Performance calculation of silicone oil fan clutch

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Abstract. This paper established the torque model of the cylinder head and end face of the silicone oil fan clutch under cylindrical coordinates. First, some correlation coefficients were determined based on the data of the corresponding device provided by the supplier, and then the model was used to directly obtain the performance curve of the fan at different inputs, speed and radiator outlet temperature conditions. The performance curves of the LE-040-Z670H-9 and LB-15.9X44-Z410W-7 silicone oil fan clutches are in line with the actual conditions, indicating that the established clutch mathematical model is correct and which provides theoretical support for designing the improved clutch.

1. Introduction

In the process of driving a car, in the face of different road conditions, the engine thermal load is different, and the requirements for cooling intensity are naturally different. Therefore, a fan clutch system is needed, which can automatically adjust the speed according to the needs of different cooling strengths, the silicone oil fan clutch is such a product. It can control the fan to run at different speeds to meet different cooling intensity needs, and has the advantages of energy saving and noise reduction. In-depth understanding of the working mechanism of silicone oil fan clutch, and constantly improve its performance, develop better performance products, improve the performance of the cooling system, improve the energy-saving effect of the car, and reduce the noise of the car, is the industry's engineers at home and abroad the goal that is pursued. In 1993, Wei Yuguan et al. [1] studied the problem of transmitting torque of silicone oil clutch, gave the calculation method, and analyzed the influence of oil quantity and silicone oil viscosity on clutch performance. Sun Jun [2] studied the influence of structural parameters on the performance of silicone oil fan clutches using computational analysis. Timothy C. Scott et al. [3] proposed a model for calculating the performance of a fan-viscous drive. First, some correlation coefficients were determined based on the data of the corresponding device provided by the supplier, and then the model was used to directly obtain the performance curve of the fan at different inputs, speed and radiator outlet temperature conditions. In 2009, Masatoshi Miyagawa et al. [4] performed numerical simulation analysis on the temperature and transmission torque of multiple wet clutches with radial and circumferential grooves, and studied the effects of radial and circumferential grooves for high durability, which provided guidance on the optimal design of the handling comfort wet clutch.

In this paper, two silicone oil fan clutches was taken as the research object, the transfer model of the clutch end face and the cylinder oil film, and the total torque model of the silicone oil fan clutch working chamber was established. The model was used to directly obtain the performance curve of the fan at different inputs, speed and radiator outlet temperature conditions. The performance curves of the LE-040-Z670H-9 and LB-15.9X44-Z410W-7 silicone oil fan clutches are in line with the actual
conditions, indicating that the established clutch mathematical model is correct which provides theoretical support for designing the improved clutch.

Model establishment: The silicone oil clutch transmits torque by the silicone oil, and the shape of the shearing working surface of the main and driven plates of the clutch is a rectangular groove, which is composed of an end face shearing surface and a cylindrical shearing surface. When the clutch enters the working state, the silicone oil will fill the gap of the shear plane. The torque transmitted by the oil film on the end face[5] between the shear radii $R_1$ and $R_2$ is $M_1:

\[
M_1 = \int_{R_1}^{R_2} dM_1 = \frac{1}{6h} \pi \mu \min \left( \omega_1 - \omega_2 \right) \left[ 3a_1 \left( R_2^4 - R_1^4 \right) + 4b_1 \left( R_2^3 - R_1^3 \right) \right]
\]  \hspace{1cm} (1)

$\alpha_1$ and $\beta_1$ are the fluid coefficient of the end face and $\alpha_2$ and $\beta_2$ are the fluid coefficient of the cylindrical shearing surface.

The cylindrical shear plane can be simplified as a cylinder with a radius of $r_1$ and $r_2$, which are respectively rotated at an angular velocity $\omega_1$ and $\omega_2$ around the $z$-axis. The inner wall of the outer cylinder and the outer wall of the inner cylinder are filled with silicone oil. The torque on the inner and outer cylinder walls is $|M_2|:

\[
|M_2| = \frac{2\pi L \mu \min \left( \omega_1 - \omega_2 \right)}{r_2 - r_1} + \alpha_2 \ln \frac{(a_2 r_2 + b_2) r_1}{(a_2 r_1 + b_2) r_2}
\]  \hspace{1cm} (2)

The silicone oil fan clutch working chamber can be divided into several end face shear surface transfer torque models and cylindrical shear surface transfer torque models. The total torque transmitted by the silicone oil fan clutch is:

\[
M_c = \frac{1}{15} \pi^2 \mu \min \left( \omega_1 - \omega_2 \right) \left\{ \sum_{i=1}^{N_1} \frac{1}{12h_i} \left[ 3a_i \left( R_2^4 - R_1^4 \right) + 4b_i \left( R_2^3 - R_1^3 \right) \right] + \sum_{j=1}^{N_2} \frac{L}{r_{2j} - r_{1j}} + \frac{a_2}{b_2} \ln \frac{(a_2 r_{2j} + b_2) r_{1j}}{(a_2 r_{1j} + b_2) r_{2j}} \right\}
\]  \hspace{1cm} (3)

2. Performance analysis of silicone oil fan clutch

The LE type silicone oil clutch is an excellent product that matches the Z670H-9 fan. The specific parameters are shown in Table 1. The LE-040-Z670H-9 silicone oil fan clutch is designed for an input speed of 2400 rpm, and uses 15,000 cP of silicone oil.

| Designed input speed(rpm) | Designed output speed(rpm) | Designed full separation speed(rpm) | Designed engagement temperature(℃) | Designed release temperature(℃) | Silicone oil viscosity(cP) |
|----------------------------|-----------------------------|-------------------------------------|-------------------------------------|----------------------------------|--------------------------|
| 2400                       | >2300                       | <1200                               | 52-58                               | 32-38                            | 1.5 Ten thousands±1%     |

Using the model established above, the performance of the LE-040-Z670H-9 silicone oil fan clutch is calculated, as shown in figure 1 ~ figure 4.
It can be seen from figure 1 to figure 3 that the LE-040-Z670H-9 type silicone oil fan clutch has a sudden change in slip when the input speed is about 4000 rpm, which causes the temperature of the silicone oil to rise sharply, and the viscosity of the silicone oil sharply decreases. The torque transmitted by the silicone oil clutch also shows a peak inflection point, and the transmitted torque is drastically reduced, as shown in Figure 4. These characteristics require a deep understanding in the design and development of silicone oil fan clutches. When providing silicone oil fan clutches to customers, the maximum engine speed must also be an important factor to consider.

Table 2 shows the design parameters of the LB-15.9X44-Z410W-7 silicone oil fan clutch. The LB type silicone oil clutch is matched with the Z410W-7 fan and uses 3050cP silicone oil.

| Designed input speed (rpm) | Designed output speed (rpm) | Designed full separation speed (rpm) | Designed engagement temperature (°C) | Designed release temperature (°C) | Silicone oil viscosity (cP) |
|----------------------------|------------------------------|--------------------------------------|--------------------------------------|-----------------------------------|---------------------------|
| 4000                       | >3150                        | <1300                                | 70±5                                 | 50±5                              | 0.305 Ten thousand±1%     |

Using the model established above, the performance of the LB-15.9X44-Z410W-7 silicone oil fan clutch is calculated, as shown in figure 5 ~ figure 8.
It is known from figure 5 to figure 8 that for the LB type silicone oil fan clutch, low viscosity silicone oil is used, and the working speed is higher than that of the ordinary silicone oil fan clutch, and the slip is also larger.

3. Conclusion

This chapter establishes the torque model of the cylinder head and end face of the silicone oil fan clutch under the coordinates. According to the established mathematical model, the performance calculation program of the silicone oil fan clutch is used for LE-040-Z670H-9 and LB-15.9X44-Z410W-7. The performance calculation analysis of the two silicone oil clutches shows the calculation results in the form of performance curves. It is clear that the maximum engine speed is also an important factor to consider when providing the fan clutch to the customer. The model for calculating the silicone oil fan clutch proposed in this paper can be used for product design and development of silicone oil fan clutch. When optimizing the design of multiple solutions, it can save a lot of improved design and experimental work and shorten the development cycle of silicone oil fan clutch.

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