Magnetic Force on Particles in Magnetorheological Fluids under Cylindrical Magnet

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1. Introduction

As a kind of smart materials, magnetorheological fluids (MRFs) are applied in dampers, brakes, shock absorbers, and high precision polishing for its reversible change in particle behavior under external magnetic field [1-3]. Generally, MRFs are composed of magnetic particles, nonmagnetic carrier fluid and additives [4]. The dipole-dipole interactions between magnetic particles is the reason that result in this reversible changes [5]. To study the effects of applied external magnetic field on particle behaviors in MRFs, scholars have carried out number of numerical simulations in recent years. However, for the difficulties in deviating the magnetic force acting on magnetic particles in the practical magnetic field, generally, magnetic fields applied in the numerical simulations of MRFs are uniform magnetic field or unidirectional gradient magnetic field [6-8]. Whereas, because of the differences between the magnetic fields applied in simulation, the simulation results of the former studies using uniform or unidirectional magnetic field have huge limitation in instructing the phenomenon analysis and process parameter prediction in MRFs preparations. Thus, in this study, the magnetic forces acted on magnetic particles under a cylindrical permanent magnet is studied.

2. Magnetic Force on magnetic particles

The analytical model of MRFs under cylindrical magnet is shown in Fig.1. This model is composed of MRF, trough and a cylindrical permanent magnet. The cylindrical permanent magnet locates right under the system formed by the MRF and the trough with radius *a* and height *h*. The gap between the cylindrical magnet top surface and the MRFs subsurface is called excitation gap, shown as h_1.

The magnetic field generated by cylindrical permanent magnet is generated according to the vector magnetic potential method. The geometrical relationship in a cylindrical magnet system is shown in Fig. 2. The magnetic field is shown as in Eq. (1).

$$\boldsymbol{B}_{ex} = \frac{\mu}{4\pi} \oiint_{s} \frac{\boldsymbol{J}_s \times \boldsymbol{R}}{|\boldsymbol{R}|^3} dS \qquad (1)$$

Based on the magnetism theory, magnetic particles under external magnetic field will be magnetized [9]. Thus, the magnetic particles are under the effects of magnetic field combined by cylindrical magnet and magnetic couples. The spatial positional relation between the dipoles and the cylindrical magnetic field system is shown in Fig. 3. The magnetic flux density B_j at particle *i* generated by particle *j* can be solved as in Eq. (2)

$$\boldsymbol{B}_j = -\frac{\mu_f}{4\pi r_{ij}^3} \boldsymbol{m}_j + \frac{3\mu_f}{4\pi r_{ij}^5} \left(\boldsymbol{m}_j \cdot \boldsymbol{r}_{ij} \right) \boldsymbol{r}_{ij} \qquad (2)$$

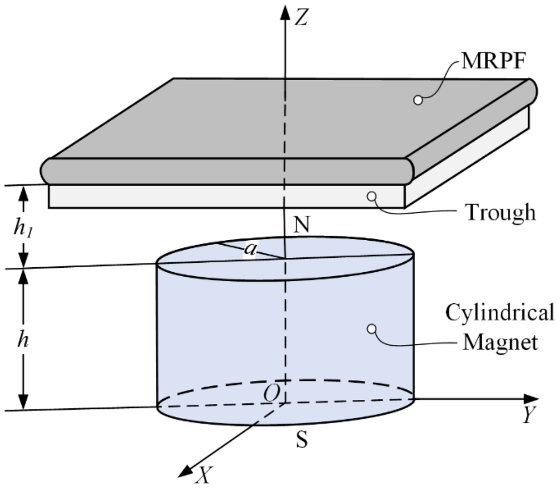

Fig.1 Analytical model of MRFs under cylindrical magnet

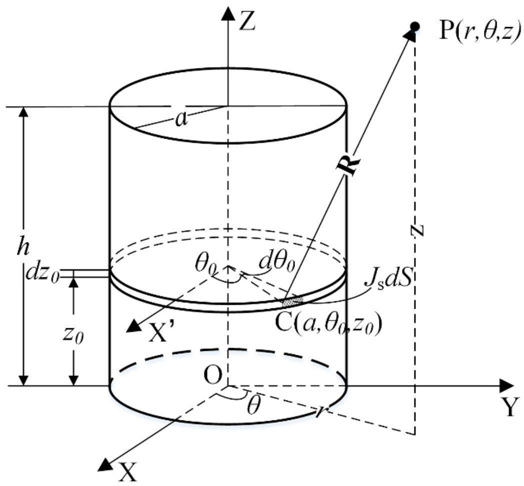

Fig. 2 cylindrical magnet system

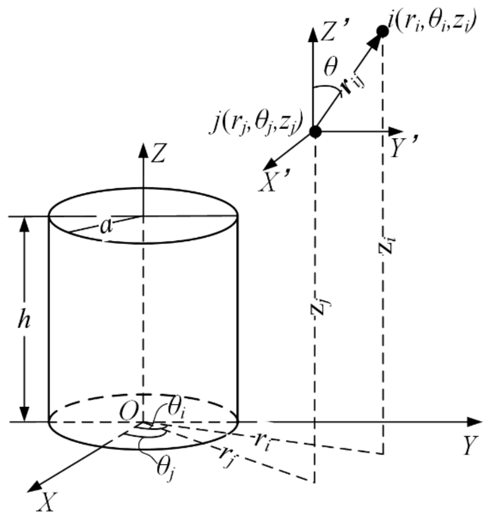

Fig. 3. Spatial positional relation between the dipoles and the cylindrical magnetic field

In magnetism theory, the magnitude of magnetic dipole moment and magnetic field gradient determine the interaction of magnetized particles with the magnetic field and with each other [8]. The magnetic interaction force F_i acting on magnetized particle *i* is described as Eq. (3)

$$\begin{aligned} \boldsymbol{F}_i &= \boldsymbol{m}_i \cdot \nabla \boldsymbol{B}_{ex} + \boldsymbol{m}_i \cdot \sum_{j \neq i} \nabla \boldsymbol{B}_j \\ &= k_2 \left(F_{i,x} \boldsymbol{e}_x + F_{i,y} \boldsymbol{e}_y + F_{i,z} \boldsymbol{e}_z \right) \end{aligned} \tag{3}$$

3. Conclusion

In this study, an analytical model is developed to study particle behaviors in MRFs under cylindrical magnet. The magnetic field generated by cylindrical permanent magnet and the magnetic force acting on magnetic particles in the permanent magnetic field are solved by mathematical derivation. This results is later used in the simulation of particle behaviors in magnetorheological polishing fluids.

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