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A novel resonance based magnetic field sensor using a magneto-rheological fluid

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ABSTRACT

A new technique to measure the magnetic flux density based on the resonance principle using magneto-rheological (MR) fluid is proposed in this paper. The magnetic field sensor is designed using MR fluid placed between two piezo laminated circular disc resonators. The resonant frequency of the disc is changed by the magnetic field dependent viscosity of the MR fluid. The key enabling concept in this work is stiffening the circular metal disc using the rheological effect of MR fluid i.e., resonant frequency varies with respect to magnetic field strength. The change in resonant frequency is measured using simple closed loop electronics connected between the two piezo crystals. The analytical model of the vibrating circular discs with MR fluid placed at the center is derived and the results are validated with experimentation. The proposed magnetic flux density measurement concept is novel and it is found to have good sensitivity and also the input output characteristic is piecewise linear.

1. Introduction

Nowadays, the usage of magneto-rheological (MR) fluid has tremendously increased to various applications other than the damper design for automobiles. This paper discusses a novel magnetic field sensing technique utilizing the magneto rheological fluid. The magnetic field sensing methods are broadly classified based on the measurement variable either the total magnetic field or the vector components of the magnetic field [1]. There are many approach for magnetic field sensing, which are namely, Hall effect sensor [2], magneto-diode, magneto-transistor, anisotropic magneto resistance (AMR) magnetometer, giant magneto resistance (GMR) magnetometer [3], magnetic tunnel magnetometer, magneto-optical sensor, Lorentz force based micro electro mechanical system (MEMS) sensor, optically pumped magnetic field sensor, fluxgate magnetometer [4], search coil magnetic field sensor and SQUID magnetometer [5,6]. The MR fluid based magnetic field sensing concept proposed in this paper is completely new. The MR fluid is one of the interesting smart materials that change their apparent viscosity with the application of magnetic field [7]. So far, the magneto rheological fluid is extensively used in the design of dampers for the automobiles [8–11]. Few attempts have been made to design intelligent and high performance smart devices like active bearings, optical polishing equipments, mount and actuators [12–14]. The challenges and the applications of designing the MR actuators, clutches and dampers are discussed in [15]. In this work, a novel magnetic field sensor is proposed by placing the MR fluid between the two centrally clamped, piezo actuated, circular metal disc with squeeze mode of operation. The most powerful mode of operation of MR fluid is squeeze mode but relatively not much is reported [16]. Generally in the squeeze mode, the MR fluid is placed between movable parallel plates with the perpendicular magnetic field to the plate surface. As the parallel plate moves close each other it squeezes the MR fluid. There are two types of squeeze mode: (1) constant area squeeze mode and (2) constant volume squeeze mode. In this proposed work, the MR fluid is operated in squeeze mode with constant volume mode.

The technical originality of this work is to propose a novel resonant sensor type of magnetic field sensing technique using a magneto-rheological fluid i.e., the stiffness of the vibrating structure is increased by utilizing the rheological property of MR fluid. A resonant sensor is a device with an element vibrating at resonance, which changes its output frequency i.e., mechanical resonance frequency, as a function of a physical parameter. The sensor output is digital in the sense that it is basically independent of analog levels and can be connected directly to digital circuitry. The conversion from the measurand to the resonance frequency of the vibrating element can be accomplished by means of a change in stiffness, mass, or shape of the resonator. Advantages of the resonant

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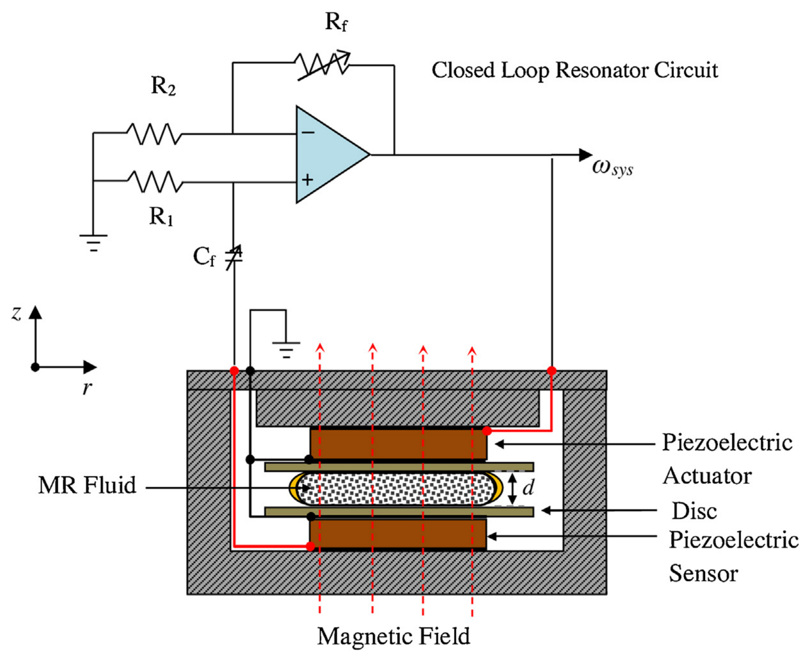

Fig 1. Schematic representation of MR actuator.

sensor are its high stability, high resolution and quasi digital output. The mechanical resonator structure has to be brought into vibration and the vibration has to be detected, and various excitation and detection technique can be seen in [17]. Smart materials in particular piezoelectric material as sensor and actuator with circular disc structure are effectively used in the area of measurement and instrumentation to measure physical, chemical, and biological quantities apart from their application in structural vibration measurement and control [18–20]. The piezoelectric excitation with following advantages like strong force, low actuation voltage, high energy efficiency, linear behavior, high acoustic quality, high speed and high frequency promises it to be an effective excitation technique.

This paper is organized as follows. Section 2 describes the description of the magnetic sensor and Section 3 describes the measurement system model, Section 4 describes the analytical and experimental evaluation of the system and the conclusion is drawn in Section 5.

2. Description of measurement system

The schematic diagram of the proposed magnetic field measurement system is shown in Fig. 1. The magnetic field sensor consists of MR fluid placed between the gap 'd' of two collocated, metallic, circular disc with radius 'a' is mounted face to face in the z-axis. Two circular piezo electric crystals with radius 'b' are bonded on both the outer surface of the discs for actuation and sensing purpose. The center of the piezo disc with radius 'c' is clamped to the frame structure on another side as shown in Fig. 2 to induce a static center mode of vibration, where $c < b$. When the piezo disc is actuated, the actuator disc is free to move in the z-axis and squeezes the MR fluid, which is sensed by the piezo laminated sensor disc. The magnetic field existing near the vibrating circular disc induces a squeeze force and produces an additional stiffness k_{MR} in the disc and changes the resonant frequency of the measurement system. The change in resonant frequency of the system is measured by the closed loop resonator electronics. In the closed loop electronic circuit, an operational amplifier is used and the sensing piezo is connected in series resonant path with capacitor C_{f}. With high gain for the amplifier the output of the circuit is connected to actuating piezoelectric patch. When the system is switched ON the piezoelectric sensor responds to the noise and produces a small voltage which is used by the oscillator to built-up a steady state oscillating condition. By designing the value of the feedback resistance R_{f} and the capacitor C_{f} for providing the required gain and phase shift respectively, the measurement system is made to oscillate at its resonant frequency [21,22]. The closed loop resonant circuit tracks

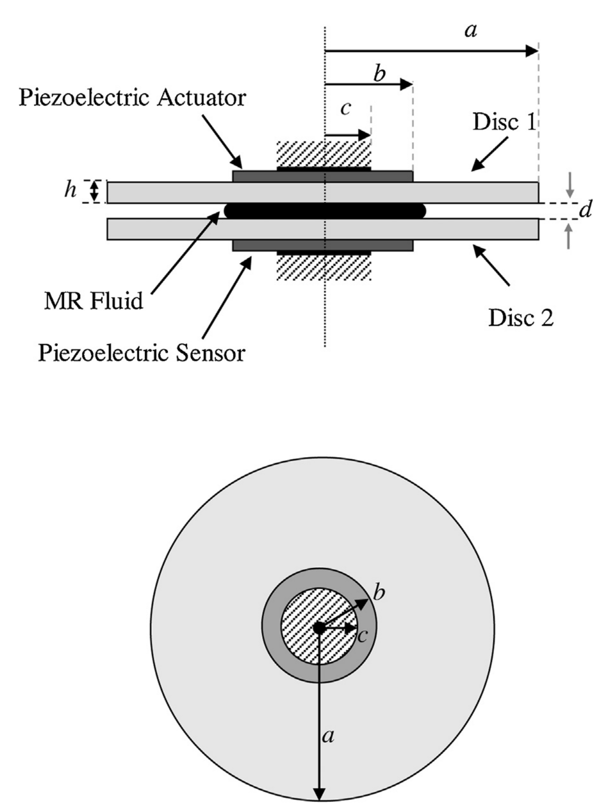

Fig 2. Geometry and co-ordinates used in the measurement system.