

# Temperature Field Analysis of Magnetorheological Fluid Dynamometer

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**Abstract:** Based on heat conduction theory, the temperature field of magnetorheological fluid (MRF) dynamometer is studied using finite element method. The device produces a large amount of heat in the work which makes its temperature rise. Temperature has influence on rheological properties of MRF which affects the working stability of MRF dynamometer. The device working condition is determined by the temperature field analysis.

**Key words:** magnetorheological fluid; temperature; dynamometer; finite element

## I. Introduction

Magnetorheological fluid(MRF) is a kind of new intelligent material which is sensitive to magnetic field. It is composed of magnetic particles, base and surface active agent. Under no external magnetic field it is characterized by free flow state. Under external magnetic field it translates from free flow state into semisolid. This translation is instantaneous and reversible in which shear yield is controllable. Due to MRF's rapid reaction, reversible change and easy to control, it is more and more widely used in the damping vibration control, produce's surface polishing and mechanical power transmission <sup>[1]-[6]</sup>.

MRF dynamometer utilizes the MRF characteristic which is reversible, quick reaction and easy to control. It uses MRF as working medium and it take advantage of MRF's shear yield stress to transfer torque which is used to test engine performance. MRF dynamometer produces a large amount of heat in its work which affects MRF's power transmission effect. Weiss had studied the temperature effect of MRF <sup>[7]</sup>. Sheng Pan had analyzed the temperature's effect on the stability of MRF's yield stress <sup>[8]</sup>. Song Chen had analyzed the influence of temperature on MRF and transmission performance <sup>[9]</sup>. There has been no study on the temperature effect on MRF dynamometer's transmission performance. Therefore, it is necessary to analyze the temperature distribution.

## II. MRF DYNAMOMETER MODEL

### 2.1 Working Principle of MRF Dynamometer

Working principle of MRF dynamometer is shown in figure 1. MRF dynamometer is mainly made of main shell, right shell, left shell, coil, turnplate and MRF. When the current does not pass into coil, this is to say no external magnetic field H, MRF is liquid. MRF dynamometer depends on MRF's viscosity to brake. At this time, braking torque is small so that the working gap generates less heat. When the current passes into coil, the working gap generates external magnetic field H. MRF instantly translates from liquid into semisolid. MRF dynamometer depends on MRF's viscosity and yield stress caused by magnetic field to brake which has bigger braking torque. Therefore, the working gap generates amounts of heat.

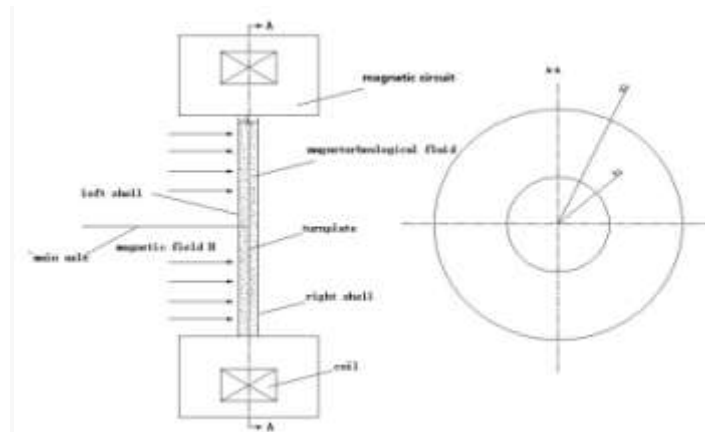


Figure1: Working principle of MRF dynamometer

2.2. Structural Model of MRF Dynamometer

Structural model of MRF dynamometer is shown in figure 2. It is mainly composed of main axle, nonporous water jacket, nonporous end cover, turnplate, right shell, out ring, MRF, enameled wire, magnetic shield, coil, left shell, perforated water jacket, perforated end cover.

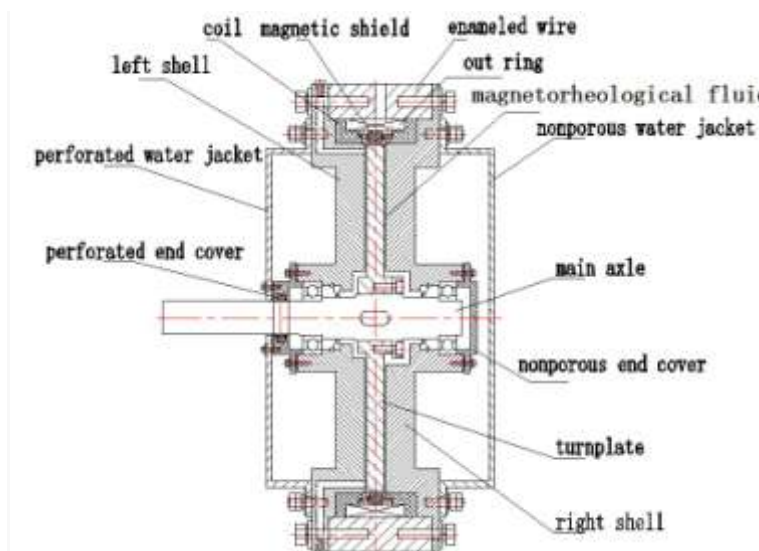


Figure2 Structural model of MRF dynamometer

2.3. Basic Control Equation

2.3.1. Heat Conduction Model

MRF dynamometer’s internal temperature distribution can be represented with heat conduction differential equation:

$$\frac{\partial}{\partial x} \left( K_{xx} \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} \frac{\partial T}{\partial z} \right) + \Phi_v = \rho c \frac{dT}{dt}$$

In equation:  $\Phi_v$  is MRF heating power per unit volume,  $\rho$  is material density,  $c$  is material specific heat,  $K_{xx}$ 、 $K_{yy}$ 、 $K_{zz}$  is the thermal conductivity coefficient of x,y,z..

2.3.2. Heating Rate Calculation

MRF average calorific power per unit volume  $\Phi_v$  can be expressed as:

$$\phi_{VA} = \frac{P}{V} = \frac{M\omega}{V} = \frac{2 R_2^3 - R_1^3}{3 R_2^2 - R_1^2} \tau \omega$$

In equation: P is power,  $\omega$  is the angular velocity, V is MRF volume, M is torque, h is the working gap,  $R_1$ ,  $R_2$  is the inner and external diameter of turnplate,  $\tau$  is MRF shear yield stress.

2.3.3. Boundary Condition

Exerting boundary conditions to MRF dynamometer are as follow:

- 1) Initial boundary condition is the time  $t=0$ . Each point temperature is  $T_0$  choosing  $T_0 = 20^\circ\text{C}$ .
- 2) Convective heat transfer is between outer surface of dynamometer and external air:

$$K_n \frac{\partial T}{\partial n} = -\alpha(T - T_0)$$

In equation: n is the direction.  $K_n$  is the thermal conductivity coefficient of the n direction.  $\alpha$  is the convective heat transfer coefficient. Considering the effect of radiation heat dissipation, according to the experience value,  $\alpha = 9.7$ .

2.3.4 Finite Element Calculation Model

Assuming that MRF dynamometer’s material physical properties do not change with temperature. Boundary conditions keep constant. If the finite element is used to calculate the differential equation, the differential equation needs to convert into the form which is as the follow:

$$[C]\{\dot{T}\} + [K]\{T\} = \{Q\}$$

In equation: [K] is the transmission matrix including thermal conductivity and convective coefficient. [C] is the specific heat matrix considering the increase of system internal energy. {T} is the node temperature vector.  $\{\dot{T}\}$  is the temperature derivative of time. {Q} is the node heat flow rate including heat generated.

**III. NUMERICAL CALCULATION**

**3.1. Calculation Parameters**

MRF dynamometer’s internal and external diameter are  $R_1 = 35\text{mm}$ ,  $R_2 = 148.5\text{mm}$  respectively. The working gap is  $h = 1.5\text{mm}$ . Material physical properties of MRF dynamometer is as shown in table 1.

Table1 Material Physical Properties of MRF Dynamometer

Name	Material	Density (Kg/m <sup>3</sup> )	Thermal conductivity (W/m <sup>2</sup> .K)	Specific heat (J/Kg.k)
Nonporous water jacket	1Gr18Ni9Ti	7850	18	460
Perforated water jacket	1Gr18Ni9Ti	7850	18	460
Right shell	A3	7800	52	486
Outer ring	A3	7800	52	486
Enameled wire	Cu	8900	393	390
coil	A3	7800	52	486
MRF	MRF	3000	1	1000
turnplate	A3	7800	52	486
Main axle	1Gr18Ni9Ti	7850	18	460
Left shell	A3	7800	52	486
Perforated end cover	1Gr18Ni9Ti	7850	18	460
Nonporous end cover	1Gr18Ni9Ti	7850	18	460
Magnetic shield	1Gr18Ni9Ti	7850	18	460
air	air	0.946	0.0321	1009

### 3.2. Calculation Results

According to the structural characteristic of MRF dynamometer, using finite element analysis software combined with the heating rate and the boundary conditions gets the steady state temperature distribution when the power is 600W as shown in figure 3 and figure 4.

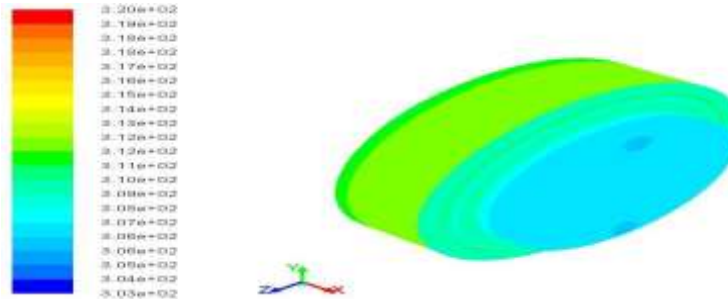


Figure3 Surface temperature distribution of MRF dynamometer

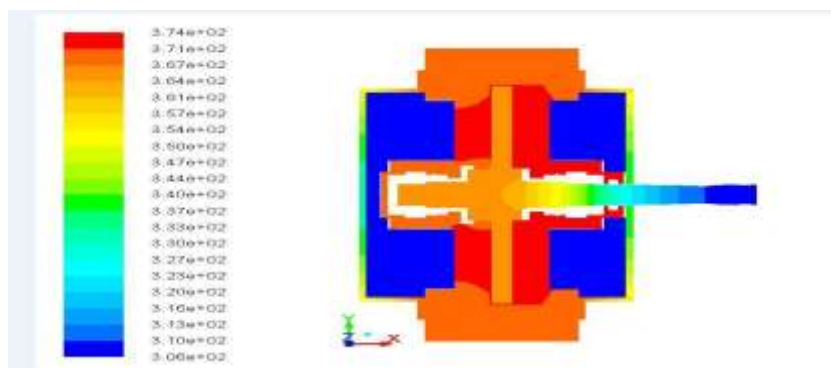


Figure4 Temperature distribution on cross-section of MRF dynamometer

From the above figure, we can find that the lowest temperature point is located in the end of main axle and the highest temperature point is between inner disc and outer disc. At the same time, it is also showed the maximal temperature is less than the allowable temperature of MRF.

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