Thermal Analysis and Test Research of the Magnetic Powder Clutch for Vehicles

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Abstract:- The magnetic powder clutch designed for vehicles was taken as the research object to analyze its working ability. The heat source intensity and thermal parameters of the magnetic powder clutch were determined based on thermal analysis theory and the operating state analysis of the magnetic powder clutch under three typical stable conditions. Then the temperature finite element model was established and the temperature distribution and change were analyzed. The feasibility and the working reliability of the designed magnetic powder clutch were evaluated by using the simulation results, which provided evidence for the later research. Finally, the test prototype and test bench of the magnetic powder clutch for vehicle was developed. The test results showed that the temperature field analysis model of magnetic powder clutch established in this paper was accurate and the designed magnetic powder clutch satisfied the requirement for working.

Key-words:- magnetic powder clutch, vehicle, temperature field, FEM, simulation, test

1 Introduction

The magnetic powder clutch has a lot of advantages, such as smooth engagement, good controllability, quick response, high transmission efficiency, a wide range of torque transmission which has nothing to do with the slip, which determined its broad application prospects in automatic transmission used in economical vehicle. In recent years, the magnetic powder clutch for vehicle was applied in the hybrid vehicle and the vehicle equipped with a continuously variable transmission by several Japanese automobile company[1-2]. Literature [3] also reported that the magnetic powder clutch was used in rear drive axle of the off-road vehicles and the traction control was realized with approving vehicle dynamics performance. However, the magnetic powder clutch has not been widely applied in the field of vehicle driveline because of several problems such as low torque transmission capacity, seriously being heated when it works and so on.

Aimed to the current problem of low torque transfer capacity of the magnetic powder clutch for vehicle, a prophase research has been done by our research group and some research results had been achieved[3-5]. In the earlier research, some methods and ways for enhancing the torque transfer performance of the magnetic powder clutch were analyzed from the two points: one point was the structure and parameters improvement and optimization of the magnetic powder clutch, the other point was the material influence on its performance. At the same time, the quantitative relation between the torque transmission performance and the key design parameters such as working gaps width of the magnetic powder clutch, width of non-working gap, number of the working gap, magnetic performance of the circuit materials and magnetic powder materials were determined[4-6].

The temperature of working parts such as magnetic powder, excitation coil and bearings rises continuously because of the generated heat when the magnetic powder clutch works, which can influence the working performance and service life of the magnetic powder clutch, cause the component failure seriously and can not guaranteeing reliable operation of the system. Therefore it is necessary to study the heating condition and the temperature rising characteristic of the magnetic powder clutch designed in this study under sevral working conditons. Firstly, the heat source intensity and thermal parameters of the magnetic powder clutch were determined based on thermal analysis theory and the operating state analysis of the magnetic powder clutch under three typical stable conditions. Secondly, the temperature finite element model was established and the temperature distribution and change were analyzed. The simulation results validated feasibility and the working reliability of the designed magnetic powder clutch, which provided evidence for the later research. Finally, the test prototype and test bench of the magnetic powder clutch for vehicles was developed. The test results showed that the temperature field analysis model of magnetic powder clutch established in this paper is accurate and the designed magnetic powder clutch satisfy the requirement for working.

Magnetic powder clutch usually consists of drive rotor 4, driven rotor 2, magnetic yoke 10, magnetic powder 7, excitation coil 9 and other components. The working medium of magnetic powder 7 was filled in the the working clearance formed between the inside cylindrical surface of drive rotor 4 and the outside cylindrical surface of driven rotor 2. The structure diagram of magnetic powder clutch was shown in Fig.1. The drive rotor, driven roto, magnetic yoke, magnetic powder were made of soft magnetic materials ang they forms a magnetic circuit. And other components of the magnetic powder clutch were made of non-magnetic conductive material to ensure that the majority of the magnetic flux in the magnetic circuit is through the magnetic layer in the clutch working gap. When the excitation coil was not electrified, the magnetic powder in working gap was in a discrete and free state and it was pressed on the drive rotor working surface under the action of centrifugal force, so the clutch was disengaged for there was no connecting force between drive rotor and driven rotor. When the excitation coil was electrified, the magnetic flux was generated and formed a close magnetic circuit. So the magnetic powder in the working gap was magnetized under the action of magnetic flux which made the drive rotor be connected to the driven rotor to transfer torque[7].

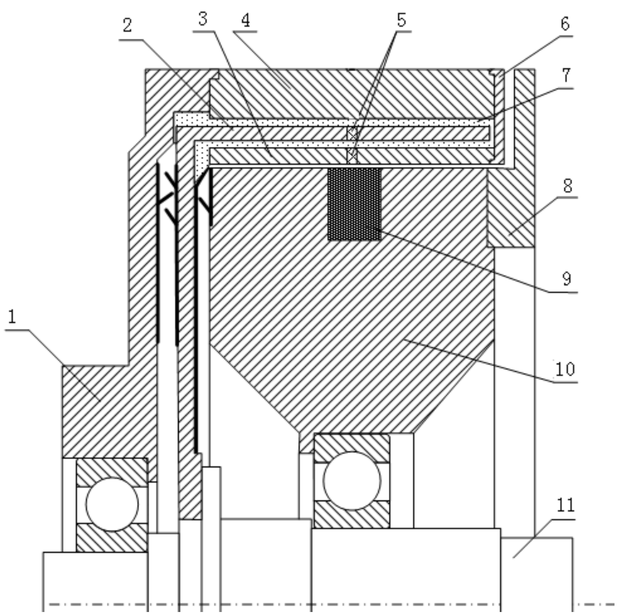

Fig.1. Structure of magnetic powder clutch(MPC)

2 Theoretical basis for thermal analysis

2.1 Fundamental theory of heat transfer

2.1.1 Ways of of heat transfer

There are three basic ways of heat transfer: heat conduction, heat convection and heat radiation[8].

The heat conduction follows Fourier's law which is also known as the basic law of heat conduction. The expression is expressed as the following

$$q = -\zeta \frac{\partial T}{\partial n}, \qquad (1)$$

where q is heat flux, W/m^2; ζ is thermal conductivity, W/m.K; T is the object temperature, K; and n is thermal transfer direction coordinate.

Convection occurs on the solid surface where the fluid and the solid contact. The heat convection follows Newton's cooling equation. The equation is expressed as follows

$$q = \alpha \Delta T, \qquad (2)$$

where ΔT is the temperature difference between the solid surface and the fluid, K; and α is convective heat transfer coefficient, W/m^2•K.

Heat radiation is a process of energy radiation for the object with a temperature by way of electromagnetic. The radiation energy is calculated by using the Stefan-Boltzmann's law which is expressed as follows

$$q = \lambda\sigma\left(T_2^4 - T_1^4\right), \qquad (3)$$

where λ is radiation rate; σ is Stefan–Boltzmann constant and its value is 5.67×10^{-8}W/m^2•K^4; T_2 is the surface temperature, K; and T_1 is body surface temperature by radiation, K.

2.1.2 Heat Conduction Differential Equations

Assuming that the object is an isotropic continuous medium and it contains an internal heat source, so its heat conductivity, specific heat and density do not change with temperature. The heat conduction differential equation is written as

$$\frac{\partial T}{\partial t} = \frac{\zeta}{\rho c}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) + \frac{q_v}{\rho c}, \qquad (4)$$

where T is temperature, K, t is time, s; ζ is thermal conductivity, W/m•K; ρ is density, kg/m^3; c is specific heat capacity, J/kg•K; q_v is heat flow in unit volume and time, W.

2.1.3 Temperature field boundary conditions

The essence of solving thermal problem is to solve the heat conduction differential equation. In order to get the definite solution, it needs to be given the initial and boundary conditions. The initial condition is the temperature value in the initial state. The common boundary conditions include three categories.

(a) First type of boundary condition:

The first type of boundary condition is used to define the boundary temperature of the object at any time, and it can be written as

$$T\big|_{s_1} = T_0, \tag{5}$$

where s_1 is the object boundary surface, and T_0 is the known temperature value.

(b) Second type of boundary condition:

The second type of boundary condition is used to give the heat flux on the object boundary surface at any time, and it can be expressed as follows

$$\left.\frac{\partial T}{\partial n}\right|_{s_2} = -\frac{q_0}{\zeta}, \tag{6}$$

where s_2 is the object boundary surface, and q_0 is the known value of the heat flux.

(c) Third type of boundary condition:

The third type of boundary condition is used to define the heat release coefficient and the temperature of the fluid medium that touches with the object. It can be expressed as follows

$$-\zeta\left.\frac{\partial T}{\partial n}\right|_{s_3} = \eta\left(T - T_f\right), \tag{7}$$

where s_3 is the object boundary surface, T_f is fluid temperature, and η is convective heat transfer coefficient.

In three types of boundary conditions, the first type of boundary condition is the compulsive boundary condition; the second and the third boundary conditions are the natural boundary conditions.

2.2 Finite element method for thermal analysis

Based on the heat differential equations and boundary conditions, the basic process of temperature field analysis based on the finite element method is to obtain the temperature function by using the numerical method, then to deduce the heat flow rate, thermal gradients and other parameters, and finally to get the temperature distribution of the system. Galerkin weighted residual method is an effective way in solving differential equations. Heat analysis form of the finite element derived by Galerkin weighted residual method can be expressed as

Steady: $[M]\{T\} = \{Q\}$,

Transient: $[M]\{T\} + [C]\{\dot{T}\} = \{Q\}$, (8)

where $[M]$ is the conduction matrix and it includes the heat conductivity, the convective heat transfer coefficient and the shape factor, $\{T\}$ is the node temperature vector, $\{Q\}$ is the node heat flux vector, $[C]$ is the specific heat matrix, and $\{\dot{T}\}$ is the time derivative of the temperature. The calculation of elements in $[M]$ and $\{Q\}$ can be found in the literature [9].

3 Parameters determination of the temperature field analysis

3.1 Analysis of heat sources

In working process of the magnetic powder clutch, the heat mainly consists of two parts: the heat generated by the slip power loss and the heat generated by the exciting coil copper loss. Slip power and copper loss power can be expressed respectively as follows

$$P_s = 2\pi \times T_q \times n_d / 60, \tag{9}$$

$$P_c = I^2 R, \tag{10}$$

where P_s is the slip power, W; T_q is the transmission torque of magnetic powder clutch, N.m; n_d is the speed difference between the driving member and driven member of magnetic powder clutch, r/min; P_c is the excitation coil copper loss power, W; I is the exciting current, A; and R is the excitation coil resistance, Ω.

The excitation coil was made of the diameter of 0.488mm copper enameled wire, and its turns was 750 turn and coil resistance Rwas 54.92Ω.

The engagement control of magnetic powder clutch in the process of vehicle starting based on fuzzy control technique has been studied in the prophase research by our research group[10]. The calculation of the heat sources is on the basis of the obtained research results. To facilitate research and better reflect the operation engagement and the working conditions of magnetic powder clutch, three typical stable conditions were selected for research. And the heat source intensity was determined based on the analysis of the working state of the magnetic powder clutch under different operation conditions.

Three typical stable operation conditions selected for research were as follows: very low speed running condition, full load running condition and medium load running condition.

(a) Running condition of very low speed:

This running condition often occurs in a state of traffic jam. Under this running condition, the slip power is greater than that of other conditions, and the speed is usually not higher than the speed when transmission is in the first gear. From the vehicle driving dynamic equations, it can be obtained that the desired torque was not higher than 4.5Nm and the speed of the transmission output shaft was 970r/min when the vehicle speed was 10km/h. Assuming the slip speed is 700r/min, the clutch slip power can be obtained from the formula (9) and its value was 330W, the required magnetizing current was 0.22A, and the copper loss power was 2.7W.

(b) Running condition of full load:
Under this running condition, the drive and the driven members of the clutch are in a mating state, the slip power is 0W, transmission torque was not less than the maximum engine torque of 115N.m, the exciting coil copper loss was great, the required exciting current of the magnetic powder clutch was not less than 1.2A, and the corresponding copper loss power was 80W.

(c) Running condition of medium load:
Under this running condition, the drive and the driven members of the clutch are in a mating state, and the slip power is 0W. Assuming the desired clutch torque is 61N.m when the vehicle runs with a constant speed of 120km/h on the plane road in the fourth transmission gear, the corresponding excitation current of the magnetic powder clutch was 0.8A, and the copper loss of power is 35W.

Heat sources intensity is determined by the heat power and heat body volume, and it can be expressed as

$$Q_s = P_s / V_g \qquad (11)$$

$$Q_c = P_c / V_c \qquad (12)$$

where Q_s is the heat source intensity of the working gap, W/m^3; V_g is the volume of working gap, m^3; Q_c is the heat source intensity of the excitation coil, W/m^3; and V_c is the volume of excitation coil, m^3.

The heat source intensity of the clutch under three stable conditions was shown in table1.

Table 1 Heat source intensity of the MPC under three stable conditions

running conditions	heat source intensity /(W/m^3)	
	copper loss	slip
Low speed, slip	2.18×10^4	6.93×10^6
Full load, mating	6.47×10^5	0
Medium load, mating	2.83×10^5	0

3.2 Determination of the thermal parameters

The thermal physical parameters of components materials of the magnetic powder clutch at 20 ℃ were shown in table 2 [8].

Table 2 thermal physical parameters of each material of the MPC

materials	density ρ/(kg/m^3)	heat conductivity ζ/(W/m•K)	specific heat capacity c /(J/kg•K)
electrical iron	7897	81.1	455
aluminum	2790	170	881
bearing steel	7865	56	460
45 steel	7840	49.8	465
copper	8930	398	386
copper coil	4030	60	172
Fe-Co-Ni magnetic powder	7849	52	452

The heat conductivity of the material changes with the temperature, which makes the computation complex. Considering that the heat conductivity of the metal material changes little with the temperature, so the heat conductivity of the metal is assumed to be a constant within a certain temperature range. The heat of the magnetic powder clutch exchanges with the outside environment through the outside surface by means of convective heat transfer and radiation heat transfer. But compared with the heat convection, the radiation has little influence on the heat transfer. So the heat convection was the main factor consideration in the calculation. In addition, the rotation of the drive member and the outside surface of the end cover may cause the air movement to some extent when the magnetic powder clutch works, the radiation coefficient rises with the air flow rate and it can be obtained from the following expression [8]

$$\eta = \eta_0 \times \left(1 + r\sqrt{v}\right), \qquad (13)$$

where η_o is free convection heat transfer coefficient and its value was determined as 8W/m^2 • K; r is the coefficient which is related to the surface area of the passing airflow and its empirical value is 0.8～1.2; and v is the relative velocity between the cooling surface and the air, m/s.

4 Temperature Field Analysis Model of the Magnetic Powder Clutch

Calculation and analysis of the temperature field distribution and change of the magnetic powder clutch under various operating conditions was completed based on the following steps: selecting the element type, defining the material properties, building two-dimensional model, meshing, defining the boundary conditions, solving and post-treatment. In order to improve the computational efficiency, several hypotheses and approximate treatment methods were put forward as follows in terms of the actual structure of the designed magnetic powder clutch, the heat source and the analysis target.

(1) It was approximately considered that the temperature distribution along the circumference direction of the magnetic powder clutch was uniform, so the physical model was simplified as a two-dimensional axisymmetric model.

(2) The components of the magnetic powder clutch combined closely, and the influence of the thermal contact resistance on the heat conduction was ignored.

(3)The influences of the thread holes, fabrication holes and the magnetic powder baffle ring in structure body on the temperature distribution were ignored.

(4) The complex parts of the end cover were simplified to reduce the unnecessary modeling and to facilitate grid.

(5) The distribution of the heat source intensity in the working gap was uniform.

(6) Assuming that the working temperature of the magnetic powder clutch varied in a narrow range and the heat conduction coefficient of the material changed little with the temperature, so the heat conduction coefficient of the material was determined as the constant and its value was that of 25℃.

The simplified two-dimension geometry model was shown in Fig.2. Several important temperature measurement points on the magnetic powder clutch were defined in the diagram. These measurement points are: the measurement point A of working clearance center, the measurement point B of excitation coil center, the measurement point C that is on the right end face of the magnetic yoke, and the measurement point D that is on the outside cylinder surface of the outside driving member.

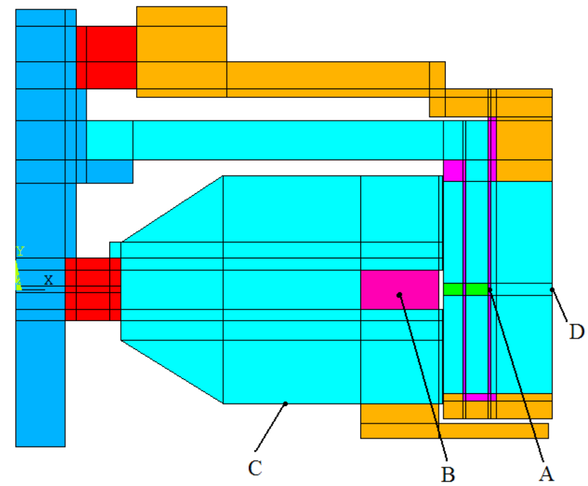

Fig.2. Simplified Two-dimension Geometry Model

The definition of the boundary conditions for the solving model was as follows. The initial temperature of the object was the first type of the boundary condition, and the value was 25 ℃. The working gap and the exciting coil are the inner heat sources, and the heat source intensity imposed on their cross sections respectively under corresponding working conditions was the second type of the boundary condition. The temperature and the convection heat transfer coefficient of the air medium which contacts the clutch were the third type of the boundary condition, and the temperature was the constant of 25 ℃ and the convection heat transfer coefficient can be calculted by the formula (13).

4.1 Analysis results under unning condition of extremely low speed

Extremely low speed running condition is a kind of extreme operation condition for the vehicle. Under this running condition, the magnetic powder clutch is in a slip state, and the working gap was heated because of the slip power loss. At the same time, the excitation coil of the clutch is also heated because of a certain amount of energy consumption. The temperature of the magnetic powder clutch components rises continuously under the action of heat sources. Fig.3 showed the temperature change curve of the measurement points of A, B, C and D on the magnetic powder clutch over the time. From Fig.3, we can see that:

(1) The temperature of each measurement point changed slowly over time and tended to be a equilibrium state, the corresponding equilibrium point temperature of the measurement point A was about 130 ℃, and the corresponding equilibrium point

temperature of the measurement point B was about 60 ℃.

(2) The temperature curve of the point A was coincided basically with that of D, and the temperature curve ofthe point B was coincided basically with that of C, which illustrated that the outside surface temperature of the drive member can accurately reflect the working state of the magnetic powder in working gap and the outside surface temperature of the magnetic yoke can accurately reflect the working state of the excitation coil.

Therefore, the research scheme was determined from the experimental point of view that the research of the working state of the magnetic powder clutch can be changed to the research of the temperature of the outer drive member outside surface, and that the research of the working status of the excitation coil can be changed to the research of the outside surface temperature of magnetic yoke.

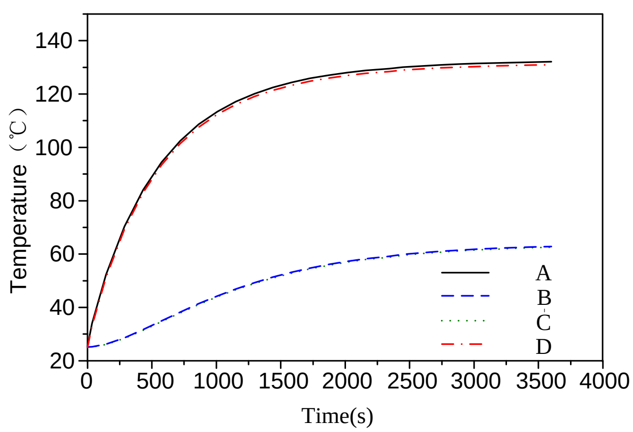

Fig.3. Temperature change of the measurement points of A,B,C and D over time under the running condition of extremely low speed and slip

Fig.4 showed the temperature distribution when the temperature of the magnetic powder clutch reaching equilibrium. As can be seen from the Fig.4, the temperature distribution near the working gap area was higher than other aeras and the highest temperature was about 132℃; the temperature of the magnetic yoke assembly area was lower and its minimum temperature was 61 ℃; and the temperature of the bearing between the end cover and output shaft was about 124 ℃ which exceeded the recommended value for the ordinary bearing about 80 ℃. Therefore the bearings was chosen and its bearing temperature is above 150 ℃.

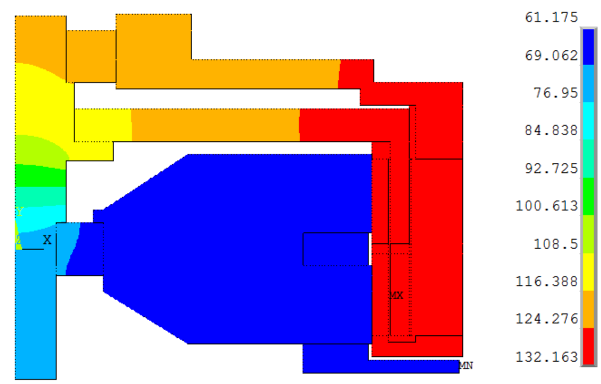

Fig.4. Temperature distribution of the MPC under running condition of extremely low speed and slip

4.2 Analysis results under running condition of full load

Running condition of full load is another kind of limit condition for vehicles. Under this running condition, the driving member and the driven member of the magnetic powder clutch are in a mating state and there is no slip power loss. However, the excitation coil should be provided with high current to satisfy the demands of torque transmission, which caused the heat intensity of the copper loss to be great. Fig.5 showed the temperature change curve of the measurement points of A and B on the magnetic powder clutch over the time. As can be seen from the Fig.5, the equilibrium temperature of the important parts of magnetic powder clutch was far less than their maximum service temperature, and it was also far less than their driving temperature under the low speed and slip condition. So it was concluded that the heat generated by slip was the main cause for the temperature rise of the magnetic powder clutch.

The temperature distribution of the magnetic powder clutch under the full load running condition was shown in Fig.6. As can be seen from the Fig.6, the highest temperature distribution was in the area of the magnetic yoke and its highest temperature was 60℃, which satisfied the requirement for long time operation.

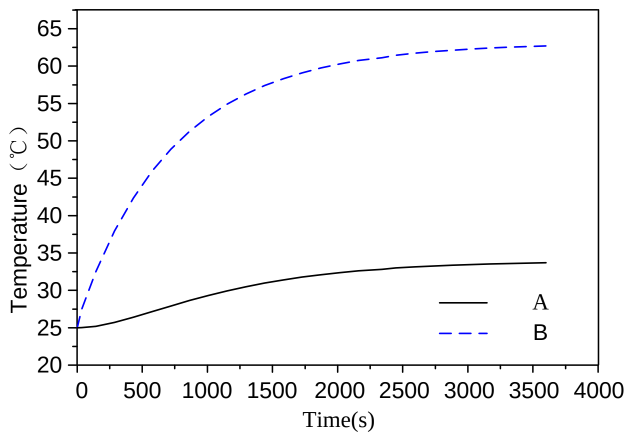

Fig.5. Temperature change of the measurement points of A and B over the time under the full load running condition

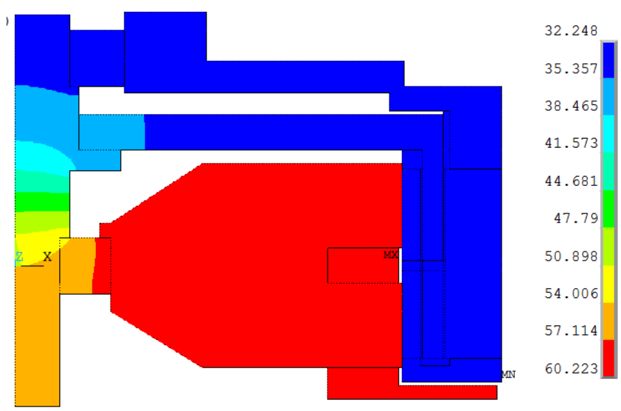

Fig.6. Temperature distribution of the MPC under the full load running condition

4.3 Analysis results under running condition of medium load

Running condition of medium load is one of the most common conditions for minivans and economical type passenger cars. Under this running condition, the driving member and the driven member of the magnetic powder clutch are in a mating state and there is no slip power loss. In addition, the required rotating torque was less than that of the full load condition, so the excitation current required was lower. Therefore the heat intensity of the copper and the temperature rising were correspondingly smaller. The temperature change of the measurement point of A and B on the magnetic powder clutch over time under the medium load running condition of was shown in Fig.7.

The temperature distribution of the magnetic powder clutch under the medium load running condition was shown in Fig.8. As can be seen from the Fig.8, the highest temperature distribution was in the area of the magnetic yoke and its highest temperature was 40℃, which satisfied the requirement for long time operation.

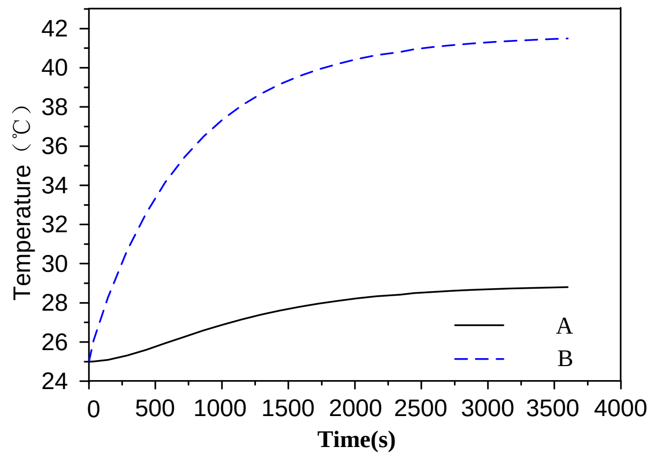

Fig.7. Temperature change of the measurement point of A and B over time under the medium load running condition

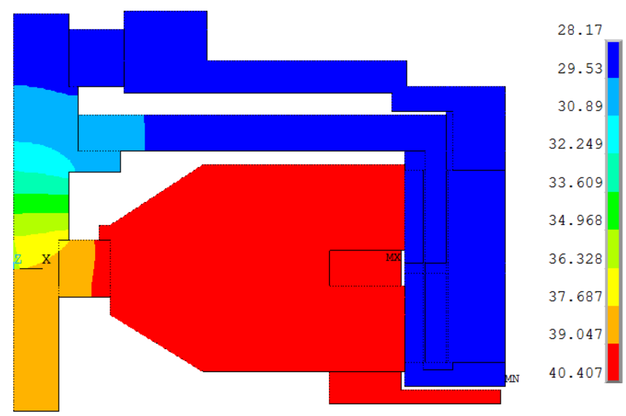

Fig.8. Temperature distribution of the MPC under the medium load running condition

Through the analysis of the temperature change and distribution of the magnetic powder clutch under three typical stability conditions, it can be concluded that the temperature rise of the magnetic powder clutch was the largest under the running condition of extremely low speed for its worst working environment, and that the equilibrium temperature of the important parts of the magnetic powder clutch met the using requirement. And it was also illustrated that the designed magnetic powder clutch for vehicle has a high working reliability.

5 Test research

To validate the temperature field analysis model of the magnetic powder clutch and the simulation results, the prototype of the magnetic powder clutch and the test bench were developed. Then the working temperature rise of the magnetic powder clutch was tested under specific conditions. Fig.9 showed the developed prototype of the magnetic powder clutch.

Fig.9. Prototype of the MPC for vehicles

The driving members of the magnetic powder clutch prototype include the outer driving part and the inner driving part and they are connected by the link ring. There is a powder hole in the outer driving member and a guidance channel on its internal cylinder to improve the magnetic powder fluidity. The inner driving part is equipped with a magnetic isolated ring. The driving member assembly was shown in Fig.10.

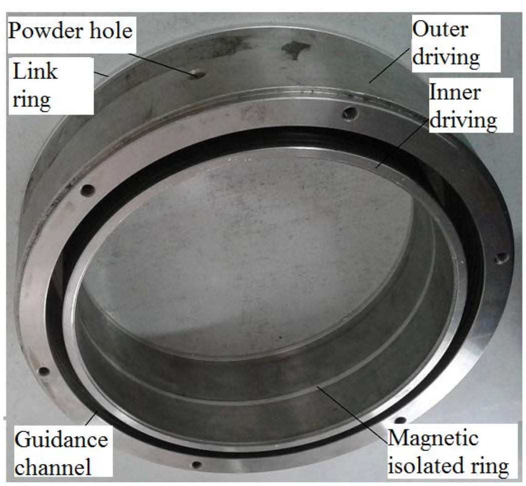

Fig.10. Driving member assembly

The driven member is also equipped with a magnetic isolated ring and it is connected with the output shaft by screw. Several magnetic powder flowing openings was designed and distributed on the driven member to improve the filling rate of the lower working face of the magnetic powder clutch. The driven member assembly was shown in Fig.11.

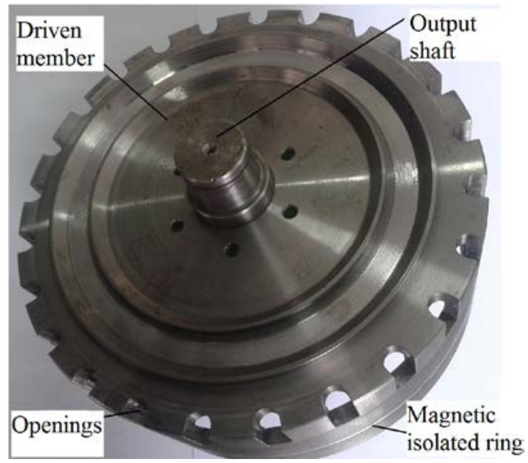

Fig.11. Driven member assembly

The magnetic yoke is composed of the left part and the right part and they are connected by bolts. The excitation coil is installed between the left part and the right part. The magnetic yoke assembly was shown in Fig.12.

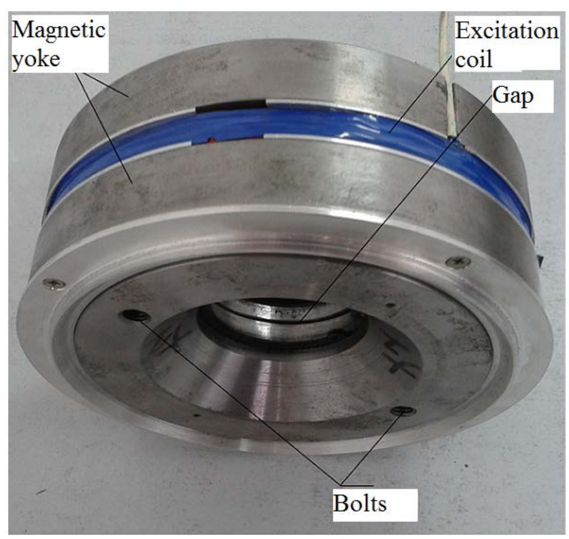

Fig.12. Magnetic yoke assembly

According to the regulations of National Profession Standard for the performance test method, the test platform for the performance test of the magnetic powder clutch was designed. The test platform is composed of frequency-modulated motor, torque-speed transducer, magnetic powder clutch, DC power supply, inertial flywheel and magnetic powder brake, and its composition schematic diagram was shown in Fig.13.

(1) Instead of the engine, the frequency-modulated motor was used as the power source to simulate the operation condition of the engine. The YVP type of asynchronous frequency-modulated motor was selected for the test. The asynchronous motor speed was determined by the motor structure and the power supply frequency. So the asynchronous motor speed can be regulated by varying the power frequency. In order to raise motor efficiency, the motor stator voltage may change with the frequency regulating. The inverter is required to use in conjunction with the frequency-modulated motor. The PI7100 type of frequency converter was selected and used for the test and its maximum speed was 5000r/min.

(2) CGQ-20 type of torque-speed transducer was selected and used for the test and it has the advantages of good stability, good stability reliability, fast response, high sensitivity and high measure precision. It measured the speed and the torque of the input and output end components on the basis of phase shift theory and electro-magnetic conversion principle. Its rated torque is 200 N.m, maximum rotation speed is 6000 r/min, measurement error is less than 0.5%, and it can meet the test requirement. The torque-speed transducer 1 was used to measure the torque and speed of the power input end of the magnetic powder clutch. The torque-speed transducer 2 was used to measure the torque and speed of the output end of the magnetic powder clutch. In addition, the instruments were used to display the output signal of the CGQ-20 type of torque-speed transducer.

(3)The inertial flywheel was used to simulate the rotation of rotating parts of the vehicle. The moment of inertia can be equivalent to the total moment of inertia of the engine flywheel that transformed by that of the vehicle wheels and other rotating parts, and it can be determined by ideal equation of the kinetic energy balance for vehicle and the kinetic energy when the vehicle worked in the highest shift.

(4) The magnetic powder brake was in conjunction with the inertia flywheel to simulate the vehicle load. It has a good linear relation between the loaded torque and the excitation current. CZ20 type of magnetic powder brake was selected for the test and it has the advantages of fast response and simple structure. For the selected brake, its rated excitation current is 2.5A, brake torque is 200N.m, and permissible slip power is 10kW.

(5) DC power supply 1 was used to provide excitation current for the magnetic powder clutch, and DC power supply 2 provided excitation current for the magnetic powder brake. WLK-3A type of DC current source was selected and used for the test and its rated output current is 3A.

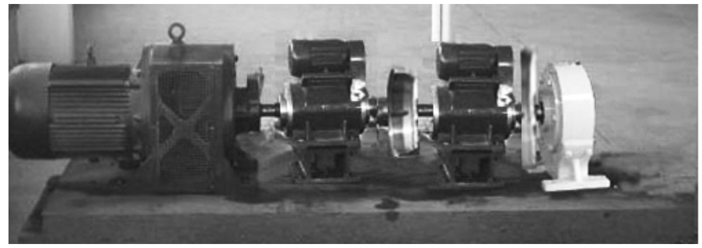

Fig.13. Performance test bench of the MPC

The surface temperature of the magnetic powder clutch was measured by using AZ8868 type of infrared thermometer. The test environment temperature was 25.6℃. The simulating test condition is the operating condition of the magnetic powder clutch when vehicle runs at very low speed. After the magnetic powder clutch operated under that simulating condition for 40 minutes, the average temperature of three test areas were measured. Three test areas are yoke assembly right end surface, outside cylindrical surface of the outer driving member and the bearing end surface. The temperature measurement of the prototype surface was shown in Fig.14. The test results and simulation results under the same operation condition were shown in Table 3.

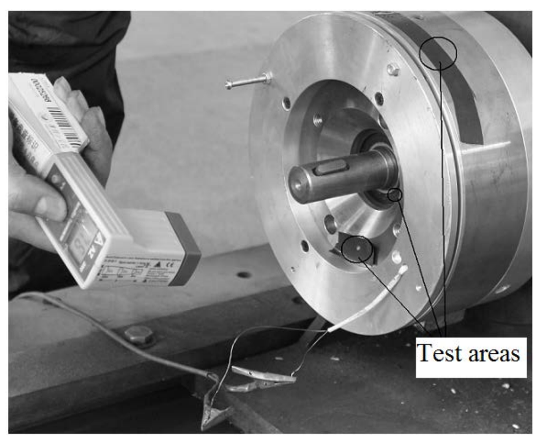

Fig.14. Temperature measurement of the prototype surface

Table 3 Surface temperature test results and simulation results of the MPC

Test area	temperature /℃	
	Test results	Simulation results
yoke assembly right end surface	57.2	61.04
outside cylindrical surface of the outer driving member	132.6	135.96
bearing end surface	69.9	72.87

As can be seen from the Table 3, there is a certain deviation between the test results and the simulation results, but the deviation does not exceed 7%. So it can be concluded that the temperature field analysis model of the magnetic powder clutch established in this paper is accurate. The results offer the evaluation basis for the operation reliability and the design feasibility of the magnetic powder clutch, and the designed magnetic powder clutch for vehicle works reliably.

6 Conclusions

The heat source intensity and thermal parameters of the magnetic powder clutch were determined based on the operating state analysis of the magnetic powder clutch under three typical stable conditions. The temperature finite element model was established and the temperature distribution and change were analyzed. The simulation results verify that the designed magnetic powder clutch is feasible and it has high working reliability. The test prototype and test bench for vehicle magnetic powder clutch was developed. The temperature measuring test for the magnetic powder clutch under specific conditions was completed. The test results showed that the temperature field analysis model of the designed magnetic powder clutch is accurate and the designed magnetic powder clutch meets the requirement for working.

Acknowledgements: This work was supported by Jiangsu Provincial University Natural Science Research Project of China (No. 12KJD580001).

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