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DEVELOPMENT OF FUZZY LOGIC CONTROLLER FOR MAGNETORHEOLOGICAL ROTARY BRAKE SYSTEM

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ABSTRACT

The conventional contact type brake system which uses a hydraulic system has many problems such as time delay response due to pressure build-up, brake pad wear due to contact movement, bulky size, and low braking performance in a high speed region. As vehicle speed increases, a more powerful brake system is required to ensure vehicle safety and its reliability. In this work, a contact less brake system using a magnetorheological is proposed to overcome the problems. A magnetic fluid changes its properties (viscosity) under the influence of an external magnetic field. This effect is the result of changes in the fluid structure: the ferromagnetic particles of the fluid, being single domains, when subjected to an external magnetic field, become orientated and concentrated along the lines of forces of the magnetic Field. The design of the electromechanical converters mentioned above permits the space between the casing and the moving component of the converter to be filled with the magnetorheological fluid. A coil supplied with power is placed on the moving component of the converter or inside the casing, depending magnetorheological fluid enable to change the parameters of a mechanic system (rigidity, braking force) as a result of electric voltage and current control.

Keywords: Fuzzy logic, Magnetorheological fluid, External magnetic field, Rotary brake.

1. INTRODUCTION

Conventional hydraulic brake systems are widely used in commercial vehicles. However, they have many problems, such as the time delay in pressure build up, noise, squeal, jitter, brake pad wear and replacement due to their contact movement, bulky size, and poor braking performance at high speeds. Thus, a more powerful and stable braking system is required to ensure reliability and vehicle safety.

Conventional brakes and clutches require complex mechanical parts to transmit the energy. Large size and therefore high weight make the problem more serious. In addition, the control of such devices is usually passive. Fortunately, this sort of problem may be solved by introducing magnetorheological (MR) fluids as a medium to transmit the required energy (Zhao Dong Xu, 2008; Zhao and Xing, 2006) (Bolter and Janocha, 1997). MR fluids, as well as their counterparts electrorheological (ER) fluids (Carlson and Duclos, 1992; Carlson *et. Al,*1995) have the characteristics that their rheological properties can be continuously and reversibly changed within milliseconds solely by applying or removing a magnetic field (Bydoń, 2003a,b). The magnetorheological brake (MRB) is a pure electronically controlled actuator and as a result (Falcao *et. al* 2004), it has the potential to further reduce braking time (thus, braking distance), as well as easier integration of existing and new advanced control features such as anti-lock braking system (ABS), vehicle stability control (VSC), electronic parking brake (EPB), adaptive cruise control (ACC), as well as on-board diagnostic features. This feature has inspired the design of a large variety of power transmission devices based on the use of MR and ER fluids, such as brakes and clutches (Friedland, 1996). Choi *et. al*. (1999) compared performance characteristics of ER and MR clutches, and derived a non-dimensional model to determine the principal design parameters. Lee *e. al*. (1999); Lee and Wereley (2000); Lee and Park (1999) produced a simplified mathematical model to describe MR clutch performance by the analysis of the magnetic field using the FEM method and the computation of fluid flow by CFD (computational fluid dynamics) (Ginder *et. al* 1994). Bolter and Janocha (1997) proposed an MR fluid disc clutch based on the shear mode and analysed the magnetic field configuration in the clutch to determine the principal design parameters. Taking into account several design considerations, including maximum torque, ratio of maximum on-state to offstate torque, and maximum speed, Carlson and Duclos (1992) presented design equations for ER brakes and clutches (Ginder *et. al* 1995). Considering the difference between static yield stress and dynamic yield stress, Lampe et al. (1998) derived torque-transmitted equation to evaluate "bell"- and "disc"-shaped clutches, and a new friction and wear less permanent magnet seal for MRF was described (Inoue *et. al* 2001). Papadopoulos (1997) proposed a multi-disc ER clutch and analyzed the field-dependent torque through experimental realization at various temperatures. A force display device in virtual reality with ER brakes was investigated by (Furusho *et. al*

1998). A clinical walker with ER-activated brakes was commercialized in Japan, with highly favorable evaluations by patients, doctors and clinical workers (Jolly, 1999).
The objective of this work was to implement high-efficiency MR brake with high transmittable torque, good long-term stability and simple construction. The mechanical performance of the MR brake was experimentally evaluated. A velocity sensor measures the rotational velocity of the brake disk, and a controller determines which brake system will be employed based on information such as the wheel speed and driver pedal input. At high vehicle speeds, the MR brake is used because it offers higher brake torque, a shorter response time. An MR brake dissipates heat better and can work independently, without increasing the temperature of the disk. In addition, the magnetic flux will be saturated as the current is increased.

2. ROTARY DAMPER

A typical rotary drum damper is schematically shown in Figure.1 it comprises an inner cylinder of length L and radius r_b and an outer r_c. When the inner cylinder rotates with an angular velocity Ω, applied torque T is obtained by $T = 2\pi r_b^2 L \overline{\tau}_b \tau_y$ Where $\overline{\tau}_b$ is the nondimensional shear stress, $\overline{\tau}_b = \tau_b / \tau_y$, τ_b is the shear stress at the inner cylinder, and τ_y is the shear stress of the MR fluid. On the other hand, the angular velocity can be described by $\Omega = \int_b^c \frac{\dot{\gamma}}{r} = \int_c^b \frac{\dot{\gamma}}{\tau_{r\theta}} d\tau_{r\theta}$

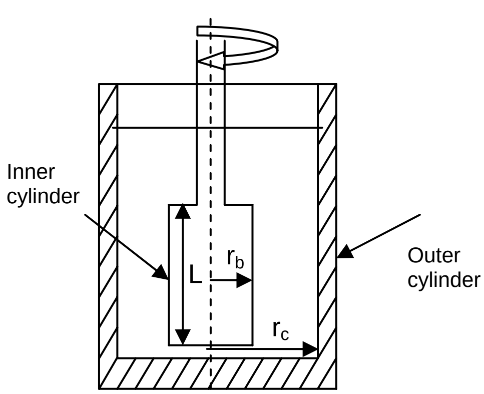

Figure 1 Schematic diagram of rotary damper.

MR brake allows for continuous control of torque (Figure 2). When the current in the coil is equal to zero, then there is no magnetic field and the torque is equal to minimum ≈ 0.34Nm. This value is equal to the torque caused by bearings, seals and viscosity of carrier liquid. When the current is equal to 1A then the MR brake has the highest possible value of the torque ≈ 4.01Nm, that is limited by maximum current in the coil and construction of MR brake. Maximum electric power consumption of the MR brake is 15W. Maximum mechanical power dissipation is about 500W (ω = 105 rad/s, Torque = 5.65Nm).

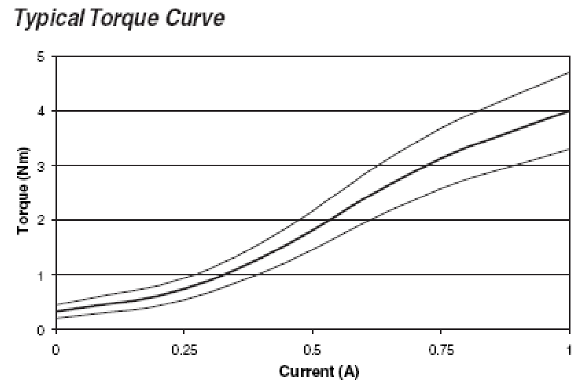

Figure 2 Torque (N m) vs. current I in the coil

Structure of MR brake (Figure. 3) enables the gap, between housing and rotor to be in magnetic field H produced by coil. Rotor is fixed to the shaft, which is placed in bearings and can rotate in relation to housing. Wires allow supplying electric current to the coil (Yang *et al* 2002). The MR fluid is cut by two surfaces (housing surface and rotor surface). LORD RD-2087-01 rotary brake is a compact, magnetorheological (MR) fluid proportional brake suitable for a wide variety of applications (Yoo and Wereley, 2001). As a magnetic field is applied to the MR fluid inside the brake, the characteristics of the fluid change to provide increased torque output with practically infinite precision (Wang and Gordaninejad, 2000).

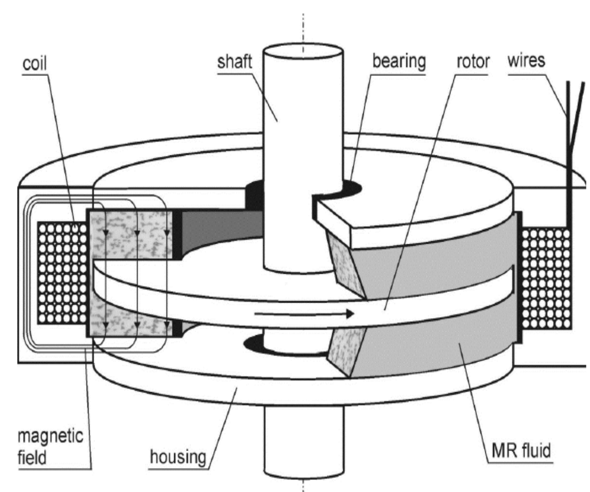

Figure 3 Schematic diagram of MR rotary brake.

3. CONTROLLER DESIGN

Fuzzy control deals with impreciseness and uncertainties present in real applications and uses expert knowledge instead of differential equations, making the algorithms rather simple (Will et al 1998, Slotine and weiping, 1991). It consists in converting linguistic control strategy based on expert knowledge to automatic control (Nagarajaiah, 1994), by creating rules that correlate the controller inputs to the desired outputs. All fuzzy controllers are composed of the following steps (1) Fuzzification, where the crisp value of the input is converted to a fuzzy linguistic value using membership functions (Sapiński, 2003). (2) Decision making, which uses "IF-THEN" rules created based on expert control knowledge to correlate the linguistic variables of the input to linguistic variables of the output. (3) Defuzzification, where the fuzzy output is converted to a crisp control value. A diagram of the system is presented in Figure 1 velocity (actual) ω angular velocity (set value) ω_z and the output as applied voltage/current to the MR damper. The membership functions for the inputs were defined on the normalized universe of discourse [-3, 3] and selected as five identical triangles with 50% overlap (Figure 5,6). For the output, they were defined on the universe of discourse [10, 30] and selected as four identical triangles with 50% overlap (Figure 7). The labels VN, N, Z, P, VP refer to the linguistic values: Very Negative, negative, zero, positive, very positive respectively (Rashid *et. al* 2007)

The control system was tested in the experimental setup shown in Figures. 4 (general view)

The experimental setup has three major components: mechanical, electric and PC based controller. The mechanical element consists of an induction motor whose shaft is connected to a MR brake shaft. The brake shaft is connected to the mass to be positioned and the angular position sensor (an incremental encoder with the resolution 360 pulses per revolution). The electric part consists of a PC with an installed multi I/O card, an induction motor supplied via an inverter and a V/A supplying the coil in a MR brake.

It includes the motor shaft velocity controller. It has one input (control error). The structure of the proposed fuzzy controller (Output is varied based on the error and error rate condition. A fuzzy logic is used to determine controller output as function of the current. Let us angular velocity (actual) ω angular velocity (set value) ω_z. So error $e = \omega_z - \omega$

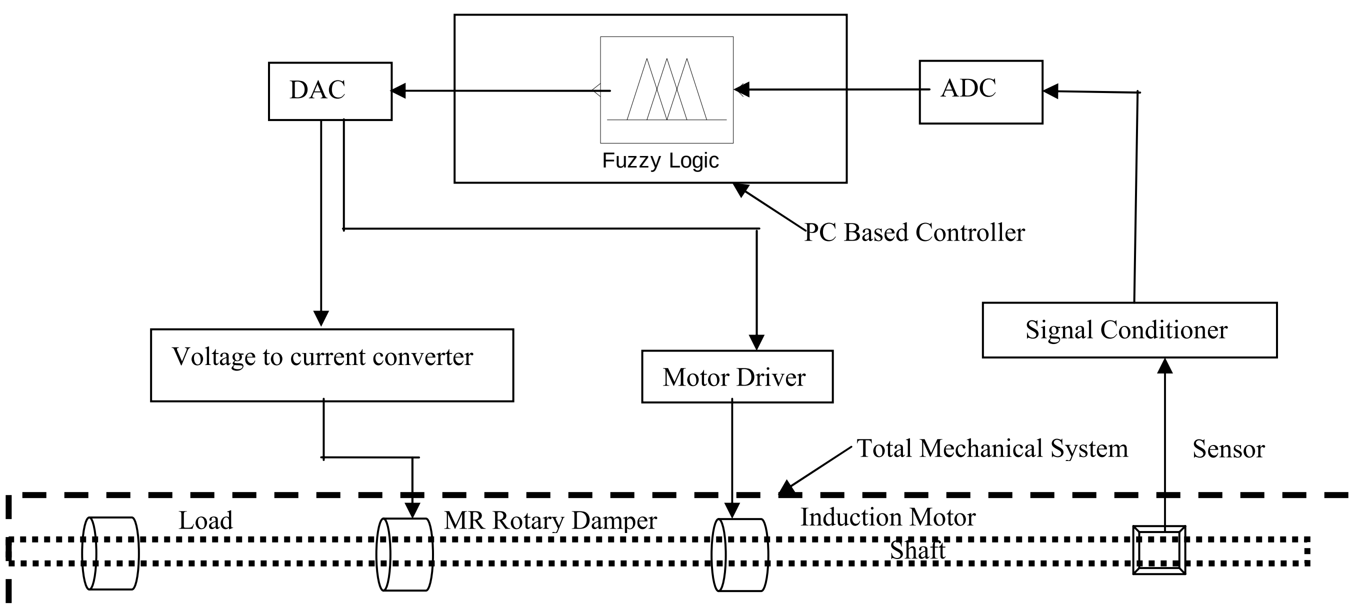

Figure 4 Block diagram of Experimental setup.

4. RESULTS AND DISCUSSION

Figure 8 shows a plot of the transmitted torque (T) versus the rotary speed (ω) at various field strengths of I = 0.0 A, 0.2A, 0.50 A and 0.75 A. It can be seen from this figure that the transmitted torque shows a linearly increasing trend with rotary speed, which is due to the fact that the viscous effect of MR fluids increases steadily with the increment of shear rate. The magnetic field relationship with the transmitted torque can also be observed from this figure. The higher the magnetic field, the larger the torque. For example, at the same rotary speed of 100 rpm, the transmitted torque increases sharply from 0.15 N m to 1.04 N m when the magnetic field is increased from 0.0 A to 0.75 A. Selected results of experimental tests are shown in Figures. 8 and 9, presents the controller performance with the MR brake.

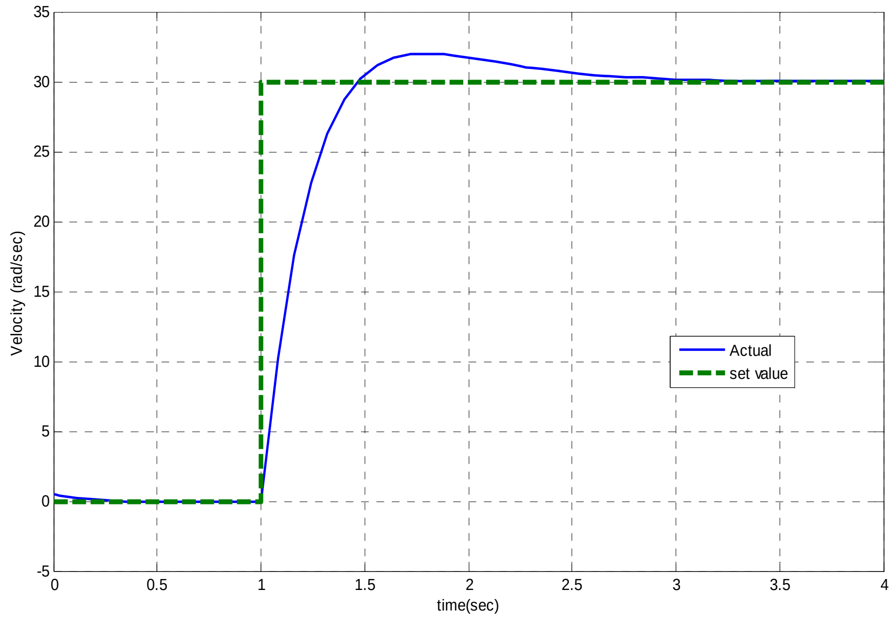

Figure 5 Torque control system response to the step change of preset velocity for the system with a MR brake,

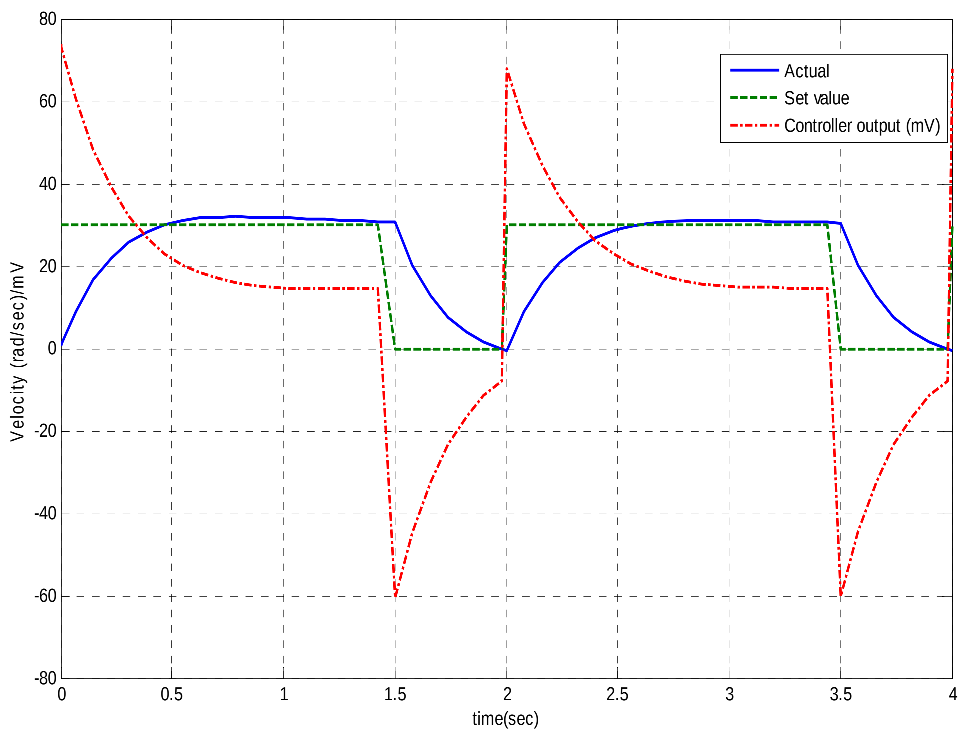

Figure 6 Torque control system response to the repeated sequence change of preset velocity for the system with a MR brake

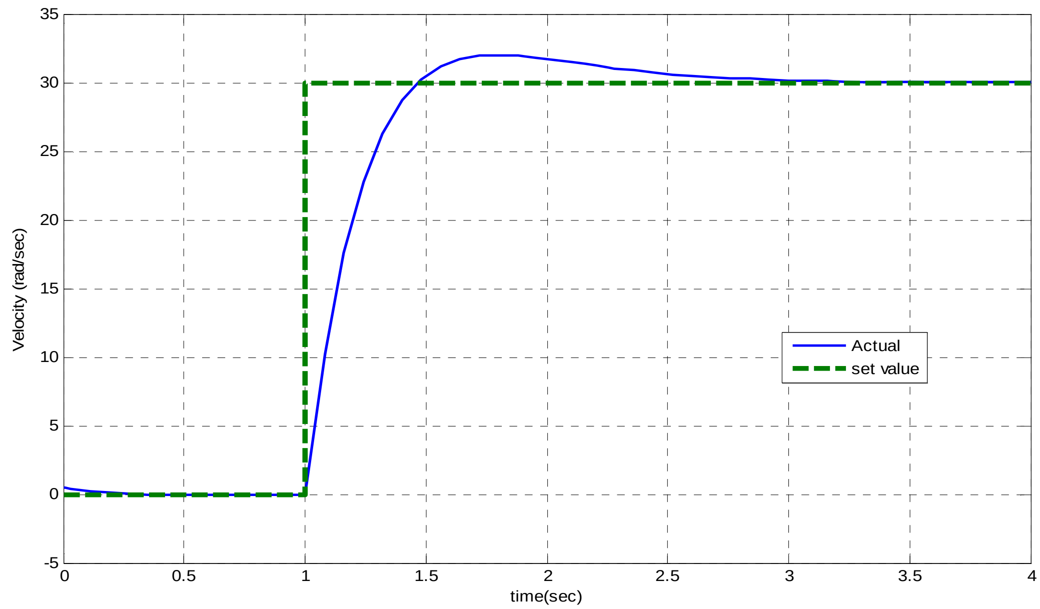

Figure 7 Torque control system response to the repeated sequence change of preset velocity for the system with a MR brake

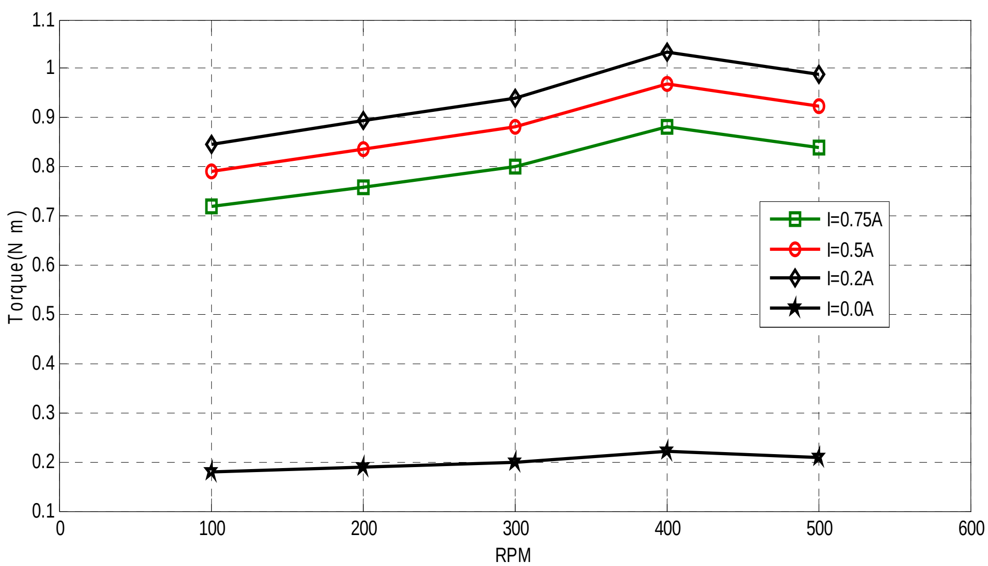

Figure 8 The torque (*T*) vs. rotary speed (ω) at various field strengths: $I = 0.0$, 0.20, 0.50, 0.75 A.

5. CONCLUSIONS

Application of MR brake as an element dissipating the kinetic energy of the rotating motion of shaft allowed the dynamic characteristics of the considered driving systems to control brake. MR brakes may be also employed in conjunction with other electric motors, and with other types of drives. In this paper, using an MR fluid as a control medium for a braking system, a simple, quiet, and rapid-response MR brake was tested. The brake performance was experimentally evaluated by using a designed test rig, including a induction motor system and torque detector. The transmitted torque increases gradually with increasing magnetic field strength except for field saturation. A high-efficiency electromagnet is designed with the help of finite element analysis. By improving MR fluid introduced to evaluate the brake performance, which can be increased by either increasing the magnetic field strength or reducing the rotary speed.

Based on a commercially available magnetorheological brake LORD RD-2087-0. The proposed MRB is naturally a pure electronically controlled brake system. This allows easy implementation of advanced braking control features with a smaller number of components, simplified wiring, improved braking response and generally optimized layout. A fuzzy logic controller was designed for an optimal brake control. Future work must focus on life-cycle tests to assess the reliability and longevity of the system and to ensure that it can effectively replace the existing hydraulic brake technology.

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