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Design of Gear Churning Power Loss Measurement Device

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Abstract. To explore the impacts of gear churning power losses, a research was conducted to achieve the internal causes of power losses of churning gear by designing a gear churning power losses measurement device. The gear churning power losses could be influenced by different gear modules, the number of teeth and the axial position of gear. Finally, the impacts of gear churning power losses were discussed by comparing experimental data and theoretical data.

1 Introduction

At present, there is a complex relationship between gear churning power losses and some factors which include gear speed, the level of lubrication oil, lubrication oil viscosity and temperature. In addition, it is difficult to directly determine by theoretical analysis in which most of them are empirical formula. Thus, it is usually confirmed by carrying out experiments.

Research methods of load-independent power consumption were described by Seetharaman et al [4]. Furthermore, Seetharaman et al state that most of the previous calculation formulas are derived from the semi-empirical formula or the basis of the disk. Moreover, Seetharaman et al [5] claim that gear speed, the level of lubrication oil and tooth thickness can mostly influence churning power losses as a result of the method of gear churning experiment on a pair of spur gears which are submerged in oil bath. Also, they established the theoretical model and calculation formula of the churning losses of a pair of spur gears. The overview of classical literature on the power consumption of gear transmission was conducted by Valerity Stavytskyy et al [6]. They listed calculation formulas of spur gear, helical gear and bevel gear churning losses and windage losses, which were established by scholars during nearly half a century, so as to provide reference for future generations to understand and master the research content and direction of the load-independent power consumption. Yasutsune et al [7] conducted a research by using a flash frequency detector which aims to analyze and discuss the characteristics of churning losses. They indicated that the churning losses mainly consists of four parts: 1) Power losses are generated by the lubricating oil which is in accelerating gear; 2) Power losses are generated by lubricating oil which move in the meshing gear cavity; 3) Power losses are generated by lubricating oil splash in the pool; 4) When the lubricating oil come into meshing gear position, power losses are generated by bending lubricating oil. Changenet et al [8, 9] pointed out that most of the current gear churning losses formulas can be more precise calculate the churning losses that were generated in meshing gear or single disk, Petry-Johnson et al [10] obtained same calculation results by analysing the experimental data which is measured under different conditions. Kahraman et al. [5] claim that the churning losses is mainly divided into two parts: 1) When the gear is rotated, the power losses were caused by the movement of the lubricating oil stuck on the gear (This part includes three aspects: power losses were generated by interaction of the periphery of gear and lubricating oil; power losses were generated by interaction of the face of gear and lubricating oil; Scroll power losses were generated by lubricating oil in gear cavity); 2) When the gear is meshed, the gap between the two gears is changed and makes the oil being sucked and extruded which cause power losses. At present, the researchers are only conducted about the power consumption of single-stage gear or disk [11]. Boness [12, 13] has measured the drag torque of different size disks which stir in different level of the lubricating oil, compared to Karman's formula [14, 15] for calculating the churning losses and summed up the formula and method for calculating the drag torque of churning losses. In recent years, the churning power losses are concentrated by foreign countries in the helical gears, bevel gears and circular arc gears in the high speed transmission gear box [16, 17]. There is no relevant literature at home and abroad for the problem of churning losses of spur gears and helical gears in medium and low speed drives. The churning losses of gear transmission [18, 19, 20] mainly includes friction power losses, meshing gear power losses, friction power losses of

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bearing, lubricating oil power losses and so on. They are interacted which makes it impossible to draw a separate assessment of the churning losses. Churning losses are also known as the load-independent losses. Because of the uncertainty of the reasons for the churning losses, it is difficult to discuss it.

In response to these problems, a measuring device for churning losses will be designed and tested to infer the defect of the theory research. In addition, the churning losses can be measured. The aim of this research is to explicit the relationship between the churning losses and the gear modulus, the number of teeth and the axial distance of the gear and find ways to reduce the power consumption which in turn improve the energy efficiency.

2 Overall design

In order to discuss the influence of internal spur gear on the churning power losses, a measuring device for churning power losses is designed. As shown in Fig.1, 1 is oil tank, 1-3 temperature sensor, 1-4 oil inlet, 1-5 oil outlet, 2 churning gear, 3 single-axis actuator, including ball, guide bar, bearing block which fixes gear shaft, bearing block displacement monitor and rotation wheel. 4 gear shaft (1), 5 gear shaft (2), 6 coupling (1), 7 drive motor, 8 coupling (2), 9 motor load, 10 speed and torque sensor (1), 11 speed and torque sensor (2), 12-1 drip tube, 12-2 valve, 12-3 drums, 13-1 stents, 13-2 ball screw (2), 13-3 guide bar (2), 13-4 slider (1), 13-5 rotation wheel (2), 14-1 oil-dripping device, 15 cross-shaped mouth.

The rotational speed of drive motor is adjusted and controlled by a controller. A coupling is used to connect the drive motor to speed and torque sensor. It measures speed and torque of the drive gear by speed and torque sensor, a coupling is used to connected the load motor (9) to speed and torque sensor, it calculates the power losses by the parameters of the input and output speed and torque sensor. Under the same conditions of other parameters, through single-axis actuator changes the axial distance of two gear, it calculates the churning losses by the parameters of speed and torque sensor and bearing block displacement monitor to research the gear churning power losses on different axial distance.

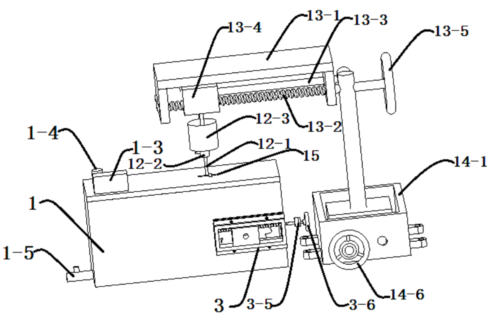

Figure 1. Measurement device.

3 Design of the tank

This gear churning power losses measurement device is mainly composed of gear, box, single axis actuator. As shown in Figure 1, the device comprises tank (1), two meshing churning gears (2) and a single-axis actuator (3) which is fixed on the side of rectangular track grooves in tank, One of the churning gear (2) is fixed on gear shaft (4) which is fixed on bearing block in single-axis actuator, another churning gear (2) is fixed on the tank (1) by gear shaft (5) and bearing block. A gear shaft (4) is connected to the output of drive motor (7) through coupling (6), the gear shaft (5) is connected to the output load motor (9) by coupling (8), while coupling (6) and coupling (8) respectively provided with speed and torque sensor (10), speed and torque sensor (11), it installs locking device inside of the rotation wheel on the ball to make that ball screw is not rotating while churning gear is rotating, drive motor (7) installs in the carriage which is moved with the moving of bearing block. A temperature sensor is fixed on the upside of the tank, which extends deeply into the oil of the tank. Oil port 1-4 is also fixed on the upside of the tank, and there is a port 1-5 on one side of the box, which is controlled by the valve. It sets a transparent surface on side of the tank (1) to observe the movement of the two churning gear. Single-axis actuator (3) is installed in the rectangular slot which is provided in the transparent surface of the tank (1) by four nuts.

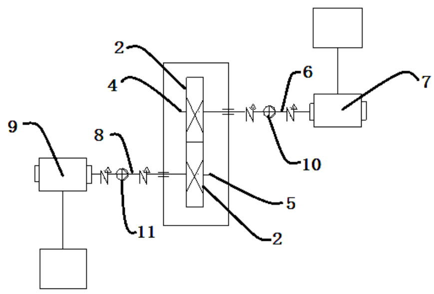

Figure 2. Overall device.

Temperature sensor measures the changing values of churning gear temperature, it injects lubricating oil though the oil inlet on the upside of the tank. The level of lubricating oil is adjusted by oil outlet on the side. It is easy to adjust the position of the oil pipe by the cross-shaped mouth which is installed on the upside of tank. Effect of axial distance on power consumption of gear can be measured by applying a single-axis actuator to adjust two axis distance of gear, measuring its change distance and calculating the power consumption of multiple sets of center distance of the meshing gear pair.

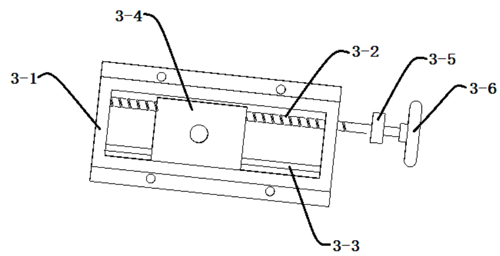

Figure 3. Single shaft drive.

4 Design of oil-Dripping device

Oil-dripping device is installed above the meshing gears, the oil-dripping device includes a drip tube 12-1

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which controls the speed of drip oil by a valve 12-2, the drum 12-3 is connected to the top of drip tube, the X, Y direction moving device adjust the position of drip tube 12-1 with the change of the meshing gear position. At the same time, the position of drip tube is adjusted with the change of the gear meshing points though the cross-shaped mouth which was installed on the top of the tank. the X-direction moving device comprises a stent 13-1 which includes ball 13-2 and guide bar 13-3, the slider were provided on the ball 13-2 and guide bar 13-3, on the side of ball 13-2 was installed a rotation wheel 13-5 while a slider 13-4 is fixedly connected to the top of the tank 12-3; The Y-direction moving device includes a base, ball and guide bar which are installed in the bottom, the slider (2) is installed on the ball screw (3) and guide bar (3), a pillar is vertically installed on slider (2), one side of the ball (3) installs a rotation wheel (3) while pillar and ball 13-2 are connecting to guide bar 13-3, the base is installed on the table by four nuts.

Gear meshing position is changed when measuring different gear modulus. Common churning device can not adjust the position of the drip tube. The device changes the X, Y direction position which is correspond with the change of meshing gear position by two drive devices, it reduces friction in meshing gear to reduce churning power losses.

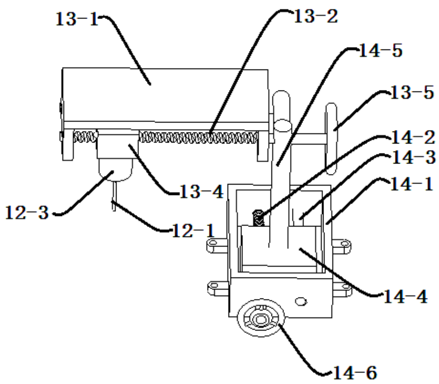

Figure 4. Oil-dripping device.

5 Testing principle of gear churning power losses measurement device

5.1 Experimental test methods

Controller adjusts the drive motor torque, motor load is adjusted by the speed controller.

The specific steps are as follows:

Power test points are respectively setting as $p_1 \ldots p_i \ldots p_j$, the speed of drive motor is setting respectively as $n_1 \ldots n_i \ldots n_j$;

At measurement point p_1, the speed of drive motor is setting as n_1, it maintains the drive motor which runs for some time at this speed to make that the input power of drive motor and the output power of the dynamometer motor keep stability. The input torque of drive motor is Tin-1, the output torque of dynamometer is Tout-1; then testing the input torque and output torque of the next point p_2, until all testing points p_1 ... p_i ... p_j are measured. Then, the input torque of drive motor is Tin-1 ... Tin-i ... Tin-j, the output torque of the dynamometer motor is Tout-1 ... Tout-i ... Tout-j;

Finally, gear churning losses of the test point p_i is:

$$P_i = \frac{(T_{out-i} - T_{in-i}) \times n_i}{9550} \text{ (i=1…m)} \qquad (1)$$

5.2 Theoretical calculation

The oil-churning power losses P_C consist of three parts: P_{c1} expresses stirring loss related to the outer diameter of the optical axis; P_{c2} expresses the churning losses with the two side of gear; P_{c3} expresses the churning losses related to the tooth surface (the outer surface of the two gears). It can be expressed by the following formula.

$$P_C = P_{C1} + P_{C2} + P_{C3} \qquad (2)$$

$$P_{C1} = \frac{7.37 f_g v n_i^3 D_o^{4.7} L}{A_g \times 10^{26}} \qquad (3)$$

$$P_{c2} = \frac{1.474 f_g v n_t^3 D_O^{5.7}}{A_g \times 10^{26}} \qquad (4)$$

$$P_{C3} = \frac{7.37 f_g v n_t^3 D_0^{4.7} B(\frac{R_f}{\sqrt{\tan\beta}})}{A_g \times 10^{26}} \qquad (5)$$

where f_g is gear submergence coefficient (under oil-injecting condition, f_g is set as 0; under full immersion condition, f_g is set as 1; under other circumstances, f_g has a value between 0~1 according to the height of immersion.); v is the kinematic viscosity of lubricating oil under working temperatures; n_i is the rotational speed of the ith gear; D_o is the size of the outer diameter of the ith gear; L is the length of shaft; A_g is a constant; B is the width of big gear or small gear; R_f is roughness factor, it is related to tooth size, it can be obtained by approximate formula:

$$R_f = 7.93 - \frac{4.648}{m_t} \qquad (6)$$

where Mt is Gear transverse module; β is helical gear spiral Angle, when $\beta \le 10^\circ$, $\beta = 10^\circ$.

5.3 Experimental data analysis method

- When the meshing gears are of same modulus, different tooth thickness and the other working conditions (working temperature, the level of lubricating oil, etc.) keep unchanged, the power losses of oil churning can be calculated by the following process:

The parameters used for calculating gear power losses P_i can be attained from speed and torque sensor (1), speed and torque sensor (2) and temperature sensor. Thus the value of gear power losses P_i can be easily calculated by Formula 1 and 2.

- The modulus of the meshing gears are different while the other parameters are equal.

Under this condition, the equation of centre distance of the meshing gear pair can be written as:

$$a = \frac{(d_1 + d_2)}{2} = (z_1 + z_2) \times \frac{m}{2} \quad (7)$$

where d_1 and d_2 respectively represent circle diameter of gear 1 and 2, z_1 and z_2 represent the number of teeth on the gear 1 and 2, m is gear modulus, the centre distance of two gears can be obtained by formula 7. Through Single-Axis Actuator adjusts the position of meshing gear, which is corresponding with the position of oil-dripping device, through the parameters of the sensor, it respectively calculates the churning power losses P_i by Formula 1 and 2.

- It changes the axial distance between two gears while the other parameters are equal. It measures the change parameters in different axial distance by speed and torque sensor and respectively calculates the churning power losses Pi by Formula 1 and 2.

6. Conclusions

The gear churning power consumption measuring device can easily measure the gear churning power losses in different modulus, different numbers of teeth and different gear axial distance. It respectively obtains experimental data and theoretical data by Formula 1 and 2. It obtains key factors which impact gear churning power losses by comparing and analysing these parameters. Then, it explores methods to reduce gear churning power losses.

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