Hysteresis Modelling of an MR Damper Applied to Suspension System

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Abstract- Comfort, reliability, functionality performance which provide a longer life cycle requires thorough understanding and analysis of the vibrations, this is a general rule for most of the static and dynamic functionality applications. Vibration is an extremely important issue to consider when designing various systems. Hysteresis is a phenomenon common to a broad spectrum of physical systems. As such, it is often present in plants for which controllers are being designed, where it introduces a problematic nonlinear multi-valued behaviour [1]. Continuing research into nonlinear systems is generating an increasing interest in the control of hysteretic plants. Here the magneto rheological damper used in active control of automobile suspension system is studied and its hysteresis is captured. This paper presents hysteresis equations of Bouc-Wen for an MR damper which is further modelled and simulated. The model is capable of representing a great many forms of hysteretic behaviour, and is also mathematically tractable enough for control design. The Bouc-Wen model is used to develop a semi-active vibration control model for a magneto rheological damper.

Key words- Suspension system, MR fluid, MR Damper, Bouc-Wen model, Hysteresis.

I. INTRODUCTION

In controlled systems, hysteresis can cause a number of undesirable effects, including loss of stability robustness, limit cycles and steady-state error, to name but a few. The major hurdles control designers must overcome when faced with hysteresis nonlinearity are obtaining an accurate tractable model of the hysteretic behaviour, and finding corresponding means of analysis and design capable of dealing with nonlinear and non-single-valued behaviour [1]. Bouc-Wen model of hysteresis is studied here as a part of hysteresis model study.

The application of the Bouc-Wen model is done to the modelling of a magneto rheological damper (MRD) attached to the semi-active vibration model with an MR damper. Vehicle suspension is normally used to attenuate unwanted vibration due to various road conditions. A successful and effective suppression of the vibration is necessary for improvement of vehicle component's life, and the ride comfort, as well as steering stability.

The MR damper is a type of semi-active damper where the flow of MR fluid is controlled by varying the amount of current supplied and thus changes the level of damping. Like other semi active control devices the MR damper is able to damp even if the current goes to zero [2]. The dampers is capable of producing large control forces by changing parameters such as damping coefficient and stiffness trough changing the magnetic field and thereby control the response of the system [3].

II. SUSPENSION SYSTEM

Traditional springs and dampers are referred to as passive suspensions — most vehicles are suspended in this manner. Fully active suspension systems use electronic monitoring of vehicle conditions, coupled with the means to impact vehicle suspension and behaviour in real time to directly control the motion of the car. With the help of control system, various semi-active/active suspensions realize an improved design compromise among different vibrations modes of the vehicle, namely bounce, roll, pitch and warp modes. However, the applications of these advanced suspensions are constrained by the cost, packaging, weight, reliability, and/or the other challenges.

III. MAGNETO RHEOLOGICAL (MR) FLUID

Magneto rheological is a branch of Rheology that deals with the flow and deformation of the materials under an applied magnetic field. Magneto rheological (MR) fluids are suspensions of non-colloidal (0.05-10 μm), multi-domain, and magnetically soft particles in organic or aqueous liquids. Many different ceramic metals and alloys have been described and can be used to prepare MR fluids as long as the particles are magnetically multi-domain and exhibit low levels of magnetic coercivity.

In the "off" state, in terms of their consistency, MR fluids appear similar to liquid paints and exhibits comparable levels of apparent viscosity (0.1 to 1 Pa-s at low shear rates)[4]. The apparent viscosity changes significantly (105 −106 times) within a few milliseconds when the magnetic field is applied. The change in the viscosity is completely reversible when the magnetic field is removed. Once the magnetic field is applied, it induces a dipole in each of the magnetic particles. The inert-particle forces originating from the magnetic interactions lead to a material with higher apparent viscosity. This dipolar interaction is responsible for the chain like formation of the particles in the direction of the field (Fig. 1).

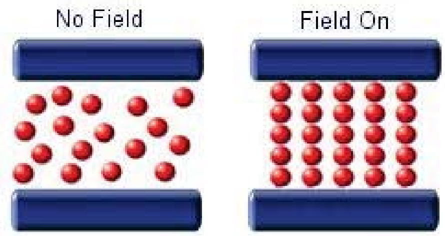

Figure 1: The Magneto rheological Fluid [5]

IV. HYSTERESIS IN MR DAMPER

Hysteresis is the dependence of a system not only on its current environment but also on its past environment. This dependence arises because the system can be in more than one internal state. To predict its future development, either its internal state or its history must be known [7]. If a given input alternately increases and decreases, the output tends to form a loop. However, loops may also occur because of a dynamic lag between input and output. Often, this effect is also referred to as hysteresis, or rate-dependent hysteresis. This effect disappears as the input changes more slowly; so many experts do not regard it as true hysteresis. Hysteresis occurs in ferromagnetic materials and ferroelectric materials, as well as in the deformation of some materials (such as rubber bands and shape-memory alloys) in response to a varying force.

V. MODELLING BY BOUC WEN MODEL

5.1 INITIAL BOUC-WEN MODEL

5.1.1 MODEL FORMULATION

Consider the equation of motion of a single-degree-of-freedom (sdof) system:

$$m\ddot{u}(t) + c\dot{u}(t) + F(t) = f(t) \qquad \textbf{(Eq.1)}$$

here, m represents the mass, $u(t)$ is the displacement, c the linear viscous damping coefficient, $F(t)$ the restoring force and $f(t)$ the excitation force while the overdot denotes the derivative with respect to time.
According to the Bouc–Wen model, the restoring force is expressed as:

$$F(t) = ak_i u(t) + (1-a)k_i z(\qquad \textbf{(Eq.2)}$$

where $a := \frac{k_f}{k_i}$ is the ratio of post-yield k_f to pre-yield (elastic) $k_i := \frac{F_y}{u_y}$ stiffness, F_y is the yield force, u_y the yield displacement, and $z(t)$ a non-observable hysteretic parameter (usually called the hysteretic displacement) that obeys the following nonlinear differential equation with zero initial condition ($z(0) = 0$), and that has dimensions of length:

$$\dot{z}(t) = A\dot{u}(t) - \beta|\dot{u}(t)||z(t)|^{n-1}z(t) - \gamma\dot{u}(t)|z(t)|^n \qquad \text{(Eq.3)}$$

Where A, $\beta > 0$ γ and n are dimensionless quantities controlling the behaviour of the model (η=∞ retrieves the elastoplastic hysteresis).

5.1.2 Modified Bouc-Wen model (with MR damper)

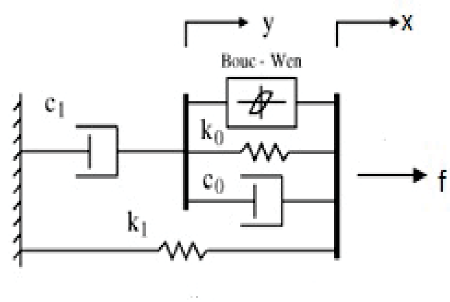

Figure 2- The modified Bouc-Wen model.

Under constant magnetic field, the fig. 2 will be considered. To obtain the governing equations for this model, consider only the upper part of the model. The resultant force on the rigid bar is zero[6].

$$\dot{y} = \frac{1}{c_0 + c_1}\{\alpha z + k(x - y) + c_0\dot{x}\} \qquad (1)$$

Where z is given by,

$$\dot{z} = -\alpha|\dot{x} - \dot{y}|z|z|^{n-1} - \beta(\dot{x} - \dot{y})|z|^{n} + A(\dot{x} - \dot{y}) \qquad (2)$$

The total force generated by the system by summing the forces in the upper and lower sections of the system fig. 2 yielding,

$$f = c_1\dot{y} + k_1(x - x_0) \qquad (3)$$

The parameters α, β and A in the Bouc-Wen model, are used to control the linearity in the unloading and the smoothness of the transition from the pre-yield to the post-yield region. The accumulator stiffness is represented by k_1 and the viscous damping observed at larger velocities is represented by c_0. A dashpot, represented by c_1, is included in the model to produce the roll-off at low velocities, k_0 is used to control the stiffness at larger velocities and x_0 is the initial displacement of spring k_1 associated with the nominal damper due to the accumulator. Z is the revolutionary variable and f is the predicted damping force.
In addition, constants c_0 and c_1 depend on the electrical current applied to the MR damper and in the Spencer model they are formulated as,

$$\dot{u} = -\eta(u - v) \qquad (i)$$

$$\alpha = \alpha(u) = \alpha_a + \alpha_b u \qquad (ii)$$

$$c_1 = c(u) = c_{1a} + c_{1b}u \qquad (iii)$$

$$c_0 = c(u) = c_0a + c_{0b}u \qquad (iv)$$

The variable u is the current applied to the damper through a voltage-to-current converter with a time constant η. The variable v is the voltage applied to the converter.

VI. RESULTS OF THE SIMULATION OF HYSTERESIS CODE OF AN MR DAMPER

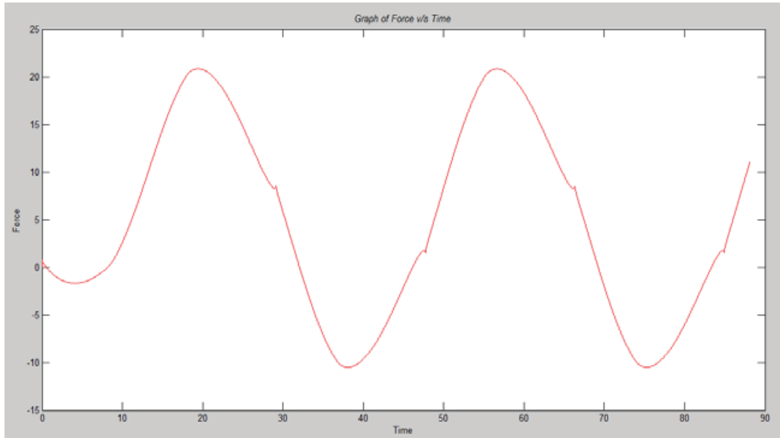

Figure 3- Graph of Force v/s Time

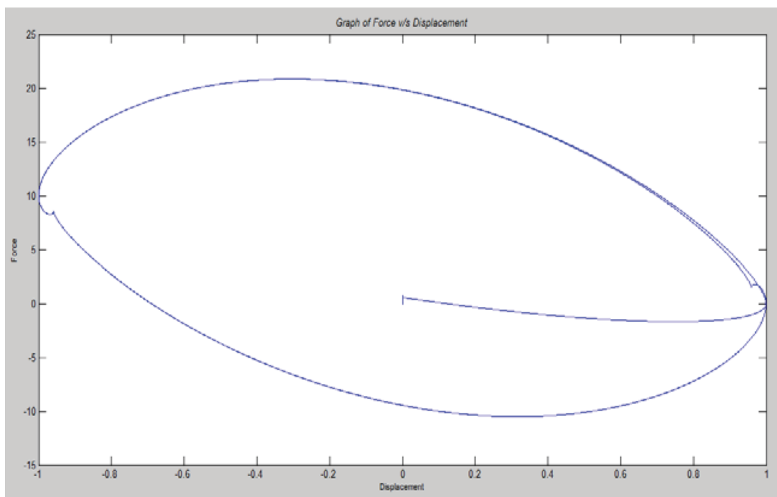

Figure 4- Graph of Force v/s Displacement

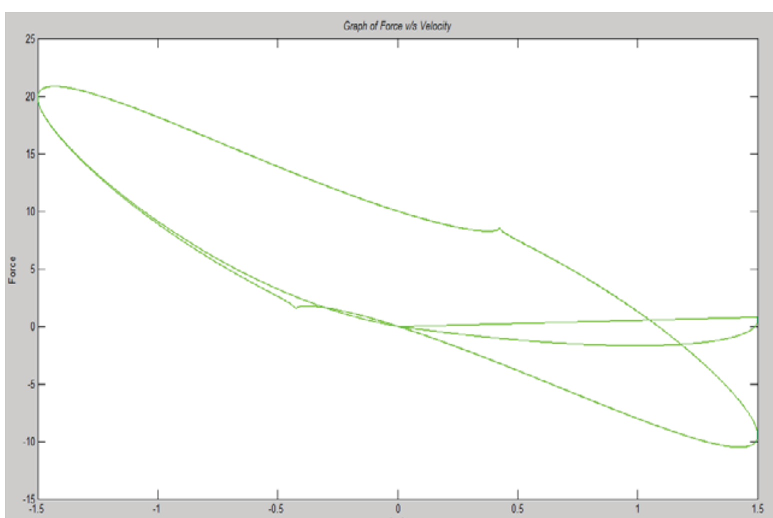

Figure 5- Graph of Force v/s Velocity

VII. CONCLUSION

MR fluid is studied and MR damper is also reviewed. Every system on earth has some non-linearity and so does MR damper. Generally the non-linearity is ignored and the system is studied as a linear system. But here the non-linearity is tried to be studied. The hysteresis which is an important phenomenon is considered. This means the path followed is different with increasing and decreasing the value of the system. This is the non-linearity encountered. This leads to energy dissipation and an area formed depicts the same.

The Bouc-Wen model for hysteresis is studied and its modelling according to the MR damper is studied. A simulink model of the MR damper considering hysteresis and the Bouc-Wen model is made. This model can tap the hysteresis of any values in force and displacement given to it. This model can be applied to the active suspension system of a car with an MR damper in it. When a voltage difference is applied across it, the fluid will become solid providing an opposite force so that adequate damping is provided. The controller will sense the difference is the actual and the expected displacement and it will be given back to tap the hysteresis which if any, be corrected to increase the comfort of the vehicle.

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