Tribology performance analysis of oil for wet drive axle

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Abstract—In order to solve the problems caused by the use of common gear oil in the wet drive axle, such as abnormal braking noise, excessive braking distance and severe wear of components, the special oil for the wet drive axle is developed in accordance with the new requirements for lubricating oil after the technical upgrade of the drive axle. Based on the actual braking condition of the wet brake, the oil tribology performance of the wet drive axle is tested and studied by using the brake test bench and increasing the energy density to improve the harshness of the braking condition. The results show that the method can distinguish oil with different tribology performance. The developed oil is superior to the reference oil in formulating smoothness, stability and mechanical transmission efficiency, providing better friction retention over long periods of use.

1. INTRODUCTION

As the core driving part of the drive axle, the brake is used to adjust the speed and locate the stop when the vehicle is working and walking. Its reliability, sensitivity and abrasion resistance directly affect the operating performance and safety of the equipment. With the development of construction machinery towards higher power and tonnage, the dry brake drive axle can’t meet the needs of use. The development of new friction materials and sealing technology make the wet brake come into being.

In the wet drive axle, the friction plate is immersed in lubricating oil, the brake uses the shear force between oil film layers to transfer torque instead of the direct contact of the friction material[1], which not only makes the braking process smooth, the braking performance stable and the braking noise reduction but also greatly reduces the wear of friction materials, thus significantly increasing the service life. The change of the braking mode of the drive axle has higher requirements on the braking friction characteristic of the drive axle oil.
At present, ordinary vehicle gear oil is still used in construction machinery equipped with wet drive axle in China, which will cause abnormal braking noise, too long braking distance, short oil change cycle, serious wear of parts and other problems, including hidden safety risks and waste of resource. In order to ensure the safe, efficient and long-time operation of the wet drive axle, in view of the new requirements for lubricating oil after the technology upgrade of the drive axle, developed the special lubricating oil of the wet drive axle, focus on improving the tribology performance of the lubricating oil, for the rational selection of the wet drive axle oil and improve the product quality to provide an effective guarantee.

2. WET DRIVE AXLE OIL

An advanced gear oil of an international brand is used as the comparison oil, the developed wet drive axle oil and the comparison oil are tested for physical and chemical indexes, the result is shown in table 1. The two oils have the same kinematic viscosity. Compared with the conventional formula system of comparison oil with high S content, the developed oil has high content of Ca, Zn and P elements, that is, the content of the added extreme pressure antiwear agent is high.

Table 1. Comparison of physical and chemical properties of two oils

|          | 100°C Kinematic viscosity (mm²/s) | Element content(10⁻⁶) |
|----------|---------------------------------|-----------------------|
|          |                                 | S        | Ca     | Zn    | P     |
| developed oil | 14.07                           | 3780    | 3506   | 1323  | 1215  |
| comparison oil | 14.16                           | 14500   | 6      | 5     | 488   |

3. TRIBOLOGY PERFORMANCE ANALYSIS

At present, the research on the tribology performance of lubricating oil mainly adopts simulation tests for analysis[2-4], such as SAE J2487 based on SAE NO.2 friction testing machine, Caterpillar TO-4, Allison TES439, and ZF friction test method. Because of the differences between the test model and the actual brake in many factors, the test results can't truly reflect the tribology performance of oil in the brake. In addition, there is no test evaluation method for the tribology performance of the drive axle oil in the public standard at home and abroad. In combination with the actual braking characteristics of wet brake of construction machinery, this paper designs the brake bench to investigate the tribology performance of oil. The test parameters fit the actual braking conditions of the brake to meet the operating requirements, and finally obtains the tribology performance of drive axle oil in the brake.

3.1. Brake test bench

The tribology performance of oil during braking is measured by wet brake test bench. The schematic diagram of the test bench is shown in figure 1. The braking test is carried out by controlling pipeline pressure, initial braking speed, oil temperature, braking times and other parameters. Parameters such as initial braking speed, braking pressure (line pressure), output braking torque, temperature and braking time are recorded for each braking.

![Figure 1. Schematic diagram of wet brake test bench](image)

3.2. Test method

The braking process converts the kinetic energy of the vehicle into the friction heat of the brake, and the generated heat energy is absorbed by the friction plate in the wet brake. Therefore, the energy density
(the heat absorbed per unit area) on the surface of the friction plate during the bonding process can represent the harsh degree of the braking condition. The higher the energy density, the greater the kinetic energy absorbed by the friction plate during braking, and the worse the working condition.

In this test, the energy density of braking process is increased to improve the harshness of working conditions. Taking the wet drive axle of a loader as the research object. The energy density of the friction plate in the wet brake under typical braking conditions of the loader is shown in table 2.

Table 2. Energy density of typical braking conditions

| Braking conditions | Speed (km/h) | Energy density (kJ/cm²) |
|--------------------|--------------|-------------------------|
| 1-speed brake      | 4.7          | 0.002                   |
| 2-speed brake      | 7.5          | 0.006                   |
| 3-speed brake      | 16.6         | 0.027                   |
| 4-speed brake      | 33.1         | 0.106                   |
| Shift from 2 to 1  | /            | 0.003                   |
| Shift from 3 to 2  | /            | 0.021                   |
| Shift from 3 to 1  | /            | 0.024                   |

The tribology performance test is designed according to the energy density value in table 2 and the actual braking parameters of the brake. Test parameters are shown in table 3. Since the driver often uses the "touch brake" when braking, there is a range of brake oil pressure. In this test, the minimum oil pressure is 1.5Mpa, and the maximum brake oil pressure is 4.5Mpa in consideration of the hydraulic shock during emergency braking.

Table 3. Tribology performance test parameters of brake

| Sequence | Energy density (kJ/cm²) | Input inertia (kg·m²) | Input speed (r/min) | Pressure (MPa) | Temperature (°C) |
|----------|-------------------------|-----------------------|---------------------|----------------|------------------|
| 1        | 0.003                   | 400                   | 50                  | 1.5            | 85               |
| 2        | 0.003                   | 400                   | 50                  | 2.5            | 85               |
| 3        | 0.003                   | 400                   | 50                  | 3.5            | 85               |
| 4        | 0.003                   | 400                   | 50                  | 4.5            | 85               |
| 5        | 0.03                    | 400                   | 150                 | 1.5            | 85               |
| 6        | 0.03                    | 400                   | 150                 | 2.5            | 85               |
| 7        | 0.03                    | 400                   | 150                 | 3.5            | 85               |
| 8        | 0.03                    | 400                   | 150                 | 4.5            | 85               |
| 9        | 0.04                    | 400                   | 170                 | 4.0            | 85               |
| 10       | 0.05                    | 400                   | 190                 | 4.0            | 85               |
| 11       | 0.06                    | 400                   | 210                 | 4.0            | 85               |
| 12       | 0.07                    | 800                   | 160                 | 4.0            | 85               |
| 13       | 0.08                    | 800                   | 170                 | 4.0            | 85               |
| 14       | 0.09                    | 800                   | 180                 | 4.0            | 85               |
| 15       | 0.10                    | 800                   | 190                 | 4.0            | 85               |
| 16       | 0.11                    | 800                   | 200                 | 4.0            | 85               |
| 17       | 0.12                    | 800                   | 210                 | 4.0            | 85               |
The test is divided into 17 sequences, and 100 cycles are run for each sequence. The energy density of the loader in common working conditions is 0.003 and 0.03 kJ/cm². Sequence 1~8 is to investigate the influence of different braking oil pressure on the tribology performance under the energy density of common working conditions. Sequence 9-17 is experiment of increasing energy density, increasing the harshness of working conditions by continuously increasing the energy density.

3.3. Results analysis

3.3.1. Effect of energy density on dynamic friction coefficient

Dynamic friction coefficient refers to the friction coefficient when the input shaft speed decreases to half of the initial speed, which is affected by many factors, such as viscosity of lubricating oil, friction surface pressure and additives[5]. It can be seen from figure 2 that the dynamic friction coefficient of the developed oil is lower than that of the comparison oil, and higher than that of the comparison oil with the increase of energy density. Because the friction improver can adjust the friction coefficient between the friction pairs, the friction improver in the developed oil formulation makes the dynamic friction coefficient slightly decrease at low energy density. With the increase of the energy density, the contact temperature between the friction plates increases, the oil sludge and other oxidation products generated by the oil oxidation decay solution adhere to the surface of the friction plate to make it glaze[6], resulting in the decrease of the friction coefficient of the comparison oil. The developed oil contains high content of detergents, which increase the dynamic friction coefficient. Therefore, the friction coefficient of the developed oil will increase at high energy density and is higher than that of the comparison oil, indicating that the oxidation stability and purification dispersion of the comparison oil are worse than that of the developed oil. Therefore, the oxidation degradation of the comparison oil is serious at high energy density and the friction coefficient decreases.

3.3.2. Effect of energy density on static friction coefficient

Figure 3. Effect of energy density on static friction coefficient

Figure 3. Effect of energy density on static friction coefficient
Static friction coefficient refers to the friction coefficient corresponding to the peak torque when the input shaft speed falls to 0, which is related to the fastness of the friction plate lock at the end of the braking process. If the friction coefficient is too small, the fastness becomes worse. The change trend of static friction coefficient and dynamic friction coefficient of the two oils with the change of the energy density is basically the same. The friction improver in the developed oil reduces the static friction coefficient at low energy density. At high energy density, the by-product of oxidation decay solution of oil attached to the surface of friction plate results in the decrease of static friction coefficient of comparison oil. The static friction coefficient of the developed oil is higher than that of the reference oil at high energy density, which is more conducive to the locking of the friction plate.

3.3.3. Effect of energy density on static-dynamic ratio

![Figure 4. Effect of energy density on static-dynamic ratio](image)

Static-dynamic ratio is the ratio of static friction coefficient to dynamic friction coefficient, which is used to measure the smoothness of the braking process and the tendency to produce braking noise. The requirement is not more than 1.0. Due to the addition of friction improver, the static-dynamic ratio of the developed oil is less than that of the comparison oil in the range of low energy density and higher than that of the contrast oil in the range of high energy density. The static-dynamic ratio of the developed oil is also stable over the entire energy density range. The static-dynamic ratio of the comparison oil varies greatly over the entire energy density range. It indicates that the developed oil is more helpful to improve the smoothness of braking process and the braking stability.

3.3.4. Effect of energy density on braking time

![Figure 5. Effect of energy density on braking time](image)

The dynamic friction coefficient is related to the braking time. The larger the friction coefficient, the shorter the braking time. Figure 5 shows that, because the developed oil only slightly reduces the dynamic friction coefficient, the braking time in the two oils is basically the same at low energy density.
density. At high energy density, the kinetic friction coefficient of the comparison oil decreases more than that of the developed oil, resulting in a longer braking time than the braking time in the developed oil. Due to the high dynamic friction coefficient in the developed oil, the friction plate can provide more friction torque when the friction pair is relative to sliding friction, so the braking time is shorter.

4. MECHANICAL TRANSMISSION EFFICIENCY ANALYSIS

In order to investigate the effect of two oils on mechanical transmission efficiency in the drive axle, the efficiency test is carried out. The speed and torque under several common working conditions are selected as the input, and the transmission efficiency is obtained by testing the output power. The test results are shown in the table 4. Under several common working conditions, the efficiency of the developed oil is slightly higher than that of the comparison oil, and the efficiency change of the developed oil is more stable than that of the comparison oil. It indicates that the developed oil has high and stable transmission efficiency when working in the drive axle.

Table 4. Mechanical transmission efficiency

| Input speed (r/min) | Torque (N·m) | Transmission efficiency (developed oil) | Transmission efficiency (comparison oil) |
|--------------------|--------------|----------------------------------------|-----------------------------------------|
| 98                 | 330          | 94.34%                                 | 91.90%                                  |
| 98                 | 548          | 94.33%                                 | 94.49%                                  |
| 98                 | 870          | 92.58%                                 | 91.53%                                  |
| 196                | 330          | 93.34%                                 | 92.70%                                  |
| 196                | 548          | 95.51%                                 | 94.36%                                  |
| 196                | 870          | 93.52%                                 | 93.60%                                  |
| 390                | 226          | 93.91%                                 | 90.16%                                  |
| 390                | 486          | 93.56%                                 | 92.10%                                  |
| 390                | 591          | 94.70%                                 | 93.55%                                  |
| 587                | 219          | 93.87%                                 | 91.39%                                  |
| 587                | 378          | 94.66%                                 | 92.91%                                  |
| 587                | 483          | 94.94%                                 | 93.81%                                  |

5. SUMMARIZE

(1) Based on the actual braking condition of the wet drive axle, a method for evaluating the drive axle oil tribology performance is developed, and the energy density on the surface of the friction plate is used to characterize the harshness of the braking condition, the effect of oil pressure and different energy density on oil friction performance is investigated. The method can distinguish oil with different tribology performance.

(2) The developed oil is better than the comparison oil in determining smoothness, stability and mechanical transmission efficiency, and can provide better tribology performance maintenance ability when used for a long time to ensure efficient and stable operation of the drive axle.

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