ （5）

Where: n - hydraulic function valve number

It can be seen from the formula (4), (5), when the valve body diameter is too small or in clogging condition, the valve flow resistance will increase, making the pressure drop between the inlet and outlet ports increase, resulting in large power loss, exacerbated the heating of the hydraulic system.

3.3. Power loss of safety valve

The safety valve is installed in the outlet port of the pump and is installed in parallel with the hydraulic main circuit. When the pressure exceeds the allowable value, the safety valve opens and can play the role of overflow, in order to protect the pump and other equipment from being damaged. In normal operating conditions, the safety valve is in the closed state, making no flow go through, so there is no power loss. However when the system pressure is too high or the safety valve pressure set unreasonably or even the safety valve malfunction, a lot of pressure oil will go through the safety valve, resulting in great power loss. The power loss of safety valve is as follows:

$$W4 = P4 \times Q4 \quad (6)$$

Where: $P4$ - the opening pressure of the safety valve
$Q4$ - the flow through the safety valve

3.4. Power loss of pipeline

Hydraulic oil need to overcome the resistance of the pipeline, so there is a part of the power loss. The power loss of pipe is as follows:

$$W5 = \Delta P5 \times Q5 \quad (7)$$

$$\Delta P5 = \frac{128 * u * Q5 * L}{\pi * d^4} \quad (8)$$

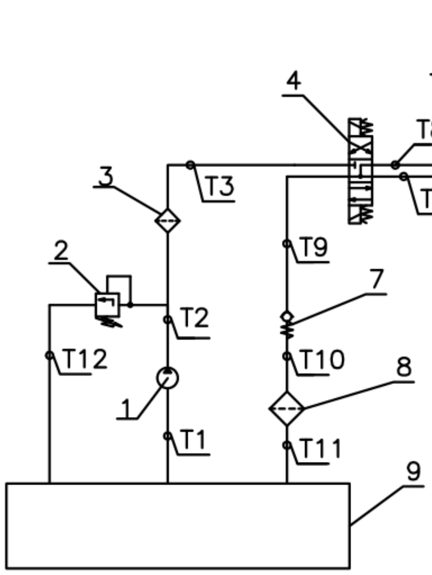
Where: u - Average speed of the oil passing through the pipe
L - the total length of the pipe
d - pipe diameter

It can be seen from the formula (7), (8), when the length of the pipeline is too long, or the pipeline diameter is too small, or the flow is too large, the pressure loss is relatively large, resulting in big power loss.

From the analysis of the reasons above, it can be seen that the amount of heat generated is related to the pressure and flow through the component, which means through measuring the pressure drop between the inlet and outlet ports and flow through the component, the power loss on the component can be calculated. If the loss exceeds the normal value, the component can be regarded as the main reason to cause excessive heat, that is, the use of energy analysis method to locate the heating source of the hydraulic system [4] [5].

4. Application

Figure 1 shows the hydraulic schematic diagram of a push-pull device. Its working principle is as follows: According to the characteristics of device, constant-pressure and variable-displacement pump and other equipment are used to build a constant pressure hydraulic system. constant-pressure and variable-displacement pump (1) is to provide hydraulic oil with constant pressure 9MPa.Hydraulic oil passes through the pressure oil filter (3), the reversing valve (4), one-way throttle valve unit(5), to promote the hydraulic cylinder (6) to the left movement. And the return oil pass through the reversing valve (4), back pressure valve (7), return oil filter (8), return to the tank (9). Changing the position of the valve seat can achieve reciprocating movement for the hydraulic cylinder. And the one-way throttle valve unit can adjust the speed of the hydraulic cylinder. Safety valve (2) set the opening pressure of 11MPa, playing the role of pressure protection.



1- constant-pressure and variable-displacement pump 2-safey valve 3-pressure oil filter
4- reversing valve 5- one-way throttle valve unit 6-cylinder 7-back pressure valve
8-return oil filter 9- tank

Figure 1 Schematic diagram of the hydraulic system

In the debugging period, a rapid temperature rise of the oil appeared, and the specific performance were as follows: the speed of the device was slow, which failed to meet the requirements. After running half an hour, the oil temperature had rose up to 80 °C, which affecting the normal operation of the device.

In this paper, according to the method of energy analysis, a total of 12 measurement points are set up on the system. T1 to T12 are used to measure the pressure value and flow. The test data are shown in Table 1.

Table 1 the pressure and flow values of T1 to T12

Measuring point	pressure （MPa）	flow （L/min）	Measuring point	pressure （MPa）	flow （L/min）
T1	0.05	86.5	T7	0.8	25.8
T2	7.8	83.5	T8	0.7	25.8
T3	7.5	51.7	T9	0.5	25.7
T4	7.2	51.5	T10	0.30	25.7
T5	7.0	51.5	T11	0.15	25.8
T6	6.2	51.5	T12	0.2	31.5

According to the data in Table 1, the operation of each component in the system is analyzed as follows:

4.1. Constant-pressure and variable-displacement pump

It can be seen from the data of measurement point T1 and T2, the pump suction port working pressure and flow are normal, and pump port flow is normal. The volumetric efficiency $\alpha = \frac{83.5}{86.5} \times 100\% = 96.5\%$, which is also normal, However the pressure of pump outlet port is only 7.8MPa, which has not reach the setting value of 9MPa. So the pump is considered to be in abnormal condition.

4.2. Pressure oil filter

It can be seen from the data of measurement point T2 and T3, the pressure drop is $\Delta P = 0.3MPa$, the flow is $Q = 51.7L/\min$. Compared with the sample manual, the pressure drop of the device is about 0.3MPa with this flow, so the pressure oil filter is considered to be in good condition.

4.3. Reversing valve
It can be seen from the data of measurement point T3 and T4, the pressure drop is $\Delta P = 0.3MPa$, the flow is $Q = 51.5L/\min$. Compared with the sample manual, the pressure drop of the device is about 0.3MPa with this flow. It can be seen from the data of measurement point T8 and T9, the pressure drop is $\Delta P = 0.2MPa$, the flow is $Q = 25.7L/\min$. Compared with the sample manual, the pressure drop of the device is about 0.2MPa with this flow. So the reversing valve is considered to be in good condition.

4.4. One-way throttle valve unit
It can be seen from the data of measurement point T4 and T5, the pressure drop is $\Delta P = 0.2MPa$, the flow is $Q = 51.5L/\min$. Compared with the sample manual, the pressure drop of the device is about 0.2MPa with this flow, so the one-way throttle valve unit is considered to be in good condition.

4.5. hydraulic pipe
It can be seen from the data of measurement point T5 and T6, the pressure drop is $\Delta P = 0.8MPa$, the flow is $Q = 51.5L/\min$, which means the pressure drop of the hydraulic pipe is too large, and should be regarded as an important reason for the hydraulic system heat. It is calculated that the fluid velocity through the pipe reaches 10.9 m/s , which has seriously exceeds the recommended flow rate range. Therefore, it is necessary to expand the pipe diameter to DN20.It can be seen from the data of measurement point T7 and T8, the pressure drop is $\Delta P = 0.1MPa$, the flow is $Q = 25.8L/\min$, which means the pressure drop of the hydraulic pipe is normal.

4.6. Back pressure valve
It can be seen from the data of measurement point T9 and T10, the pressure drop is $\Delta P = 0.2MPa$, the flow is $Q = 25.7L/\min$. Compared with the sample manual, the pressure drop of the device is about 0.2MPa with this flow, so the back pressure valve is considered to be in good condition.

4.7. Return oil filter
It can be seen from the data of measurement point T10 and T11, the pressure drop is $\Delta P = 0.15MPa$, the flow is $Q = 25.7L/\min$. Compared with the sample manual, the pressure drop of the device is about 0.15MPa with this flow, so the return oil filter is considered to be in good condition.

4.8. Safety valve
It can be seen from the data of measurement point T2 and T12, the pressure drop is $\Delta P = 7.6MPa$, the flow is $Q = 31.5L/\min$ .With the starting pressure setting to 11MPa, the safety valve should be closed when the pressure of pump outlet port is 7.6MPa, so the safety valve is in an abnormal condition, resulting in hydraulic system in high pressure overflow state, and the power loss is :

$$W = \Delta P \times Q = 7.6 \times 31.5 \div 60 = 3.99 \text{ kw}$$ 。

Combined with the phenomenon that the pressure of pump outlet port does not meet the expected value of 9MPa, the spring failure of safety valve is considered as the main reason. The overflow pressure has changed from 11MPa to 7.6MPa, so when the pressure of pump outlet port rise to 7.6MPa, the safety valve began to overflow, which make the pressure of pump outlet port can not increase, and a large number of oil with a high pressure overflow, resulting in oil temperature rise.

After the energy analysis above, the main reasons for the heating of the hydraulic system are as follows:

(1) the diameter of pipe between T5 and T6 is too small,

(2) failure of safety valve.

According to the phenomenon of heat, the safety valve has been dismantled, and find that the preload spring has been broken, so a new spring has been replaced. At the same time , the diameter of pipe between T5 and T6 has increased to DN20. After the rectification, the pressure of pump outlet port returns to 9MPa, and the speed meet the requirements. After long-term operation, the hydraulic oil reach the temperature equilibrium state, and the maximum temperature is 40 ℃, which means the hydraulic system failure has been eliminated, and the hydraulic system is in good condition.

5. conclusion

(1) In this paper, the energy analysis method is used to analyze the heating of the constant-pressure system to realize the evaluation of the technical status of the hydraulic components, and the heat source is found accurately, which has great application value.

(2) The heating value of the hydraulic element is related to the pressure drop and flow through the element. By measuring the relevant data and comparing with the sample data, the heat source of the hydraulic system can be accurately found.

(3) For constant-pressure system, the starting pressure of safety valve has to be set higher than the pressure of pump outlet port, otherwise there will appear high pressure overflow phenomenon, resulting in the system heating.

(4) Hydraulic pipe path with too small diameter, will cause greate pressure loss, easily lead to system heating, so a reasonable choice of pipeline diameter is very important.

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