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MR DAMPER CONTROLLERS FOR VEHICLE AIRBAG REPLACEMENT

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ABSTRACT

Vehicle crashes continues to occur despite all the human efforts to prevent them resulting in injuries and loss of lives. The implementation of air bags has been shown to offer passenger safety in a collision. However, premature deployment of air bag has resulted in fatalities and injuries to drivers and front seat passengers. In this study, a Magnetorheological (MR) damper is used as a replacement of air bag in vehicles to serve as a protective system. MR damper is a smart damping device which can be programmed to dynamically absorb shocks and high impact force when used in application such as passenger cars. In this paper, the implementation of MR damper in reducing the impact force on driver during frontal car crash is studied through MATLAB simulation. The current air bag model in MATLAB has been replaced with the designed MR damper to study the impact force on the driver. In this paper two control techniques; a conventional Proportional Integral and Derivative (PID) and Fuzzy Logic Control (FLC) controllers are proposed for MR damper current control. The performances of the controllers were analysed based on efficiency to minimize F_d, damping force of MR damper system during the crash de-acceleration. Simulation results proved that Fuzzy based MR damper system yields better results compared to PID based MR damper system.

Keywords: MR damper, proportional integral, derivative controller (PID), fuzzy logic controller (FLC).

INTRODUCTION

Airbags are standard safety feature used in vehicles today to reduce G-force to less than 15g [1]. It is an example of active device designed to deploy at the moment of impact when a collision occur, absorbing the impact. Airbag systems utilize various acceleration sensors placed at different positions on the vehicle bodywork. The deceleration happening during a crash is caught by the system, assessed and if necessary the airbags will be triggered. The National Highway Traffic Safety Administration (NHTSA) reports that airbags spare many lives every year, however premature deployment of airbags and malfunction of airbags can cause fatalities [2].

A recent incidence of airbag explosion due to malfunction deployment involving airbags made by the Takata Corporation includes the death of a pregnant lady from Malaysia. The driver crashed into another vehicle and her vehicle's airbag deployed abnormally due to defective inflator and propellant devices. She was hit in the neck by a fragment of metal nearly 2.5cm in diameter when the airbag tore apart. As a result, Honda Motor Co is recalling yet another 4.5 million cars globally to replace airbag inflators made by Takata. Honda claimed those airbags could contain degraded propellant or explosive that is thought to have caused the woman's airbag to deploy violently. Other reasons for airbag deployment failure includes defective crash sensor which prevents deployment. Next probable issue is with the electrical components and wiring between the crash sensors. Wiring is routed though vulnerable areas resulting in wires getting cut during a crash sequence and thus preventing deployment signal from reaching the air bag modules.

In this paper, the research is explored to replace air bag with MR damper to avoid the disparities as mentioned above. The proposed MR damper is to be placed in series with seat belt anchored to the car chassis. MR dampers have the ability to vary damping force in real time using much less energy than fully-active systems due to the properties of the MR fluid. MR fluids are smart materials, which are made by mixing fine ferrous particles into a liquid with low viscosity. These liquids can be mineral oil, synthetic oil, water or glycol. In the presence of an applied magnetic field, the particles form a linear chain parallel to the field [3]. In the absence of magnetic field, the suspended ferrous particle solidifies with high viscosity. By controlling the current to the MR damper, the strength of the magnetic field can be varied and thus, the damping force of the MR damper can be controlled.

Therefore, suitable controllers are being developed to control MR current in order to minimize the G-forces acting on human body during the crash time. From existing literature, several classical and active control design approaches have been employed to yield optimal driving comfort, safety and driving stability. Fuzzy controller has been used for driver seat vibration control by H.Metered [4]. In addition, references [5-7] introduce application of MR damper suspension for system with fuzzy controller. Similarly PID controller for vehicle suspension system and vibration control has been used by Mat Hussain [8].

In this paper, comparison between PID and FLC control techniques for MR damper system are developed and analysed to the replace current airbag system.

Vehicle collision model

In this section, the modelling of the airbag system is discussed by analysing the crash data in terms of seatbelt force, torso force, torso g-force and passenger stopping distance. The MATLAB Airbag Collision System block diagram is shown in Figure 1. In this system, the vehicle velocity is considered at *30 km/h(8.33m/sec)* and collision occurs at *0.6 sec*. The same vehicle, torso and

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seatbelt model are used for development and analysis of crashing force. In Figure-1, the crash velocity changes the momentum force and triggers the airbag. The deployment of airbag counters the torso momentum force resulting in less seatbelt force.

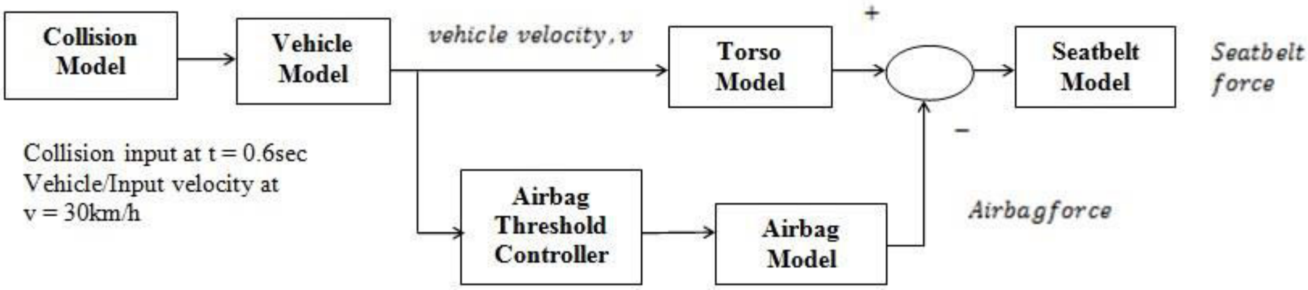

Figure-1. Block diagram of Vehicle Collision Model in MATLAB simulink.

Mathematical model of car crash mechanics

In a car crash against a fixed object like a wall, the crash force acting on passenger has two implications.

- The time interval, impulse time Δt over which the crash force is subjected on the passenger
- The crash force subjected on the passenger, F

Combining the impulse time, Δt and crash force, F the Impulse forces obtained as in (1).

$$Impulse\ Force = F\ \Delta t \quad (1)$$

In physics term, impulse force is the change in momentum, Δp as shown in Eqn (2) below.

$$\Delta p = F\ \Delta t \quad (2)$$

Where $\Delta p = m\ \Delta v$ (3)

Equating Eqn. (2) an (3) yields the Impulse force, Fexerted on the passenger during the collision where m is the torso mass, Δv is the vehicle velocity and Δt is the impulse time. In the vehicle collision model studied in this work, the torso mass is 30kg and travelling at 30km/h within vehicle before crashing into a wall. Based on the simulation design, the impulse time of the impact is found to be 0.1sec. Therefore, the impulse force exerted on the passenger during the collision can be calculated as in Eqn (4).

The Force, $= \frac{m\Delta v}{\Delta t}$ (4)

$$= \frac{30\ kg\ (8.33-0) m/sec}{0.1}$$

$$= \underline{2700\ N}$$

Therefore, in a car crash mechanics, the force acting on the car and passenger are due to momentum.

Human tolerance limit in a car crash

In 1959, Eiband compiled what was then known about the tolerance of a restrained individual to abrupt accelerations [9]. He studied human tolerance on live volunteers using acceleration devices. He also performed the experiment on subjects such as hog and chimpanzee. In a frontal car crash, the direction of acceleration force would be from chest to back. This direction is depicted as –Gx in the human coordinated system to a seated human. Table-1 summarizes all the human tolerance limits for every direction of force.

Table-1. Human tolerance limit.

Direction of Acceleration force	Occupant's Inertial Response	Tolerance Level
Headward (+Gz)	Eyeballs Down	20-25 G
Tailward (-Gz)	Eyeballs Up	15 G
Lateral Right (+Gy)	Eyeballs Left	20 G
Lateral Left (Gy)	Eyeballs Right	20 G
Back to Chest (+Gx)	Eyeballs Out	45 G
Chest to Back (Gx)	Eyeballs In	45 G

MAGNETO-RHEOLOGICAL (MR) DAMPER MODELLING

A non-parametric approach for modelling the MR Damper employs analytical expressions to describe the characteristics of the modelled devices. In the paper, the data used for identifying the force-velocity characteristics of the dampers and calibrating the models were provided by Lord Corporation [10]. The following polynomial technique is adopted for expressing the damper force for the MR damper [11].

$$A_{MR}(I) = \sum_{i=0}^{n} a_i I_i \quad (5)$$

Where A_{MR} is the maximum damping force as a function of the applied current, I applied to the MR damper, a_i is the polynomial coefficients with appropriate units, and n is the order of the polynomial. In order, to

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represent the correlation between damper force and relative velocity across the damper, and also represent the bilinear behaviour of the force-velocity curve, the following function is adopted.

$$S_b = \tanh(v) \tag{6}$$

In Eqn. (6), v is the velocity across the MR damper. Combining Eqn. (5) and (6) yields the damper force as a function of damper current and relative velocity as shown in Eqn (7).

$$F_s = A_{MR}(I)S_b(V) \tag{7}$$

The MR damper characteristics in Eqn (5-7) are modelled and simulated in Figure-2. Damping force characteristics curve of MR damper for current and velocity input are plotted in Figure-3. The parameters considered in this study to model the MR damper are as shown in Table-2.

Table-2. Parameters of MR damper model for vehicle collision system.

Parameters	Symbols	Values
Input/Vehicle Velocity	v	[-5 20] m/sec
Current	$A_{MR}(I)$	[0, 0.25, 0.5,1] A
Damper Force	F_s	[0 3500] N

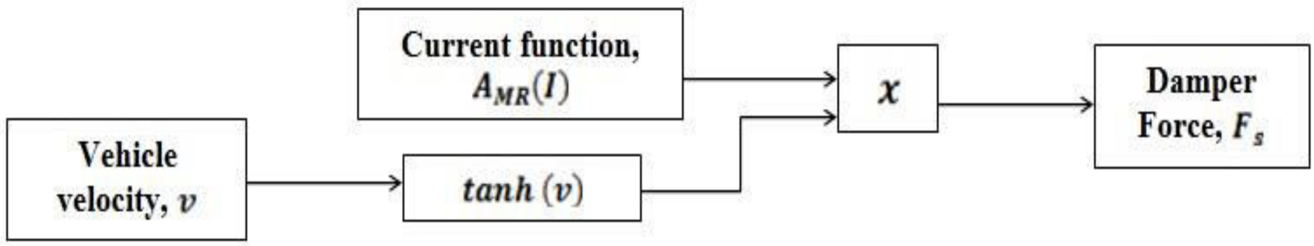

Figure-2. Modelling of MR damper.

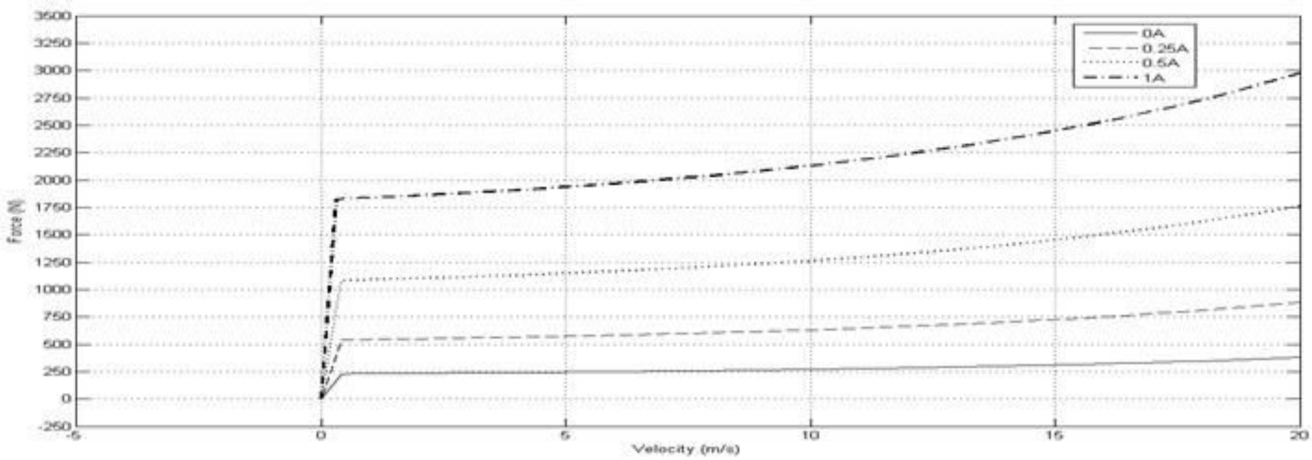

Figure-3. Damping force characteristics curve of MR damper for current and velocity input.

SIMULATION FOR MR DAMPER SYSTEM

Airbag system of a vehicle model, available in MATLAB Simulink environment shown in Figure-1. In this study, MR Damper as replacement of airbag is investigated as integrated part of seatbelt anchored with car body. Two controllers are studied and compared here in terms of damping efficiency as shown in Figure-4. This setup comprises of MR damper located in between vehicle and the seat belt model as shown in Figure-5. As mentioned before, the vehicle velocity is considered at *30 km/h(8.33m/sec)* and collision model detects the collision *0.6 sec*. The torso model and MR Damper model act as a counter force to reduce the seatbelt force exerted on the human body during the crash de-acceleration**.**

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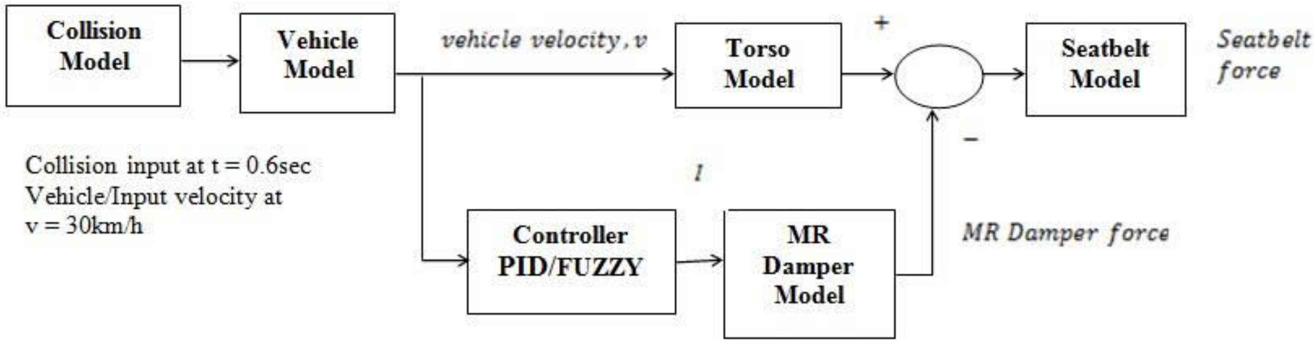

Figure-4. Simulation for MR damper system.

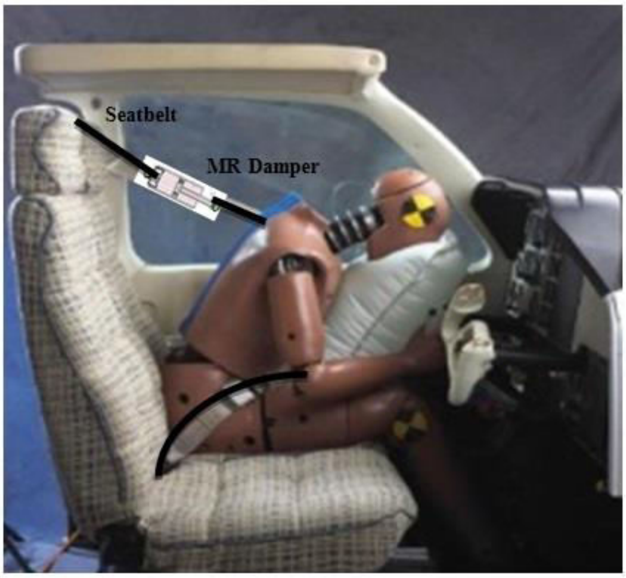

Figure-5. Position of MR Damper in the proposed design.

Fuzzy Logic Controller (FLC)

This section gives an overview of the fuzzy controller applied in this study in order to enhance passenger safety in a vehicle. The main goal of fuzzy controller is to minimize the F_d damping force of MR damper during the crash de-acceleration. The two inputs of the fuzzy controller are the vehicle stopping distance, d and vehicle velocity, v and a single output current, I obtained as shown in Figure 6. In this work, Mamdani inference and the centroid de-fuzzification methods are considered with 25 rules fired to the inference engine. Table-3 below shows the rule base of the system, and five membership functions that yields current for MR damper; negative big (NB), negative small (NS), zero (ZE), positive small (PS), and positive big (PB) respectively. The first input, d ranges from [-10 10] while the second input that is the vehicle velocity, v ranges from [0 10] and finally the output range set at [0 1].

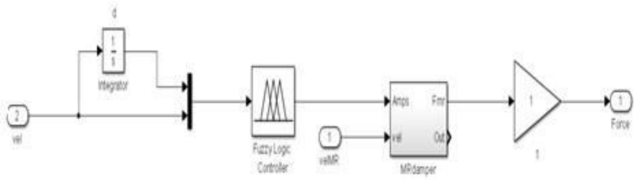

Figure-6. MR damper fuzzy logic controller simulink diagram.

Table-3. FLC rule base.

			v		
d	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

Proportional Integral and Derivative Controller (PID)

PID controller was interfaced with the MR Damper system as shown in Figure-7. The parameters, K_P, K_I and K_D were obtained through optimization. Adjustments were made with respect to the K_P, K_I and K_D parameters, which were optimized in a way that the seatbelt force is minimized. A significant response was obtained at K_P=2.5, K_I =5 and K_D = 10.

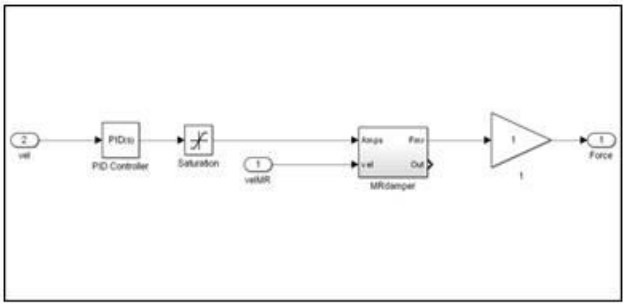

Figure-7. Simulink diagram of PID controller for MR damper system.

RESULTS AND ANALYSIS

The airbag exerts the belt force on torso during the collision as shown in Figure-8. Airbag collision force response is the benchmark for MR damper controller proposed in this research work.

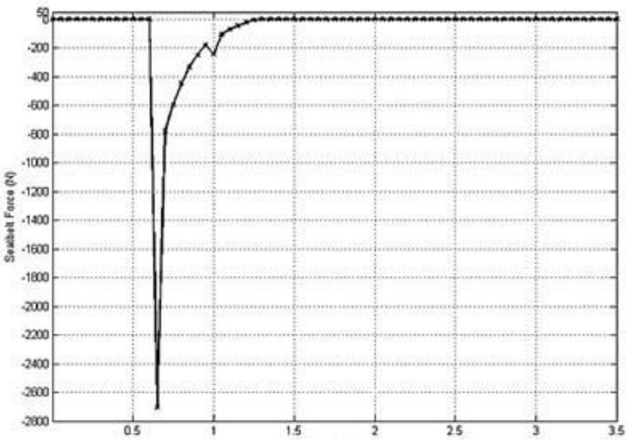

Figure-8. Airbag system collision force response used for bench-marking the MR damper controller.

The results obtained from the two proposed control techniques used are compared in this section. The seatbelt force for FLC based MR damper system and PID based MR damper systems are shown in Figure-9.

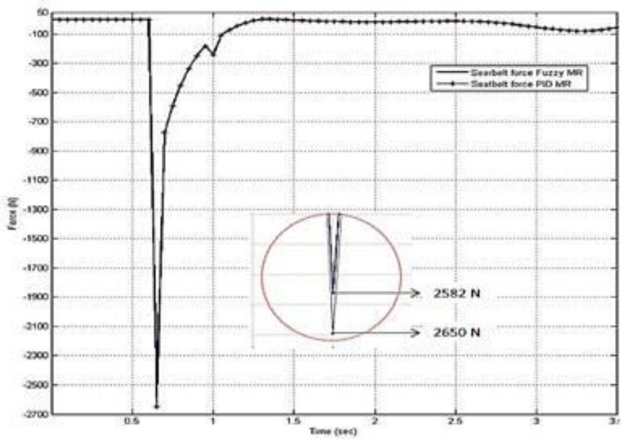

Figure-9. Comparison of seatbelt forces for FLC based MR damper system and PID based MR damper system

Airbag system exerts 2700N force as in Eqn (4) and in Figure-8. Therefore, with the implementation of the PID and FLC based MR damper system as in Figure-9 the forces exerted on the torso are 2650N for PID and 2582N for Fuzzy controller. Finally, for the applied current for MR damper from the controllers is shown in Figure-10. The MR damper current in Table-2 is between [0 1] A. The saturation block in Figure-7 limits the current from the PID controller. The limited PID current and Fuzzy current response is shown in Figure-10. In conclusion, the Fuzzy controller exerts minimum force on the torso in comparison to the bench-marked airbag system and PID-MR controller. The current control ability is visible in Fuzzy controller which resulted in better and efficient seatbelt force control.

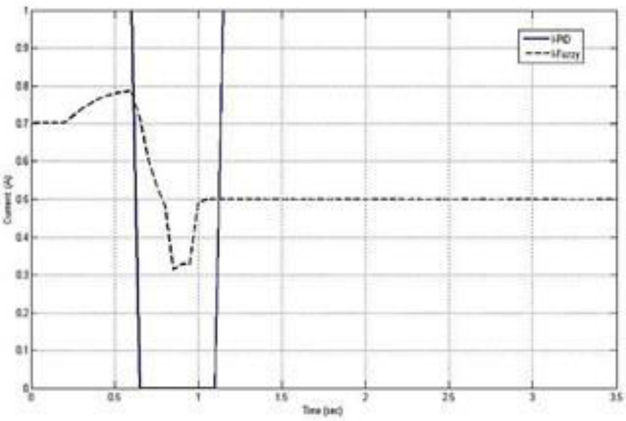

Figure-10. Saturated PID and Fuzzy MRdamper current response.

CONCLUSIONS

This paper describes the use of MR damper as an alternative to the air bag system. Both models are simulated to determine the collision force on torso. Airbag system collision force response was used for bench-marking the MR damper controller. Two MR damper controllers, FLC and PID were adopted and compared in this research work. Based on the simulation results, it is shown that the proposed FLC based MR damper system exerts minimum force on the torso in comparison to the bench-marked airbag system and PID based MR damper system.

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