Analysis on the flow field of straddle monorail train gear box

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Abstract. Taking the gearbox of straddle monorail train as the research object, reasonable simplification of the geometric structure of the gearbox. Based on incompressible gas-liquid two-phase flow in gearbox, the overlapping grid technology in STAR-CCM+ software is used to solve the internal flow field of the gearbox. The effects of gear forward rotation and initial oil injection on the mass flow rate of lubricating oil in each bearing inlet / return hole in the gearbox are studied and analyzed. The results show that: with the increase of the initial oil injection rate, the mass flow rate of the oil inlet hole of each bearing increases; The positive and reverse rotation has a great influence on the mass flow rate of lubricating oil in each bearing intake hole. In the case of the same amount of oil injection, the mass flow rate of each intake hole in forward rotation is larger than that in reverse condition. The results of this research provide a theoretical basis for the detailed structure design and improvement of lubricating oil runner in gearbox.

1. Introduction

The gearbox of straddle monorail train is not only an important part of the bogie, but also the key equipment of train power transmission. When running at high speed, if the lubrication is poor, the high temperature and high pressure caused by the rolling of the bearing and the meshing of the gear teeth in the gearbox will cause wear, gluing and pitting corrosion between the bearing and the gear, affecting the service life of the gearbox and even affecting the safe and stable operation of the train[1].

At present, some scholars at home and abroad have carried out simulation analysis and research on the internal flow field of the gearbox. Ren Chonghui[2] simulated the internal flow field of the gearbox by VOF method, and analyzed the influence of eddy current in the gearbox on the fluctuation of lubricating oil. Yu Baoyi[3] and others use numerical simulation method to study the changing law of complex oil-gas two-phase flow in the gearbox. Through the comparison of the initial oil simulation results of different depths, we can know that the oil immersion depth of three times the tooth height can give full play to the role of lubricating oil. Zhou Chuanchao[4] used VOF to track the free liquid level, adopted PISO algorithm, and applied dynamic grid technology to study and analyze the effects of driving speed, gear forward and reverse rotation and oil injection on the instantaneous distribution of oil in the gearbox, the pressure distribution in the gearbox and the mass flow of lubricating oil in each bearing intake hole. John Vande Voorde [5] and others use Fluent software to calculate the internal flow field of the rotary volumetric pump and simulate the internal liquid flow. The existing research uses Fluent software to calculate the time, so it is difficult to achieve steady state. The internal flow field of the rotary volumetric pump is calculated, and the internal liquid flow is simulated. The existing research uses Fluent software to calculate the time, so it is difficult to achieve steady state.
Spatter lubrication is generally adopted in train gearbox[6]. The flow rate of lubricating oil is affected by main factors such as positive and reverse gear rotation and oil injection. In this paper, the STAR CCM+ software is used to analyze the influence of positive and reverse rotation and oil injection on the mass flow rate of lubricating oil in the inlet / return hole of the bearing.

2. STAR CCM+Software and overlay Grid Technology

The overlay grid technology is used in the STAR geometry CCM+, which has high computational efficiency. The overlapping grid (Overlapping Grid) divides the computing region into several relatively simple sub-regions to generate grids independently, and the flow field information of the overlapping region is matched and coupled by interpolation[10]. The oil stirring motion setting of the gear is completed by using the overlapping grid technology of STAR-CCM+ software. Create overlapping grid areas of 1 -, 2 -, and 3-axis large and small gears, and set their interfaces with the internal watershed as overlapping grids (zero gap). The overlapping grid area needs to completely wrap the corresponding gear, and because it is only responsible for information transmission, it can go slightly beyond the internal watershed area. The surface property of the wrapping gear is set as the overlapping mesh boundary, and the gear is set as the wall boundary, so as to simulate the oil stirring motion of the gear.

3. Calculation Model and working condition of Gearbox

3.1. Internal structure of gearbox

The internal section of the gearbox is shown in figure 1. The gearbox is a two-stage deceleration transmission, and the basic parameters of the transmission gear are shown in Table 1. When the train is running at high speed, the large bevel gear rotates at high speed, which makes the lubricating oil spatter and realizes the lubrication and cooling of the gearbox. In order to ensure the accuracy of the simulation results, combined with the structure and working principle of the gearbox, the three-dimensional model of the gearbox is reasonably simplified by using Solidworks to remove the small and non-important structural features such as fillets, chamfers and bolt holes, retain all the inner flow channels and bearings, and maintain the physical model as much as possible to truly reflect the internal fluid flow state of the gearbox.

Figure 1. Internal section model of gearbox

There are four gears and eight bearings in the three gear shafts inside the gearbox, as shown in figure 2. There are 7 oil intake holes and 4 oil return holes in the bearing cavity, including 3 oil intake holes on the motor side of the first shaft (no. 1j1, 1j2, 1j3 and 1h1, 1h2), one oil return hole on the rubber wheel side of the two-shaft bearing (No. 2h1), two oil intake holes (No. 2j1, 2j2) and one oil return hole (No. 2h2) on the brake side of the bearing 4 and 5, and 2 oil intake holes on the three shafts (No. 3j1, 3j2).
### Table 1 Main structural parameters of gear pair

| Gear parameters                     | driver | follower |
|-------------------------------------|--------|----------|
| Normal modulus/mn                  | 8      |          |
| Number of teeth/Z                  | 13     | 33       |
| Transmission ratio/i               | 2.538  |          |
| Addendum circle diameter/d. mm     | 121.56 | 267.05   |
| Axis angle/°                       | 90°    |          |
| Normal modulus/mn                  | 7      |          |
| Number of teeth/Z                  | 17     | 44       |
| Transmission ratio/i               | 2.588  |          |
| Addendum circle diameter/d. mm     | 150.62 | 351.78   |

3.2. Finite element Analysis Model and Computational meshing of Box flow Field

The inner watershed is extracted by enveloping processing. Because of the complex internal structure of the gearbox, the surface reconstruction model is selected. The gearbox internal watershed grid model is shown in figure 3. The initial grid has a total of 1106 2905 nodes, 3029 7870 internal faces and 1032 1060 cell grids, of which more than 96% of the meshes are of good quality and there is no negative volume grid.

When the gear rotates, it needs to exchange information, so the mesh in the meshing area is locally refined, and the local mesh in the meshing part of the gear is shown in figure 4. The clearance at the meshing point of the gear is small, which affects the generation and calculation of the mesh, so the method of increasing the clearance is generally adopted to solve the problem. In order to ensure the feasibility of the simulation, the large and small gears are reduced by a certain proportion at the same time without changing the basic parameters of the gear.
3.3. Calculated working condition
The simulation condition is shown in Table 2, in which the oil position and positive rotation are shown in figure 5, and vice versa.

Table 2. Simulation calculation conditions

| Working condition | Turn around | Driving speed km/h | Input shaft speed r/min | Oil injection volume/L |
|-------------------|-------------|--------------------|-------------------------|-----------------------|
| 1                 | F           | 70                 |                         | H                     |
| 2                 | Z           | 70                 |                         | h                     |
| 3                 | Z           | 70                 |                         | H                     |
| 4                 | F           | 70                 | 3035                    | h                     |

*2 Forward, 1 Reverse*

3.4. Boundary conditions and physical parameters setting

3.4.1 Rotational motion and field function
There are three rotation regions in the fluid region of the gearbox, and three sub-coordinates (Cartesian coordinate system) are established with the center of the 1-axis, 2-axis and 3-axis gear as the coordinate origin respectively. According to the simulation conditions, the corresponding rotation angular velocity and rotation direction of each gear and the overlapping grid region are set to realize the rotation of the gear, and the information exchange between the static domain and the rotation domain is realized by defining two sets of boundaries. The initial oil injection is set by the field function, the scalar field...
function is created and the liquid level height is set. The field function is defined as: $\{\text{Position}[1] < -0.222?1:0$.

3.4.2 Euler multiphase flow and gravity

The fluid in the gearbox is gas-liquid two-phase flow, the upper part is divided into air, and the lower part is divided into lubricating oil. The initial gas-liquid two-phase distribution of the gearbox is shown in figure 6.

Gravity is selected in the physical model, and the direction of gravity is-y after the model is imported, so the acceleration of gravity is loaded in the-y direction in the initial conditions: $9.81\text{m/s}^2$.

4. Flow field analysis and result discussion

The transient calculation method is used to calculate 8 turns of large bevel gear rotation ($0.401\text{s}$). After monitoring, the mass flow rate of lubricating oil in the inlet and return hole has reached a stable state. The mass flow rate of lubricating oil in the inlet and return holes of each bearing is shown in Table 3, and the mass flow rate in the reflux hole is ",", which means "reflux".

Table 3. Lubricating oil mass flow rate of each inlet / return hole under different operating conditions (kg/s, $10^{-3}$)

| working condition | 1(FH) | 2(Zh) | 3(ZH) | 4(Fh) |
|-------------------|-------|-------|-------|-------|
| 1j                | 1j1   | 1j2   | 1j3   | 1j4   |
| 1j                | 1.16245 | 4.43713 | 6.04808 | 0.40756 |
| 1j1               | 0.65394 | 1.27483 | 1.89653 | 0.24344 |
| 1j2               | 0.26891 | 1.40034 | 1.94107 | 0.06413 |
| 1j3               | 0.23958 | 1.76196 | 2.21048 | 0.09995 |
| 1h                | 1h1   | 1h2   | 1kz   | 1h1   |
| 1h1               | 12.5299 | -2.27976 | 11.2061 | 0.92924 |
| 1h2               | 6.26389 | -0.78431 | 5.53292 | 0.13914 |
| 1h2               | 6.26606 | -1.49545 | 5.67323 | 0.79010 |
| 2j                | 2j1   | 2j2   | 2h1   | 2h2   |
| 2j1               | 2.77235 | 4.79876 | 8.14710 | 0.61169 |
| 2j2               | 1.9884 | 1.91724 | 3.62067 | 0.23576 |
| 2j2               | 1.27351 | 2.88152 | 4.52642 | 0.37593 |
| 2h1               | -0.12685 | -0.22617 | -0.20497 | -0.13065 |
| 2h2               | -0.27505 | -0.88650 | -1.8354 | -0.07402 |
| 3j                | 3j1   | 3j2   | 3j1   | 3j2   |
| 3j1               | 0.42432 | 0.50937 | 0.88480 | 0.06874 |
| 3j2               | 1.60853 | 0.91143 | 0.96859 | 0.43962 |

An analysis of Table 3 shows the following results:

1. The positive and reverse rotation has a great influence on the mass flow rate of lubricating oil in each bearing inlet hole. In the case of the same amount of oil injection, the mass flow rate of each oil inlet hole in forward rotation is larger than that in reverse condition; in the case of the same rotation direction, the mass flow rate of each bearing oil inlet hole increases with the increase of oil injection rate.

2. Under working conditions 1, 3 and 4, the oil return of one shaft is higher than that of oil intake, indicating that some lubricating oil enters the bearing cavity through the gap between the three rollers of the one shaft bearing. There is a reflux phenomenon in the oil return hole in condition 2, compared with condition 2 and 3, it is known that the initial oil injection is less, the gear rotates positively, the outlet position of the 1-axis oil return hole is in the high pressure area, and the weight of the lubricating oil in the oil return hole is not enough to overcome the pressure at the outlet to form reflux. This is confirmed by velocity vector figure 7 and 1h return hole section pressure distribution figure 8.

3. 2j2 is the common oil intake hole of two shafts No. 4 and No. 5 bearings, and the mass flow is larger under each working condition, which is beneficial to the cooling and lubrication of the heat sources of the two bearings.
(4) The reverse flow occurs in the oil return hole of the 2 axis, as shown in figures 9 and 10. The pressure at the outlet of the oil return hole of 2h1 and 2h2 is higher than that in the bearing cavity, which leads to reflux.

5. Conclusion

- The flow field of the gearbox is analyzed by using STAR-CCM + software, and the calculation efficiency is high. The lubricating oil flow in the gearbox can be monitored in real time, the mass flow of lubricating oil in each inlet and return hole can be monitored, and the dynamic change law of oil velocity in the gearbox can be obtained, which lays a foundation for quantitative analysis of the influence of gears under different working conditions on lubrication effect.
- In the case of the same amount of oil injection, the mass flow rate of each oil intake hole is larger than that of the reverse condition; in the case of the same rotation direction, with the increase of lubricating oil, the flow speed of lubricating oil in the gearbox increases, and the mass flow rate of each inlet hole increases in varying degrees.
- The position of the oil return hole should avoid the fluid high pressure area as far as possible to ensure the smooth flow of the oil return and give full play to the lubrication effect of the oil.

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