Research on Oil Pump for Hybrid Transmission and Development of One-dimensional Simulation Model

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Abstract. In the context of reducing energy consumption, the theoretical research on the cycloid rotor pump for hybrid transmission is carried out, and the important design parameters of the existing pump are obtained by reverse mapping. The CAE technology is used to draw the rotor curve. Based on the AMESim platform, the oil pump simulation model is built. The development of the one-dimensional simulation model of the hybrid transmission oil pump is realized, which provides reference for subsequent design, optimization and research performance.

1. Introduction
The oil pump is the power source of the hybrid transmission hydraulic system. It mainly realizes the following functions: 1. cooling the motor; 2. providing sufficient pressure oil for the shifting components; 3. providing sufficient lubrication flow for all the gear shaft parts in the gearbox. In the design of the hybrid transmission, the oil pump should be satisfied: the volume should be as small as possible, the energy consumption should be as low as possible, the noise should be as small as possible, and the reliability should be as high as possible. This paper mainly discusses the related mechanism and the development of one-dimensional simulation model of the cycloidal rotor pump commonly used in hybrid transmission, which lays a foundation for studying the power loss of this type of pump in hybrid transmission.

2. Theoretical research of rotor pump
The cycloidal rotor pump is referred to as the cycloidal pump. The rotor tooth profile curve is complex. This section will derive the important structural parameters of the known pump based on the formation mechanism of the rotor curve and the internal and external rotor meshing theory.

2.1 Working principle
The cycloidal rotor pump is mainly composed of main components such as inner rotor, outer rotor, pump body, pump cover, sealing ring and bolt. As shown in Figure 1, when (a), the area of the A cavity is the smallest, and by counterclockwise operation, the A cavity is continuously enlarged, and when it is (d), the area of the A cavity reaches the extreme value, and the process is suction oil. Conversely, during (d) to (h), the area of the A cavity is continuously reduced, the pressure in the cavity is increased, and the working oil is discharged through the oil discharge port, and the process is delivery oil.
Figure 1. Cycloid rotor pump working principle.

2.2 Theoretical study of rotor curve

The internal rotor profile of the cycloidal pump is shown in Figure 2. Knowing the eccentricity a, the number of teeth Z, the base circle and the spheronization can be obtained. It is known that the spheronization is fixed to the point C on the spheron, that is, the creation circle, and the short oscillating line can be drawn. On this basis, the package is known. The circle is rounded to obtain the inner rotor profile curve, while the outer rotor is a partial arc conjugated to the inner rotor. Table 1 shows the basic design parameters of the rotor curve[1].

Figure 2. Cycloid rotor pump profile curve.

| **Known parameters** | Inner rotor teeth:Z1 | outer rotor teeth:Z2 | Eccentricity: a | Spheron:R | Creation circle:L |
|----------------------|----------------------|----------------------|----------------|---------|-----------------|
| **Calculation parameter** | Inner rotor pitch radius:r1 (Z1*a) | Generating coefficient:K (L/r2) | Inner rotor tip radius (L-R+a) | Outer rotor tip circle radius (L-R) |
| | Outer rotor pitch radius:r2 (Z2*a) | Arc diameter coefficient:h (R/r2) | Inner rotor root radius (L-R-a) | Outer rotor root radius (L-R+2a) |

The internal rotor profile curve equation can be derived by means of parametric equations or vector equations:

\[
X = L \cdot \cos (\phi_2 - \phi_1) - R \cdot \cos (\phi_2 + \theta - \phi_1) - a \cdot \cos (\phi_1) \\
Y = L \cdot \sin (\phi_2 - \phi_1) - R \cdot \sin (\phi_2 + \theta - \phi_1) + a \cdot \sin (\phi_1)
\]  

(1)

Where \( \phi_1 \) is inner rotor pitch angle, \( \phi_2 \) is outer rotor pitch angle, \( \phi_1, \phi_2 \) are satisfied: \( \phi_1 = r_2 \cdot \phi_2 / r_1 \), \( L \) is radius of creation circle, \( R \) is radius of envelope circle, \( \Theta \) is the angle between the straight line O2C and the normal PC of the cycloid, \( \Theta \) is satisfied:

\[
\frac{r_2}{\sin \theta} = \frac{L}{\sin(\pi - \phi_2 - \theta)}
\]  

(2)

Based on the CAE technique, a complete curve is obtained, where \( \phi_1 \) is rotated by \( 2 \times Z2 \times \pi \). According to a certain transmission oil pump, the parameters are obtained in reverse and the curve is drawn based on Creo software[2].
3. Simulation model construction

The one-dimensional model of cycloidal pump is established in AMESim (Amesim Modeling Environment for Simulation of engineering systems).

3.1 Speed output module

The speed output module provides the oil pump speed, which is the input speed of the inner rotor. At the same time, it converts the rotary motion into linear motion and outputs an angle change curve from 0° to 360°. The speed uses a signal module and outputs the speed as a change in angle via the control element. The internal conversion relationship of the control element is:

\[
\frac{d\text{output}}{dt} = k \cdot \text{input} \tag{3}
\]

Where \text{output} is output angle, \text{input} is input speed[3].

3.2 Tooth cavity module

The main idea of a rotor pump based on AMESim is to model the pump by simulating the volume change between the teeth and the resulting flow of liquid between the volumes. As shown in Figure 3, it is the shape of the corresponding angular cavity.

![Figure 3. Tooth Cavity.](image)

The relationship between the volume change of the tooth cavity and the volume change of the piston cavity is:

\[
A_dB = \frac{\pi D^2}{4}x \tag{4}
\]

Where \text{B} is the tooth width, \text{A_d} is the cavity area, \text{D} is the piston end face area diameter, and \text{x} is the piston displacement.

Calculated that \text{x} is satisfied: \text{x}=(744.7+676.5*\sin(\pi*(\text{x}-83.6)/192.8))/153.93804.

3.3 Tooth cavity module

The trend of the change of the area of the inlet and outlet and the change of the area of the tooth cavity is shown in Figure 4. Internal leakage is an important indicator of the gear pump, which directly determines the efficiency of the gear pump. In order to achieve sealing, the inlet and outlet ports cannot work at the same time[4].

![Figure 4. The trend of the change of the area of the inlet and outlet and the change of the area of the tooth cavity.](image)

3.4 Simplified model

As shown in Figure 5, in the model, the speed input, piston area change, inlet and outlet area changes are signal input, combined hydraulic components and mechanical components form the model of a single tooth. The internal rotor of a hybrid transmission oil pump has a total of 8 teeth. As shown in Figure. 6[5], The entire model has a tooth phase difference of 45° and the entire model is simplified by the super component function.
4. Simulation results

The output flow rate at 30°C, 50°C, 100°C, 879rpm, 1000rpm, 1143rpm, 1500rpm, 2000rpm were set, and the oil properties at different temperatures were set. The correctness of the model was proved by comparing experimental data with simulation data. Table 2 shows the oil properties, Table 3 shows the experimental data, and Figure. 7 shows the simulation results. The test conditions are 30°C, 50°C, 100°C, all of which are normal temperature conditions. Simulating the flow rate under extreme cold conditions of -30°C, and it is found that the output flow is insufficient at high speed. The model can predict the low temperature of the pump. The failure occurs underneath, and subsequent design optimization can be performed according to the model.

Table 2. The Oil Property.

| Temp. [℃] | Density [kg/m³] | Kinematic viscosity [cSt<=>mm²/s>] | Dynamic viscosity [mPa s] |
|-----------|-----------------|-----------------------------------|--------------------------|
| -20       | 870             | 1051.8                            | 1053                     |
| 30        | 840             | 44.4                              | 37.3                     |
| 50        | 828             | 21.0                              | 17.4                     |
| 100       | 798             | 6.0                               | 4.8                      |

Table 3. Experimental Data.

| Speed [rpm] | Temp. [℃] | Flow [L/min] 30 | Flow [L/min] 50 | Flow [L/min] 100 |
|-------------|-----------|-----------------|-----------------|-----------------|
| 879         | 30        | 9               | 8.8             | 8.4             |
| 1000        | 50        | 10.3            | 10.2            | 9.9             |
| 1143        | 1143      | 11.8            | 11.7            | 11.3            |
| 1500        | 1500      | 15.6            | 15.4            | 14.8            |
| 2000        | 2000      | 20.4            | 20.5            | 20               |
5. Conclusion

By comparing the flow simulation with the experimental data, it can be proved that the simulation model is built correctly, and the existing deviations need to be further optimized in the next step.

The simulation model is based on the AMESim simulation platform and is multi-domain joint simulation of signal domain, mechanical domain and hydraulic domain. The key of the simulation model is to convert the volume change of the tooth cavity into the volume change of the piston cavity. The change laws of the volume of the tooth cavity, inlet and outlet are all fitted through the mining point, and the deviations are caused by the signal input to the model. In the subsequent optimization, the input of the three signals can be the key. At the same time, the connection between the components of the AMESim platform is not only connected by external variables, but also contains internal implicit variables. When analyzing the characteristics of the oil pump, it can be used according to the demand parameters. Different components build the model to derive the demand parameters.

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