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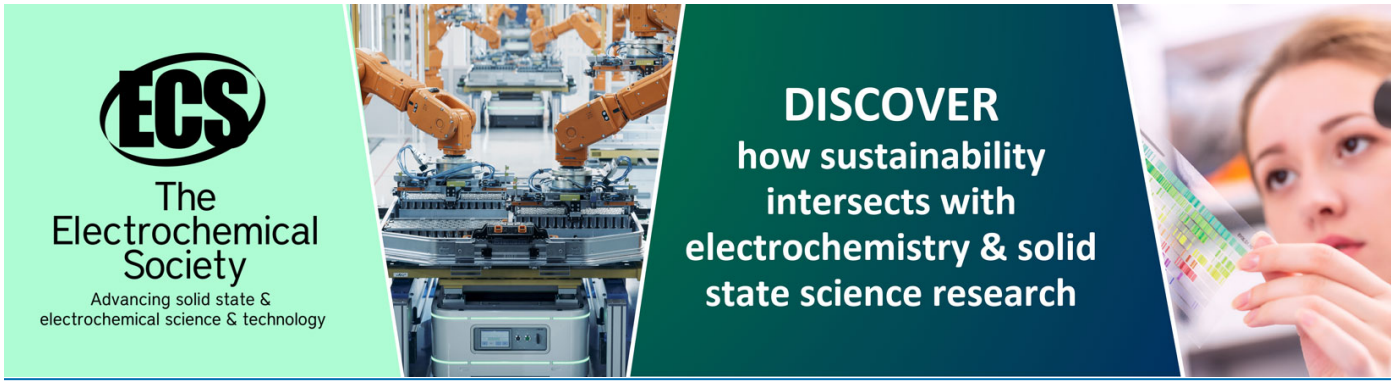

Experimental Study on Friction Torque of Wet Clutch under Three Kind of Contact Areas

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Abstract. It is of great significance to study the friction characteristics in the process of slippage and friction of the wet clutch for optimizing vehicle start, improving vehicle driving comfort and prolonging the service life of the clutch. Based on the test data of wet multi-plate clutch under braking condition in SAE#2 test bench friction torque test, we analyze the influence of rotate speed and average pressure on the friction torque through the comparison of friction torque under two friction pairs. The results show that in the case of sufficient lubricating oil flow, the attenuation of multiple pairs of friction plates has nothing to do with the proportion of the groove area of friction plates. Friction torque attenuation will occur under any groove area, but different groove areas will affect the rotate speed and average pressure of this phenomenon. In general, the frictional torque attenuation of wet multi-plate clutch gradually increases with the increase of relative speed and decreases with the increase of average surface pressure.

1. Introduction

As an indispensable mode of transportation in modern society, automobile has been developing towards the direction of high life span, high power density and high reliability[1]. As an important part of automobile transmission system, the working performance of the wet clutch directly determines the working performance of the transmission system, thus affecting the safety, comfort and shifting smoothness of the whole vehicle. The friction torque transferred by the clutch in the process of sliding and friction has a significant impact on the wet clutch. The study on the friction torque characteristics in the process of sliding and friction of the clutch is of great significance for improving the comfort of the vehicle in the driving process, extending the service life of the clutch and improving the working performance of the transmission system.

At present, domestic and foreign scholars have done a lot of theoretical analysis and experimental research on the friction torque in the process of sliding friction of wet clutch. Cao fei and Zhu hongqing studied the friction performance and thermal load performance of wet clutch[2-3]. Yu liang, Li heyan et al. established a torque calculation model considering the axial average specific pressure attenuation of the friction pair with key friction, and simulated the influence of key friction on the

axial average specific pressure attenuation of the friction pair with clutch[4]. Zhang heng et al. proposed the friction torque attenuation coefficient of wet multi-plate clutch based on the friction torque attenuation phenomenon in SAE#2 friction torque test[5]. Hashimoto and Kato first studied the oil film distribution between the friction sheet and the steel sheet under the action of centrifugal force, which laid a framework for establishing an accurate model of the towing torque[6-7]. Holgerson et al. conducted the bench test of the wet clutch with the SAE#2 test bed, and concluded that appropriate reduction of the joint pressure and temporary closure of the driving torque could effectively reduce the instability of the transfer torque caused by the maximum temperature rise of the friction pair during the engagement of the wet clutch[8]. Chinar et al. studied the influence of grooves on gas-liquid flow in the separation state through experiments and numerical calculations[9].

In order to study the torque transfer capacity of the clutch multi-friction pair, this paper studies the friction torque attenuation phenomenon according to the friction torque test data of two and six friction pairs measured on the SAE#2 test bench. We find that this phenomenon will occur under any groove area, but different groove areas affect the relative speed and average surface pressure when this phenomenon occurs. Finally, we analyze the reason of friction torque attenuation of wet multi-plate clutch.

2. Study on friction torque mechanism of clutch

In the process of clutch sliding and friction, the friction torque is calculated by the formula[10]

$$T = \frac{2\pi}{3} \cdot N \cdot \mu \cdot p_0 \cdot \left(R_O^3 - R_I^3\right) \tag{1}$$

In formula (1), N is the number of friction pairs; p_0 is the average surface pressure of friction pair; R_0 and R_i are the outer diameter and inner diameter of the friction plate respectively; μ is the average friction coefficient of two pairs of clutches.

2.1 Pressure p_0

In this test, five working conditions of clutch pressure were selected, namely 25kPa, 50kpa, 75kpa, 100kpa and 200kpa. The average surface pressure of the piston on the friction pair was 0.2Mpa, 0.4Mpa, 0.6Mpa, 0.8Mpa and 1.6Mpa respectively.

2.2 Friction characteristic μ

Based on the data obtained from the pin-disk friction and wear test, the empirical formula of the comprehensive friction coefficient of the wet friction pair (65Mn-copper-base powder metallurgy) with velocity, temperature and pressure as independent variables was fitted as

$$\mu = 23e^{\left(\frac{-3v}{(\ln T-3.2)((28.3p)^{0.44}-0.87)}-5.16\right)} + 0.08(e^{-0.005T}-1)(e^{-0.2v}-1) + \frac{0.008\ln(4v+1)}{e^{0.005T}} - 0.005\ln(28.3p) + 0.020 \tag{2}$$

In formula (2), v is the relative sliding linear velocity of the median diameter of the friction pair, $v = (n \cdot r_e)/60$, its unit is *m/s*; T is the temperature, the unit is $℃$.

Therefore, the formula for calculating the friction torque is

$$\mathrm{T} = \frac{2\pi}{3} \cdot N \cdot \left[23e^{\left(\frac{-3v}{(\ln T-3.2)((28.3p)^{0.44}-0.87)}-5.16\right)} + 0.08(e^{-0.005T}-1)(e^{-0.2v}-1) + \frac{0.008\ln(4v+1)}{e^{0.005T}} - 0.005\ln(28.3p) + 0.020\right] \cdot p_0 \cdot \left(R_O^3 - R_I^3\right) \tag{3}$$

By the reference 3, it can be seen that due to the existence of friction at the spline, the total friction torque has a non-linear relationship with the number of friction pairs. The more the number of friction pairs, the smaller the average single pair of friction torque, and the more obvious the role of friction at the key. So the formula can only be used for single pair ideally. In many cases, wet clutch friction damping torque, in order to study the differences, this paper analyzes SAE# 2 brake friction testing machine working conditions of the test data. Combined with formula (3), we studied the influence of groove area and the number of friction pair on friction torque.

3. Test method

The SAE#2 test bed is a test device used to study the friction characteristics of the clutch. The whole test system is shown in figure 1. The motor provides power to drive the inertia and the active end of the clutch to rotate. The compressed air of the air pump ACTS directly on the piston to complete the combination of the clutch friction pair. The clutch oil by the hydraulic pump through the filter and cooling switch, into the lubricating oil road.

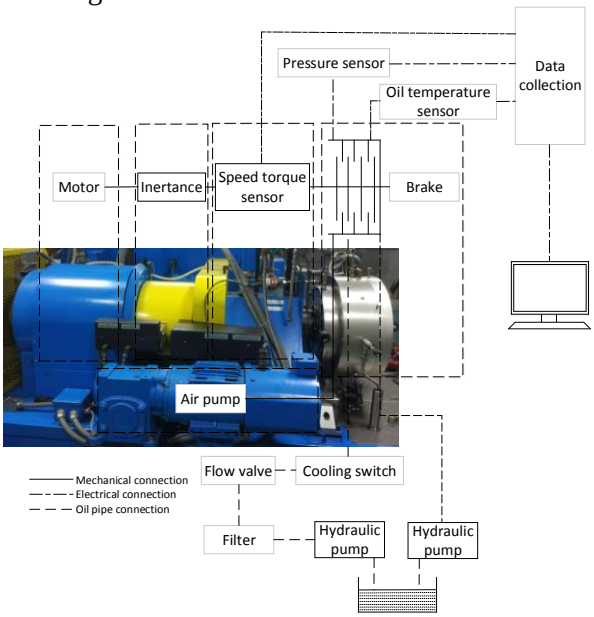
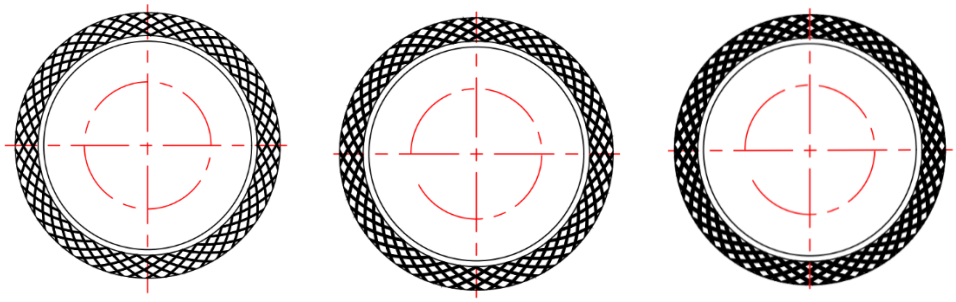


Figure 1. SAE#2 clutch test system

The dual steel sheet material used in the test clutch is 65Mn. the friction sheet material is copper based powder metallurgy material and nano-modifier is added. And the lubrication groove is double circular groove, with groove area accounting for 25%, 35% and 50%, respectively, as shown in figure 2.The lubricating oil model is 10W/40-CF, the lubrication flow is 4mL/min/cm^2. The lubricating oil temperature is controlled by the cooling switch.



(a)25% groove area (b)35% groove area (c)50% groove area

Figure 2. The friction plate form of three lubricating oil groove

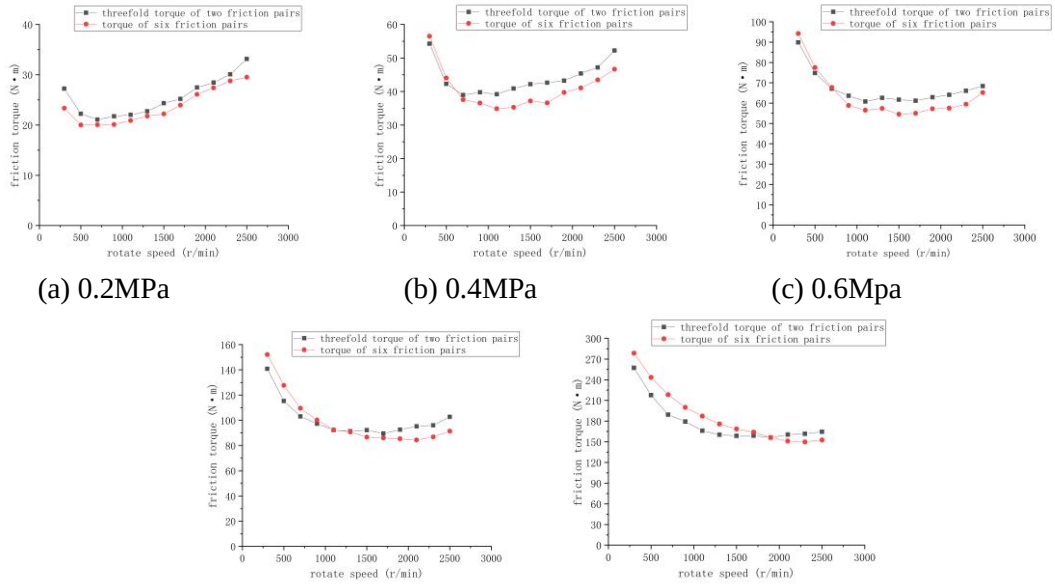
4. Friction torque

It can be obtained from formula (3)

$$T_6 = 6 \times r_e \cdot p \cdot A_c \cdot \xi_{2-6} \cdot \mu = 3 \times (2 \times r_e \cdot p \cdot A_c \cdot \xi_{2-6} \cdot \mu) = 3T_2 \quad (4)$$

In the formula (4), T_2 represents the measured friction torque of two friction pairs, and T_6 represents the calculated friction torque of six friction pairs relative to the friction torque of two friction pairs. Therefore, under the same working condition, the calculated friction torque of six friction pairs should be three times of the benchmark friction torque of two friction pairs.

According to the test data of friction torque of two and six friction pairs under the three grooves of 25%, 35% and 50% measured by SAE#2 friction testing machine, the friction torque of wet multi-plate clutch under braking conditions is drawn as shown in Figure 3, 4 and 5.

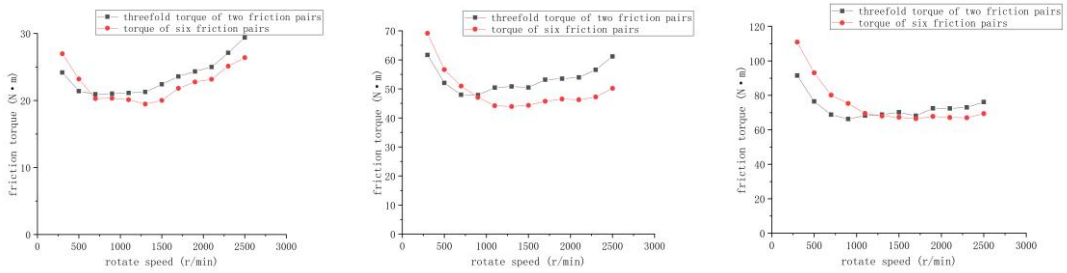


(a) 0.2MPa (b) 0.4MPa (c) 0.6Mpa

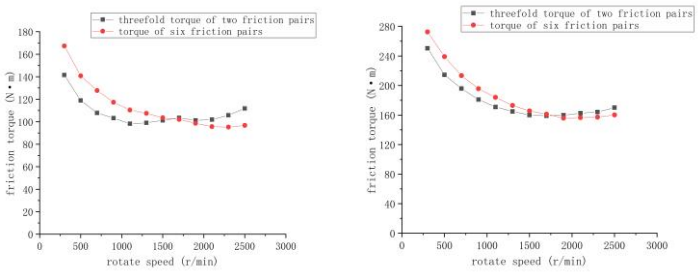
(d) 0.8MPa (e) 1.6MPa

Figure 3. Comparison of friction torque under 25% groove area

Figure 3 shows the comparison between the threefold friction torque of two friction pairs and the friction torque of six friction pairs under different surface-pressure when the groove area accounts for 25%. As figure 3 (a) shows, the friction torque of 3 times two friction pairs is always greater than that of six friction pairs. As figure 3 (b) shows, when the speed is lower than 600r/min, the friction torque of six friction pairs is greater than 3 times that of two friction pairs. When the speed is higher than 600r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 3 (c) shows, when the speed is less than 700r/min, the friction torque of the six friction pairs is greater than 3 times of the friction torque of the two friction pairs; when the speed is higher than 700r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 3 (d) shows, when the speed is less than 1100r/min, the friction torque of the six friction pairs is more than 3 times that of the two friction pairs. When the speed is higher than 1100r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 3 (e) shows, when the speed is lower than 1900r/min, the friction torque of six friction pairs is greater than 3 times of the friction torque of two friction pairs; when the speed is higher than 1900r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. The speed at which the frictional torque is equal is called the critical speed.



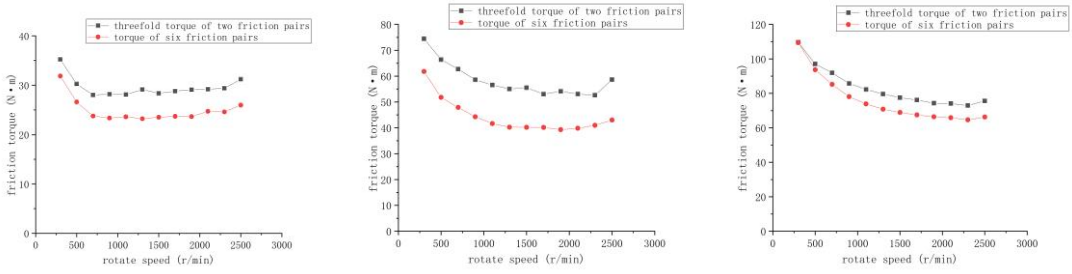
(a) 0.2MPa (b) 0.4MPa (c) 0.6Mpa



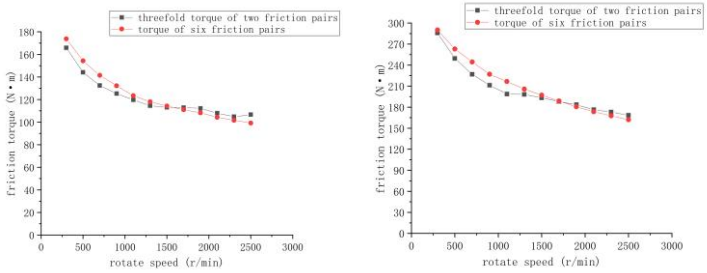
(d) 0.8MPa (e) 1.6MPa

Figure 4. Comparison of friction torque under 35% groove area

Figure 4 shows the comparison between the friction torque of two friction pairs and the friction torque of six friction pairs under three times the pressure on different surfaces when the proportion of groove area is 35%. As figure 4 (a) shows, when the speed is lower than 600r/min, the friction torque of six friction pairs is greater than 3 times that of two friction pairs; when the speed is higher than 600r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 4 (b) shows, when the speed is lower than 900r/min, the friction torque of six friction pairs is greater than 3 times of the friction torque of two friction pairs. When the speed is higher than 900r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 4 (c) shows, when the speed is less than 1200r/min, the friction torque of the six friction pairs is more than 3 times that of the two friction pairs; when the speed is higher than 1200r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 4 (d) shows, when the speed is lower than 1600r/min, the friction torque of six friction pairs is greater than 3 times of the friction torque of two friction pairs. When the speed is higher than 1600r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 4 (e) shows, when the speed is lower than 1800r/min, the friction torque of six friction pairs is greater than 3 times of the friction torque of two friction pairs; when the speed is higher than 1800r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs.



(a) 0.2MPa (b) 0.4MPa (c) 0.6Mpa



(d) 0.8MPa (e) 1.6MPa

Figure 5. Comparison of friction torque under 50% groove area

Figure 5 shows the comparison between the friction torque of two friction pairs and the friction torque of six friction pairs under three times the pressure on different surfaces when the groove area

accounts for 25%. As figure 5(a) and (b) show, the friction torque of three times of two friction pairs is always greater than that of six friction pairs. As figure 5 (c) shows when the speed is higher than 300r/min, the friction torque of the two friction pairs 3 times is greater than that of the six friction pairs; when the speed is higher than 1700r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 5 (d) shows, when the speed is lower than 1500r/min, the friction torque of six friction pairs is greater than 3 times that of two friction pairs; when the speed is higher than 1500r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs. As figure 5 (e) shows, when the speed is less than 1700r/min, the friction torque of six friction pairs is greater than 3 times of the friction torque of two friction pairs; when the speed is higher than 1700r/min, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs.

5. Analysis of influence factors

As can be seen from literature 3, the theoretical required lubrication flow rate of a single friction pair covered by the whole oil film decreases with the increase of the average surface pressure of the friction pair and increases with the increase of the relative speed, and the required maximum lubrication flow rate is lower than 0.03L/min. In this test, the lubrication flow per unit area of the clutch friction pair was 4mL/min/cm2, and that of the single friction pair was 0.217L/min, which was much higher than the theoretical lubrication flow required by the single friction pair under the full oil film. Lubricating oil film dynamic pressure effect. Therefore, the remaining lubricating oil covered by all-oil film will lead to an increase in the ratio of viscous torque of multiple friction pairs and a decrease in the contact area of micro-convex peak, resulting in a smaller friction coefficient of six pairs under the same working condition. And a smaller friction torque of multiple friction pairs under the same working condition is equivalent to a smaller friction torque of two friction pairs.

Take the friction torque when the proportion of groove area is 35% as an example. When the pressure is constant, when the speed is lower than the critical speed, the friction torque of the six friction pairs is greater than 3 times the friction torque of the two friction pairs. When the speed is higher than the critical speed, the friction torque of the six friction pairs is gradually less than 3 times the friction torque of the two friction pairs. This is because the friction pair mean surface pressure is constant, with the increase of relative speed, full oil film lubrication theory demand under the cover of friction pair traffic increases, the oil membrane covering the rest of lubricating oil flow is reduced, oil film thickness increases, the rough peak contact gradually reduce, declining real contact area, six friction pair friction coefficient decreases, and six vice friction torque decreases. With the increase of the average surface pressure, the critical speed increases gradually. This is because with the increase of the average surface pressure, the flow rate of the remaining lubricating oil covered by the whole oil film increases, the oil film thickness gradually decreases, and the rough peak contact gradually increases, the friction coefficient of the six friction pairs increases accordingly, resulting in the increase of the friction torque of the six friction pairs, which requires a higher speed to reduce the pressure on the flow rate of the lubricating oil.

6. Conclusion

Based on the test data on SAE#2 test bench on the sliding and friction process of wet multi-plate clutch under braking conditions, the variation trend of friction torque of two and six friction pairs under different groove areas was measured, and the causes of the trend were analyzed. The research results show that:

1) The test results show that, the friction torque of the six friction pairs is less than 3 times that of the two friction pairs when the relative speed is larger the critical speed. This is because under the condition of sufficient flow of lubricating oil of friction pair, the ratio of rough contact torque of multi-pair clutch is small, and the ratio of viscous torque is large. With the same relative speed and average surface pressure, the friction coefficient of multiple friction pairs is less than that of two friction pairs.

2) The frictional torque attenuation phenomenon occurred under the three kinds of groove areas of 25%, 35% and 50%, and the groove area only affected the relative speed and average surface pressure when the phenomenon occurred. The larger the groove area, the greater the average surface pressure.

3) When the critical speed is reached, the friction torque of the six pairs is equal to that of the three pairs, and then the friction torque of the six pairs is gradually less than that of the three pairs. The critical speed increases as the pressure increases.

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