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A new magneto-rheological fluid actuator with application to active motion control

Suresh Kaluvan [a], Vinopraba Thirumavalavan [b], Soomin Kim [a], Seung-Bok Choi [a,*]

[a] Smart Structures and Systems Laboratory, Department of Mechanical Engineering, Inha University, Incheon 402-751, South Korea
[b] Department of Electrical and Electronics Engineering, National Institute of Technology Puducherry, Karaikal, Puducherry 609605, India

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ABSTRACT

A novel magneto-rheological fluid based actuator (MR actuator in short) is proposed for the micro level motion control application. The proposed MR actuator is working based on the principle of magnetic extension and contraction by the MR fluid sandwiched structure between the two electrode type coils. The key enabling concept in this work is to precisely control the biasing current of electrode-coil for achieving the desired displacement of the proposed actuator. The direction and amount of current input to the top and bottom electrode-coils decides the characteristics like contraction, extension and the force generated by the actuator, respectively. In order to undertake a proof-of-concept of the proposed actuator, a simple proportional-integral (PI) controller is designed and implemented in real time for the MR actuating system to control the desired displacement. The process parameters of the MR actuating system are obtained by applying a step input to the electrode- coils, and the PI controller are designed using internal model control (IMC) tuning rule. The experimental realization of the micro-level motion control is easily performed using the MR actuator. It is demonstrated from displacement tracking results that the proposed MR actuating system has a distinctive control characteristic in an active mode. Therefore, this salient control characteristic leads to wide and various applications, especially in micro electro mechanical systems (MEMS) devices fabrication.

1. Introduction

During the last few decades, tremendous effort has been made towards the development of actuators using smart materials. The characteristics of commercially available smart materials such as magneto-rheological fluid (MRF), magneto-rheological elastomer (MRE), electro-rheological fluid (ERF), piezoelectric material (PM), shape memory alloy (SMA), dielectric elastomer (DE) and ionic polymer (IP) are described in detail in-terms of actuating aspect in [1]. The enormous research work has been carried out in piezo electric material and shape memory alloy. The piezo electric actuators have advantages such as strong force, low actuation voltage, high energy efficiency, linear behavior, high acoustic quality, high speed and high frequency [2,3]. On the other hand, the SMA actuator has characteristics such as low stiffness, high displacement, thermally driven. Since SMA actuators are thermally driven, the response time of such actuator is low. Thus, the SMA actuators are slow and unsuitable for high frequency applications [4,5]. Another interesting smart material is magneto-rheological fluid, which changes its apparent viscosity with the application of magnetic field. So far, the magneto rheological fluid is extensively used in the design of various dampers and mounts for vibration control for the automobiles [6–13]. There are many other applications of MR fluid such as aircraft, high speed train, building protection [14,15]. In all previous works, MR fluid based devices and systems have been designed and operated in a semi-active control mode in which damping characteristics only can be controlled. To the authors' best knowledge the research work on MR applications based on active control mode in which dynamic actuating force is generated has not been reported.

Consequently, the technical novelty of this work is to propose a new type of MR actuator which is operated in active control mode instead of the semi-active control mode. The working principle of the proposed MR actuator is similar to piezoelectric actuator with two electrodes. A rubber case is filled with MR fluid to form a sandwich of uniform thickness between two electrodes. As a proof to verify the proposed motion control in the active mode, a simple closed loop MR actuating system with PI controller is designed using internal model control (IMC) rule [16] and experimentally

* Corresponding author.
E-mail addresses: sureshmooncity@gmail.com (S. Kaluvan), vinopraba@gmail.com (V. Thirumavalavan), dkenl928@gmail.com (S. Kim), seungbok@inha.ac.kr (S.-B. Choi).

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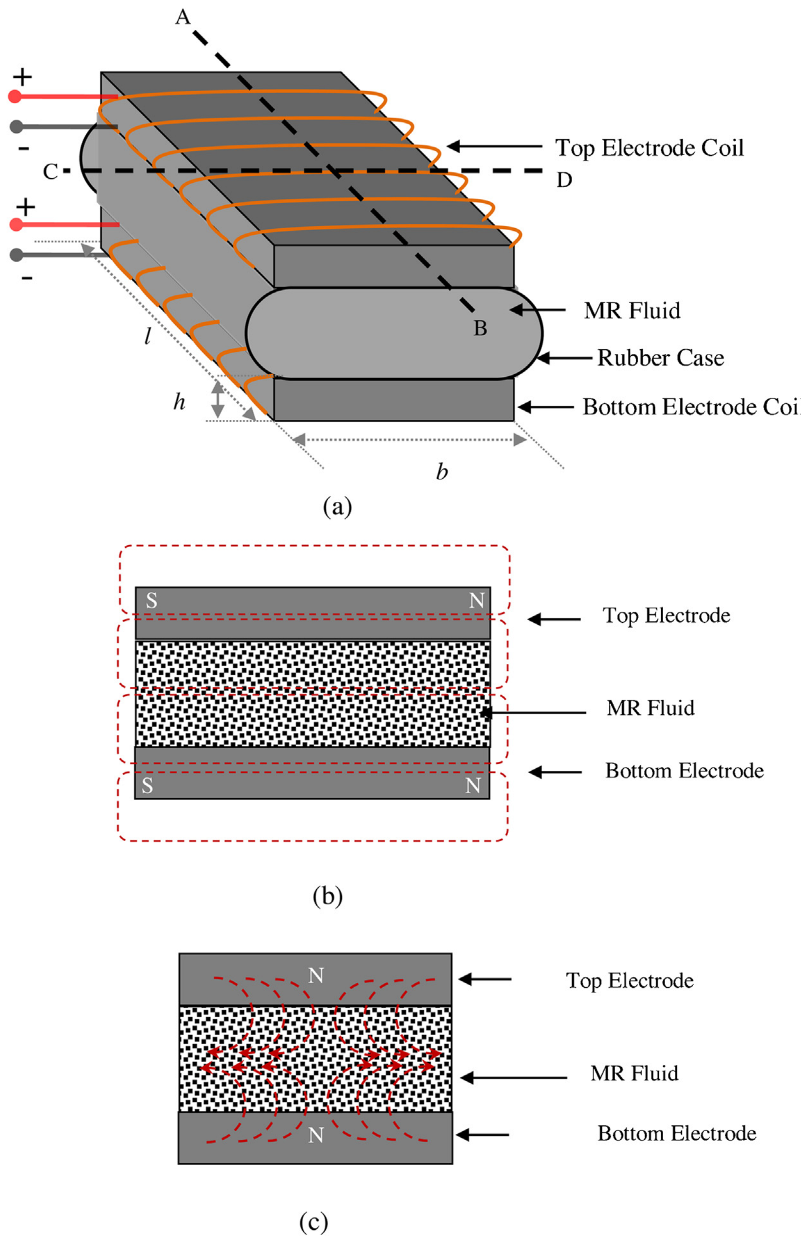

Fig. 1. (a) Schematic representation of MR actuator (b) cut way side view (AB) direction (c) cut way front view (CD) direction.

realized for micron level displacement control. It is noted here that since the main technical contribution of this work is to develop a new MR actuator, a simple but very effective PI controller which dominates the industrial applications is adopted [17,18]. Among the many tuning techniques available to design PI controller [19], IMC tuning rule has gained widespread acceptance in the control industry because the controller is easily designed just by taking the inverse of the model with a single tuning parameter namely the IMC filter time constant [20]. The optimal value of filter time constant is determined by a trade-off between speed of response (small value of time constant) and robustness (large value of time constant). The model based controller design needs an accurate mathematical model of the system under control. The transfer function model of the proposed actuator system is identified by applying a step input to the electrode coils. It is demonstrated that the proposed closed loop MR actuating system with PI controller can accurately control the displacement in the micro meter level and thus this closed loop system finds wide applications such as auto focusing stages for optical/electronic microscope, digital cameras and micro fabrications. In addition, it is shown that the designed closed loop system is easy to implement and affordable in cost.

2. Design of MR actuator

The MR actuator is designed by sandwiching the magneto rheological fluid between the two electrode type electromagnetic coils. The magnetic rheological fluid is enclosed in a soft flexible case to form a sandwich. The coil kept on the upper surface of MR fluid acts as a top electrode and the one on the lower surface acts as a bottom electrode. The MR fluid and the electrode-coils are tightly bonded with epoxy adhesive material. The schematic representation of the MR actuator is shown in Fig. 1. The electrode-coils are tightly winded with copper wire to produce sufficient magnetic field inside the MR fluid. An iron plate is chosen as the core material of the electrode-coil. The proposed actuator is working based on the principle of coupled mode forces such as active force gener-