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# A study on the pinch mode of magnetorheological fluid flow

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## ABSTRACT

Magneto-Rheological fluid (MR fluid) is a smart material whose rheological characteristic can be altered with the external magnetic field. Usually, according to the configuration of the magnetic field in the device, MR fluid can be divided into four operating modes: flow, shear, squeeze and pinch mode. The pinch mode can change the gap size of the flow channel when it is applied to the MR damper. Thus, it can be expected that the damping coefficient can be changed by the applied magnetic field level. In the last few years, the interest of pinch mode has been increased. However, some phenomena associated with MR flu id behavior in this mode are still not clear. Therefore, this study identifies how the damping coefficient is changed in detail when the pinch mode is applied to the damper through the theoretical analysis. After presenting the configuration of the pinch mode MR damper, the magnetic analysis is conducted to define magnetic circuit and analyze the relationship between the magnetic intensity and applied current. A quasi-static flow analysis is undertaken to identify the damping force variation in different conditions on the basis of Navier-Stokes equation.

## 1. INTRODUCTION

It is well known that magneto-rheological (MR) fluid is one of the smart materials whose rheological property can be altered by a magnetic stimulus (Vicente 2011, and Ghaffari 2015). This fluid is composed of micro-sized magnetic particles dispersed in silicone oil. When the magnetic field is applied to the fluid, the magnetic particles align in the field direction and form the chain-like structures. Because of this effect, MR fluid has yield stress in the magnetic field and behaves like solid material. Because the so-called MR effect is reversible and very fast controlling high yield stress, the MR fluid has been utilized in various devices such as dampers, valves, mounts, and brakes (Imaduddin 2013, and Lee 2017). Moreover, according to the configuration of the magnetic field in the device, the MR fluid can be divided into four operating modes: flow,

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shear, squeeze and pinch mode. For the last decades, many types of researches have been reported to determine the characteristic of each mode (Sung 2005, and Horak 2018). However, the research on the pinch mode is relatively rare compared with the other operating modes of MR fluid. Consequently, the main technical contribution of this work is to formulate a mathematical model to identify the pinch mode behavior in MR fluid flow.

## 2. MODEL ANALYSIS

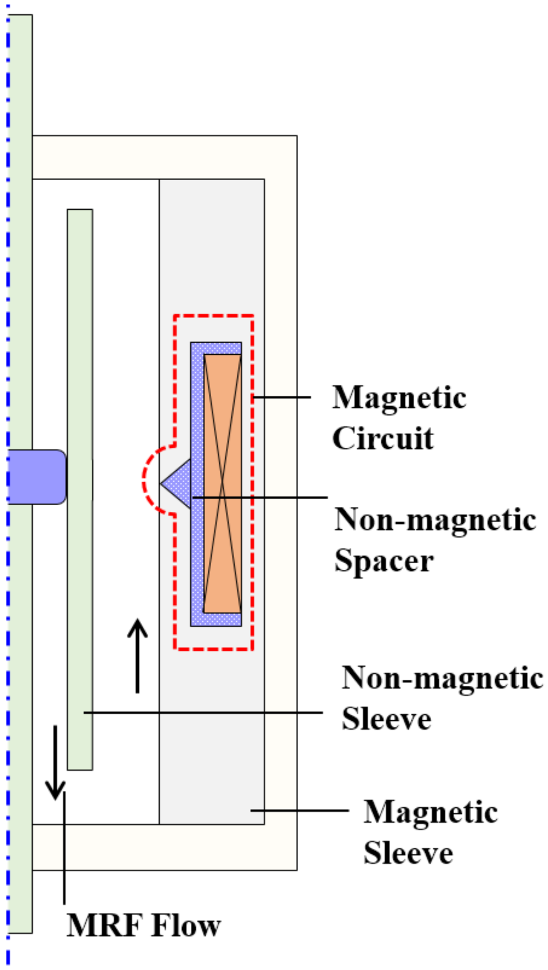


Fig. 1 Configuration of the pinch mode MR damper

Fig. 1 shows the configuration of the MR damper which has an annular flow channel. When the current is applied to the coil, the pinch mode is generated on the annular flow channel. The magnetic flux density on the flow channel can be presented as followed:

$$B_{mr} = NI \frac{\mu_0 \mu_{mr}}{\pi \sqrt{x^2 + y^2}} \quad (1)$$

Here, $N$ is the turn number of a coil and $I$ is the input current. And $\mu_0$ and $\mu$ are the magnetic permeability of vacuum, and relative permeability in each path. And $x$ and $y$ are horizontal and vertical distance between the specific point and nonmagnetic spacer. And the relation between the magnetic flux density and the yield stress of MR fluid can be presented as:

$$\tau_y = 21.662\, B_{mr}^{\;5} - 19.007\, B_{mr}^{\;4} - 86.83\, B_{mr}^{\;3} + 108.05\, B_{mr}^{\;2} + 25.142\, B_{mr}\ \text{(kPa)} \quad (2)$$

Fig. 2 presents the typical shear stress, $\tau_s$, and yield stress, $\tau_y$, in the annular flow channel of the pinch mode. In order to solve the pressure gradient, $R_1$, $R_2$, and $R_3$ should be solved by quasi-static flow analysis.

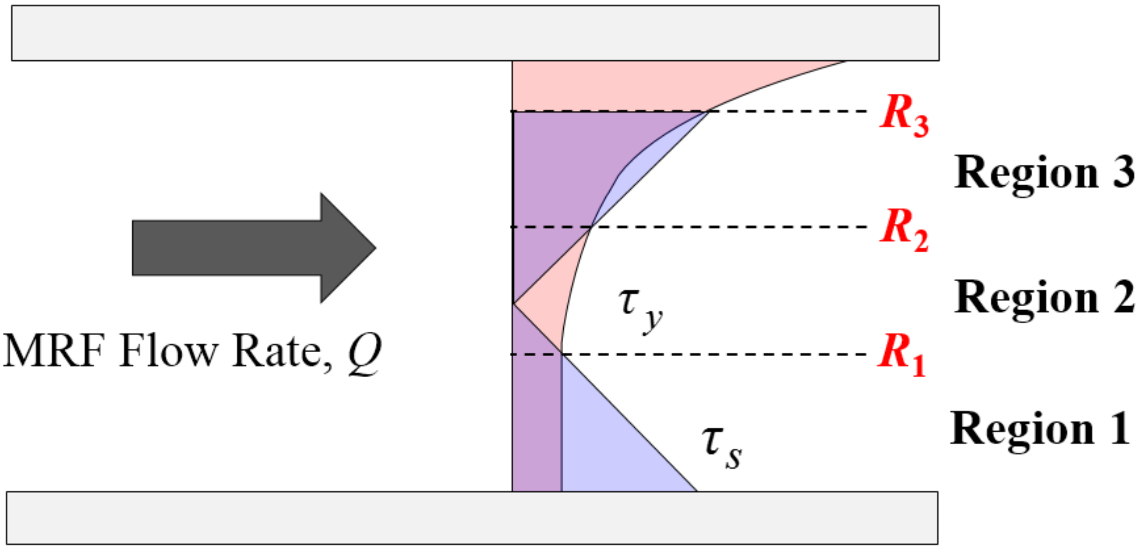


Fig. 2 Typical shear stress in the annular flow channel of the pinch mode

In this work, Navier-Stokes equation and Bingham plastic model of MR fluid is used, and three boundary condition is established to solve the three variables. Consequently, the block-up point, $R_3$, can be presented as shown in Fig. 3. It can be observed that the block-up region is increased as the input current is increased.

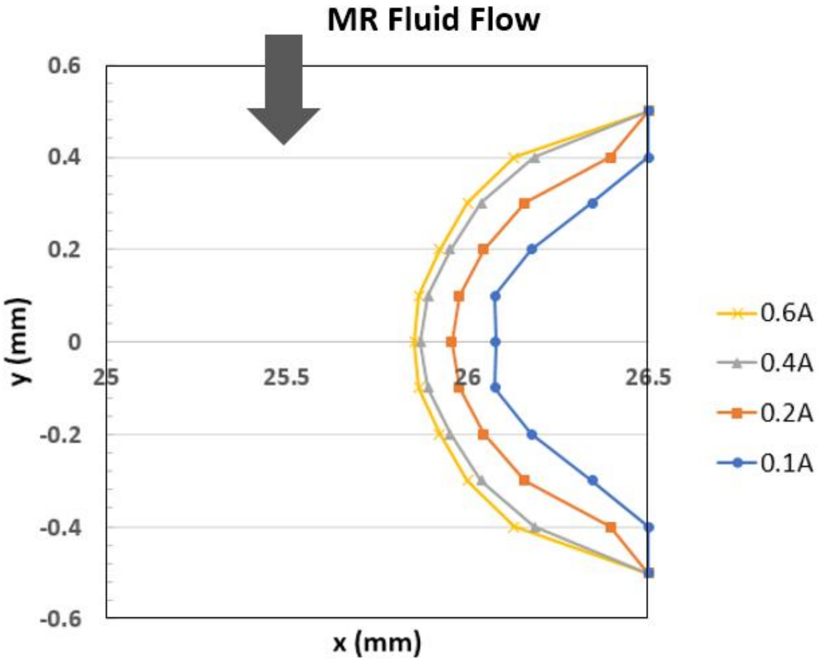


Fig. 3 Block-up point, $R_3$ in the different input current

## 3. CONCLUSIONS

Consequently, it can be estimated that the gap size of flow channel can be controlled by the applied current. That is, the pinch effect was verified by the analytical model. It should be remarked here that, damping force is investigated with gematric parameters of MR damper as the second phase of this work.

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