Modeling Ferrofluid Flow in an Annular Gap Moving with Reciprocating Shaft

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Introduction: Ferrofluids have been successfully used in the seals for rotary shafts, but few studies focus on the reciprocating motion seals. Since the completely different operational regimes, previous experiences on the rotary motions could not be directly applied on the cases for reciprocating shafts. In this study, we present a simplified model to describe the process that a shaft linearly moving in a cylinder housing, which coated with a layer of ferrofluids.

Computational Methods: Considering the geometry is axisymmetric, firstly we solve Maxwell's equations in the full modeling domain, then a magnetic volume force would be imposed to couple the resulting magnetic field to the flow field described by the Navier-Stokes equations.

$$-\nabla\cdot\left(m_0\nabla f - m_0\mathbf{M}\right) = 0$$

$$\mathbf{B} = \begin{cases} m_0 m_{r,mag}\mathbf{H} + \mathbf{B}_{rem} & \textit{permanent magnet} \\ m_0\left(\mathbf{H} + \mathbf{M}_{ff}(\mathbf{H})\right) & \textit{ferrofluids} \\ m_0\mathbf{H} & \textit{air} \end{cases}$$

$$\nabla\cdot\mathbf{u} = 0$$

$$r\left(\frac{¶\mathbf{u}}{¶t} + \mathbf{u}\cdot\nabla\mathbf{u}\right) = -\nabla p + r\mathbf{g} + h\nabla^2\mathbf{u} + m_0\mathbf{M}\nabla\mathbf{H}$$

The Level Set method was introduced to capture the free interface of the ferrofluid film.

$$\frac{\partial A}{\partial t} + \mathbf{u}\cdot\nabla A = g\nabla\cdot\left(e\nabla A - A(1-A)\frac{\nabla A}{|\nabla A|}\right)$$

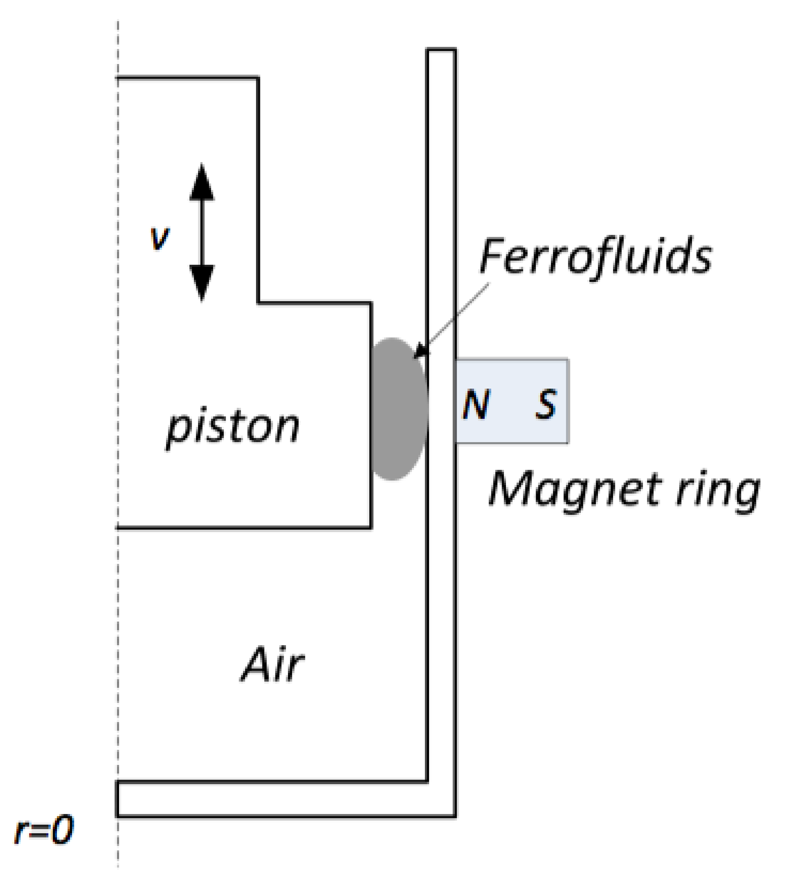

Figure 1. Geometric representation of the model

Results: Assuming the ferrofluids as linear magnetic materials. The reciprocating motion of the piston was divided into four stages.

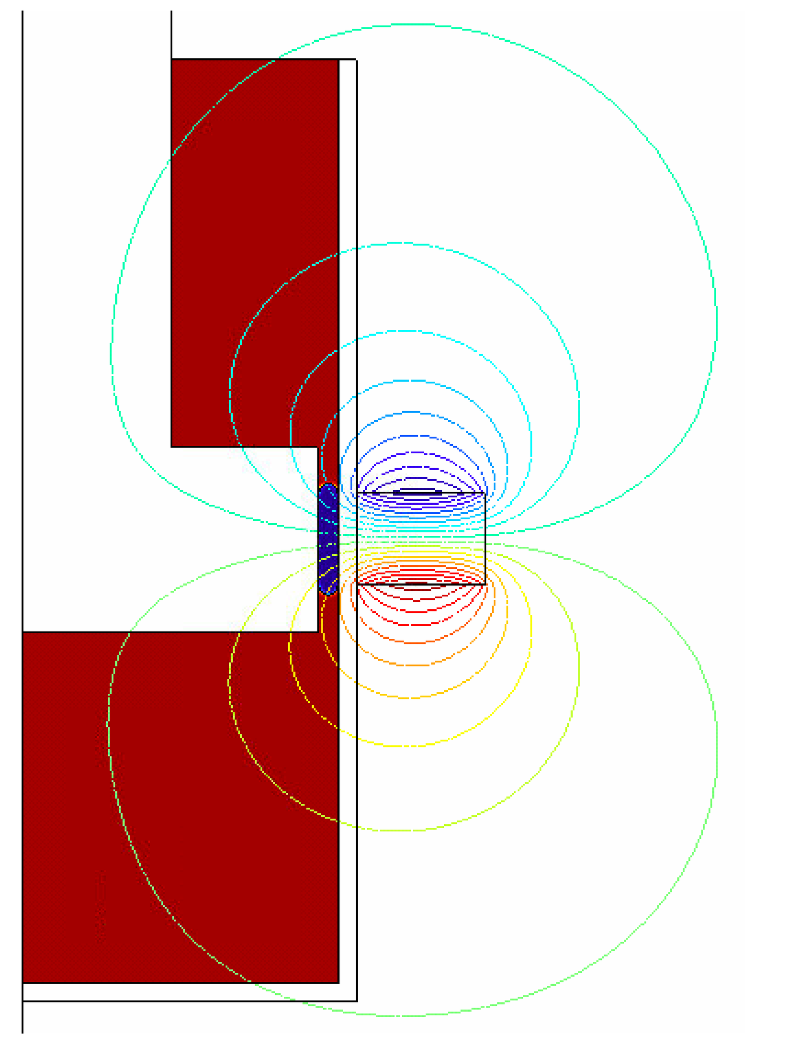

Figure 2. ferrofluid film interface

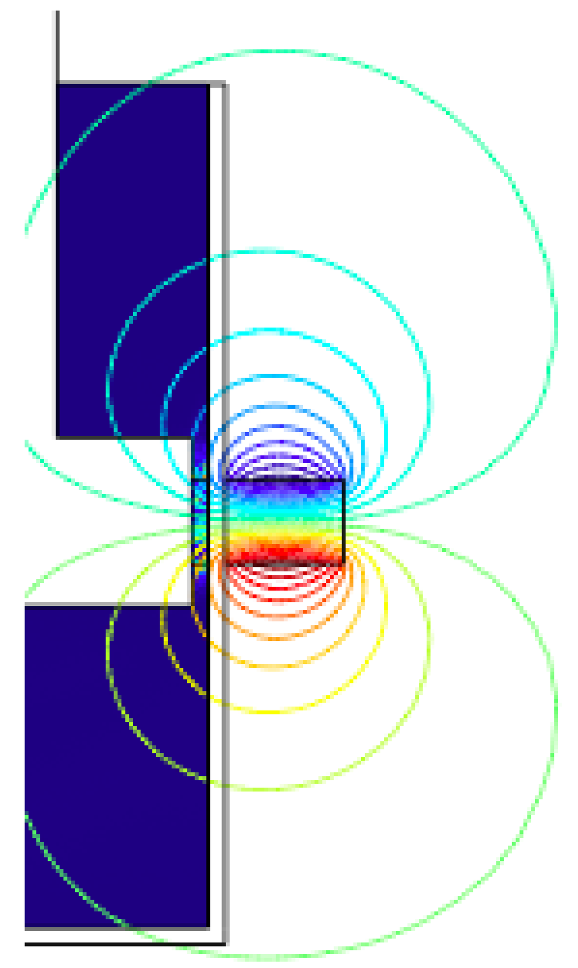

Figure 3. ferrofluid film velocity field

Variable	Value	Units
Density	1210	Kg/m^3
Dynamic Viscosity	6	*Pa·s*
Initial Magnetic Susceptibility	2.63	
Surface Tension	0.029	*N/m*

Table 1. Physical properties of ferrofluids (EFH1 – Ferrotec©)

Conclusions: The results shows that the external magnetic field increases the load capacity of ferrofluid seal when the frequency of shaft lower than a critical value. However, considerable inertia force due to high frequency reciprocating motion weakened the function of magnetic fore, and caused the loss of ferrofluids.

References:

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