Design of Automotive Magneto-rheological Fluid Dual-clutch

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Abstract. To fulfill the requirement of the torque transmission for the medium and small displacement vehicles, design a magneto-rheological fluid dual clutch (MRDC). MRDC adopts magneto-rheological effect of magneto-rheological fluid (MRF) to transmit torque. Only by changing the current in the coil, the separation and combination of the clutch is realized. This new type of dual clutch has the characteristics of no wearing, low energy consumption, high control accuracy, fast response and simple structure. Its working process is introduced and the relationship between the torque and the magnetic flux density is obtained.

Introduction

Dual Clutch Transmission (DCT) is a mechanical automatic transmission and has been widely applied on automobiles [1,2]. It was developed based on manual transmission (MT). A car equipped DCT has a lower fuel consumption than AT. The core component of the DCT is the dual clutch. It is composed of two clutches, the active part is connected to the engine crankshaft and the driven parts of the two clutches are connected respectively to the two input shafts (internal and external) of the gearbox. The two input shafts are decorated respectively with odd and even gears. There has no power interruption during shifting. But the structures of the dual clutch and the control valves are complicated and have high requirements on machining accuracy. The service life of the friction pieces is short and has a high requirement. This looks forward to a new type of dual clutch with simple structure, reliable operation, small wear, high controllability and fast response.

Magneto-rheological fluid (MRF) is a kind of intelligent material. Without magnetic field, MRF flows like fluid; while under magnetic field, it shifts into Bingham plastic solid and forms chain-structure within millisecond level. This phenomenon is called magneto-rheological effect [3,4,5,6]. Magneto-rheological clutch (MRC) uses magneto-rheological effect to replace traditional friction to transmit torque.

In this paper, we designed a magneto-rheological fluid dual clutch (MRDC), which could fulfill the requirement of the torque transmission for the medium and small displacement vehicles, to replace the traditional friction dual clutch [7]. Only by changing the current in the coil, the separation and combination of the clutch is realized.

The Structure Design of MRDC

The assembly drawing of MRDC is shown in figure 1 and the sectional view of the three-dimensional model is shown in figure 2.

The structure has a drive shaft and two driven shafts. The two clutches (the internal and external clutch) are placed nested in radial. The maximum radius is 258 mm.

The drive shaft is connected to the engine crankshaft and the driven shafts of the two clutches are connected respectively to the two input shafts of the gearbox. The drive cylinders and the drive shaft are connected by welding; the driven cylinders and the middle plate are welded. The gap between the drive and driven cylinders is filled with MRF.

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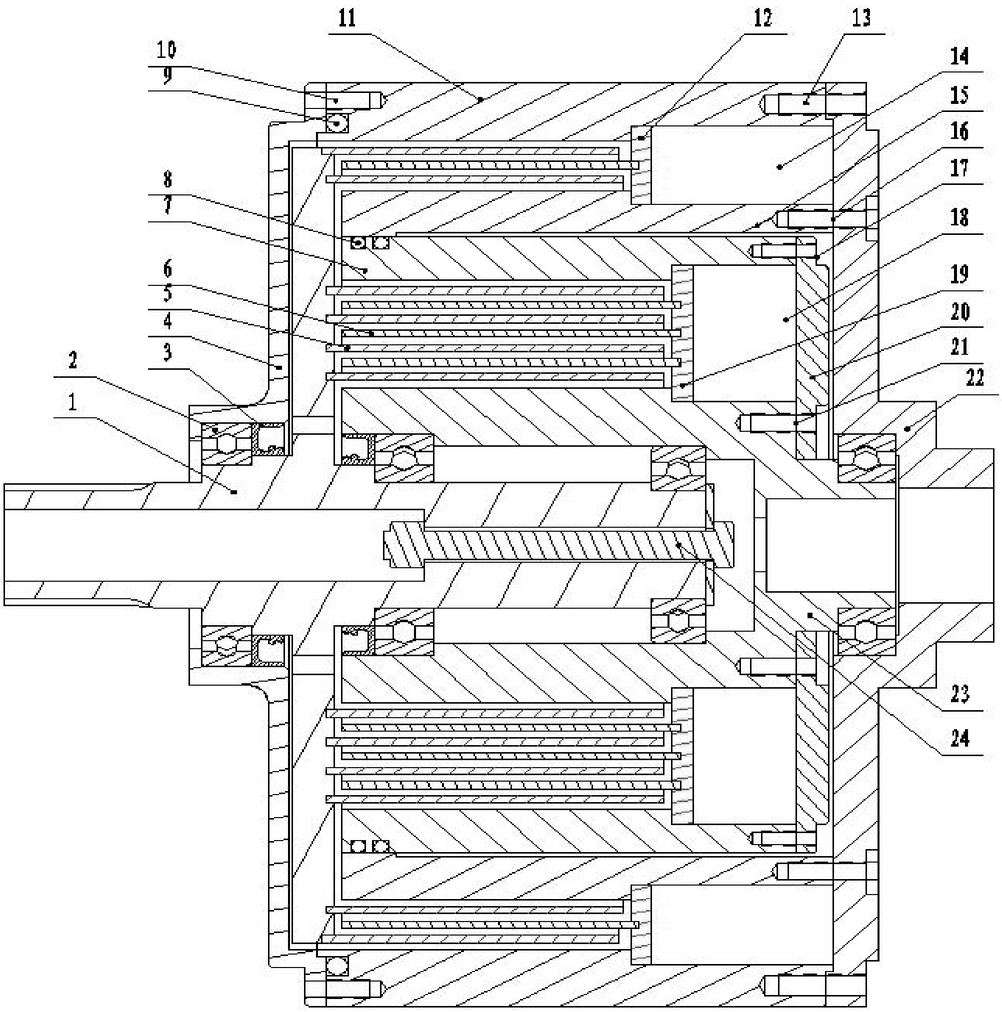

Fig.1 The assembly drawing of MRDC

1-drive shaft; 2-deep groove ball bearing; 3-lip-type packing; 4-cover; 5-drive cylinders; 6-driven cylinders; 7-shell of the internal clutch; 8,9-O ring; 10,13,16,17,21-socket head cap screw; 11-shell of the external clutch; 12,19-middle plate; 14,18-coil; 15,22-driven shaft of the external clutch; 20-coil cover; 23-driven shaft of the internal clutch; 24-screw bolt and cap.

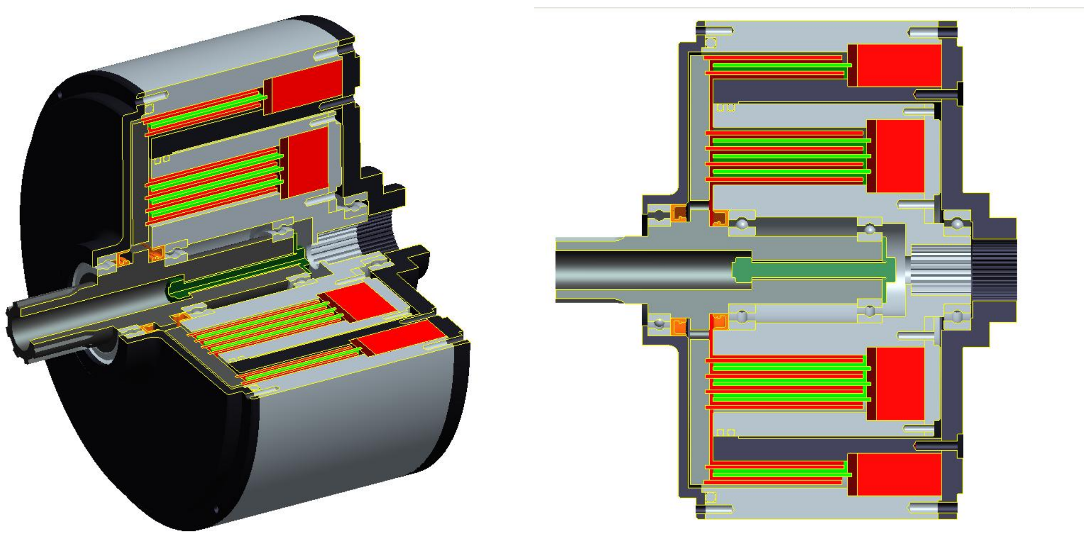

Fig.2 The sectional view of the three-dimensional model

In the internal clutch, there are 4 drive cylinders and 3 driven cylinders, forming 8 MRF work areas. The cylinder's length is 80mm and the thickness is 2 mm. The gap between the drive and driven cylinder is 2 mm. The internal and external radius of each cylinder of the internal clutch is shown in table 1.

Table 1 The radius of the cylinders of internal clutch

Internal radius [mm]	44	48	52	56	60	64	68	72
External radius[mm]	46	50	54	58	62	66	70	74

In the external clutch, there are 2 drive cylinders and 1 driven cylinder, forming 4 MRF work areas. The cylinder's length is 70mm and the thickness is 2 mm. The gap between the drive and driven cylinder is 2 mm. The internal and external radius of each cylinder of the external clutch is shown in table 2.

Table 2 The radius of the cylinders of external clutch

Internal radius [mm]	99	103	107	111
External radius[mm]	101	105	109	113

Working Process

When there has no current in the coils, there has no magnetic field in the MRF work areas. The MRF don't transmit torque, the dual clutch is in separation state.

The clutch starts to work when its current is switched on. The magnetic field in the work areas is created. The magnetic particles in the MRF begin to form chain structures. The drive and driven cylinders are connected by shearing and then transmit toque. The torque transmission capacity is related with the magnetic flux density. When the current is small, the clutch is in slip state. As the current increases, the transmission torque increases. If the clutch transmission torque is larger than the load torque, the clutch is combined. By controlling the current in the coil, the state of the clutch can be controlled.

The current in the two clutches are not switched on at the same time. When the internal clutch is working, the external clutch is standby, and vice versa.

When shifting the gear, decrease the current in the present coil, and increase the current in another coil. There has no power interrupt during the shift.

Calculation of Electromagnetic Parameters

For the common medium and small displacement vehicles, the transmission torque is 250N·m, the reserve coefficient of the clutch is 1.5, so the target torque is 375N·m.

For the multi-cylindrical MRC [8,9,10] which has *n* work areas, the transmission torque is

$$T=\sum_{1}^{n}\left(\frac{4\pi L r_{i1}^{2} r_{i2}^{2}\ln(r_{i2}/r_{i1})}{r_{i2}^{2}-r_{i1}^{2}}\tau_{Bi}+\frac{4\pi L r_{i1}^{2} r_{i2}^{2}(\omega_{i2}-\omega_{i1})}{r_{i2}^{2}-r_{i1}^{2}}\eta\right). \quad (1)$$

Where L is the length of the cylinder; τ_B is the shear yield strength; r_1 is the internal radius of the cylinder, r_2 is the external radius of the cylinder, and the corresponding angular velocity are ω_2 and ω_1; η is the viscosity. The torque related to η is called viscosity torque. It's small and negligible.

According to equation (1) and neglect the viscosity torque, the torque of internal clutch is

$$T_1=\left(\frac{r_1^2r_2^2\ln\frac{r_2}{r_1}}{r_2^2-r_1^2}+\frac{r_3^2r_4^2\ln\frac{r_4}{r_3}}{r_4^2-r_3^2}+\frac{r_5^2r_6^2\ln\frac{r_6}{r_5}}{r_6^2-r_5^2}+\frac{r_7^2r_8^2\ln\frac{r_8}{r_7}}{r_8^2-r_7^2}+\frac{r_9^2r_{10}^2\ln\frac{r_{10}}{r_9}}{r_{10}^2-r_9^2}+\frac{r_{11}^2r_{12}^2\ln\frac{r_{12}}{r_{11}}}{r_{12}^2-r_{11}^2}+\frac{r_{13}^2r_{14}^2\ln\frac{r_{14}}{r_{13}}}{r_{14}^2-r_{13}^2}+\frac{r_{15}^2r_{16}^2\ln\frac{r_{16}}{r_{15}}}{r_{16}^2-r_{15}^2}\right)4\pi L_1\tau_B. \quad (2)$$

The torque of external clutch is

$$T_2=4\pi L_2\tau_B\left(\frac{r_{17}^2r_{18}^2\ln\frac{r_{18}}{r_{17}}}{r_{18}^2-r_{17}^2}+\frac{r_{19}^2r_{20}^2\ln\frac{r_{20}}{r_{19}}}{r_{20}^2-r_{19}^2}+\frac{r_{21}^2r_{22}^2\ln\frac{r_{22}}{r_{21}}}{r_{22}^2-r_{21}^2}+\frac{r_{23}^2r_{24}^2\ln\frac{r_{24}}{r_{23}}}{r_{24}^2-r_{23}^2}\right). \quad (3)$$

The relationship between the shear yield strength τ_B of the used MRF and the magnetic flux density B is

$$\tau_B=-16.08B^3-54.05B^2+130.8B-5.7. \quad (4)$$

According to equation (2), equation (4) and the radius of each cylinder, the relationship between the magnetic flux density and the transmission torque of the internal clutch is

$$T_1=179.608L_1(-160.8B^3-54.05B^2+130.8B-5.7). \quad (5)$$

After calculation, when the magnetic flux density reaches 0.34 T, the clutch can transmit the requirement torque. Graph equation (5), as shown in figure 3.

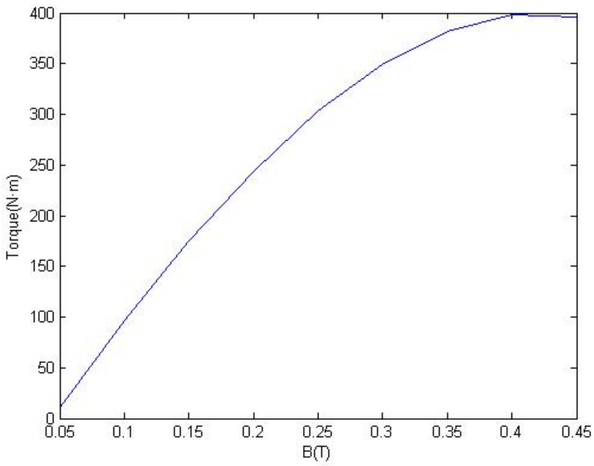

Fig.3 The internal clutch's transmission torque

According to equation (3) and equation (4), the relationship between the magnetic flux density and the transmission torque of the external clutch is

$$T_2=282.6L_2(-160.8B^3-54.05B^2+130.8B-5.7). \quad (6)$$

When the magnetic flux density reaches 0.225 T, the clutch can transmit the target torque. Graph equation (6), as shown in figure 4.

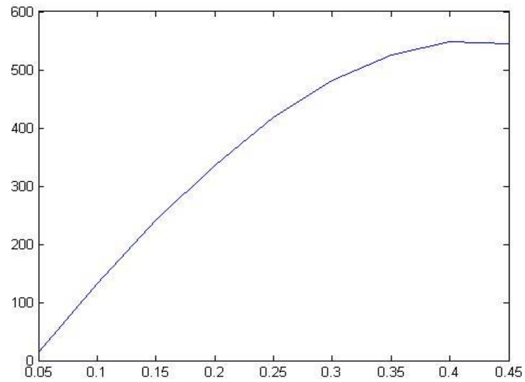

Fig.4 The external clutch's transmission torque

Summary

In this paper, we designed a new type of dual clutch, MRDC, for medium and small displacement vehicles. MRDC uses MRF to replace traditional friction to transmit torque. This new type of dual clutch has simple structure, reliable operation, small wear, high controllability and fast response speed. Only by changing the current in the coil, the separation and combination of the clutch is realized. Through the characteristic of the MRF and the transmission torque of multi-cylindrical MRC, got the relationship between the magnetic flux density and the transmission torque of the dual clutch. This type of dual clutch can play an important role in the intelligent control of a car.

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