# Vibration Control of MR Damper Landing Gear

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***ABSTRACT*—— In the field of Automation, Fuzzy Control Fuzzy control has significant merits which are utilized in intelligent controllers, especially for vibration control systems. This paper is concerned with the application aspects of the developed MR damper for landing gear system, to attenuate the sustained vibrations during the landing phase. Also a comparative study is made on the responses obtained from the MR damper landing gear by utilizing PID and Fuzzy PID controllers.Theory is a well-known technique to acquire the desired response of different non-linear systems.**

***Keywords*——Magneto-Rheological (MR) damper; Proportional Integral Derivative (PID) Controller; Fuzzy Logic Controller (FLC)***

## I. INTRODUCTION

Magneto-Rheological (MR) Fluid is an intelligent material with an ability to amend itself from free-flowing viscous liquids to semi-solid state under the effect of magnetic field. By the use of such materials, MR's damping force can be utilized to obtain proper control on vibration, which is not possible with traditional dampers based on oil gas or hydraulic pressure. The specific properties of MR damper make the same to be used in this application such as small volume, light in weight, low energy dissipation, quick response and a large adjustable range of damping force [2].

During the process of takeoff and landing of an aircraft, the impact of road is greatly reduced by the landing gear that consists of the MR damper [3]. The fundamental characteristics of MR damper is its non linearity, hysteresis and saturation while that of landing gear is a multifaceted nonlinear pulsation system with multiple degrees of freedom. Thus it is difficult to create an accurate mathematical model, i.e. why the traditional linear control model can't achieve the satisfactory outcome.

By and large, a variety of nonlinear control algorithms are utilized for nonlinear systems such as optimal control, fuzzy control and neural network control in order to improve the response of the respective system. Among all the algorithms, the fuzzy control has various merits; simple modeling, high control precision and better capability [1]. Therefore, Fuzzy Controller is applied in intelligent controllers, especially for vibration control systems. Juang and Cheng have developed four ANN controllers to land a simulated aircraft under the effect of vibration and tested by FNC varying turbulence conditions [6].

## II. MR DAMPER

A magneto-rheological (MR) fluid is a non-colloidal solution, composed of ferromagnetic particles dispersed in a non-conductive carrier fluid. On the application of external magnetic field, the rheological property of the MR fluids reversely changes. Due to this feature, a large number of devices such as shock absorbers, vibration insulators, brakes and clutches use MR fluids in their respective operations. Apart from this, devices using the MR fluid can be made uncomplicated in construction, high in power, and low in inertia. Therefore, the use of the MR fluid actuators is very effectual in improving the function and performance of conventional control systems [2].

Recently, the authors have projected an electromagnetic design methodology for the magneto-rheological (MR) damper. If sufficient amount of magnetic field is applied to the MR fluid, the performance of the MR damper is improved to a much larger extent [3]. For this purpose, two effective approaches are proposed: In the first approach, the redundant bulk of the repression is removed due to which the magnetic flux path is abridged, hence improving the static characteristics of the MR damper; While in the second approach, the cross-sectional vicinity of the ferromagnetic material, through which the magnetic flux passes is minimized, due to which the magnetic reluctance of the material increases hence improving the dynamic and hysteresis characteristics [3]. The superiority of the proposed design methodology to a conventional one was verified through the magnetic field analysis and a series of basic experiments.

## III. MATHEMATICAL MODELING OF MR DAMPER LANDING GEAR

Vibration Control System for landing gears mainly consists of MR damper and tires. MR damper plays the major role in vibration control. Its mechanical model is shown in Fig.1 [11] and based upon its model, the equations respective to the model can be postulated as in Eq.1 and Eq.2.

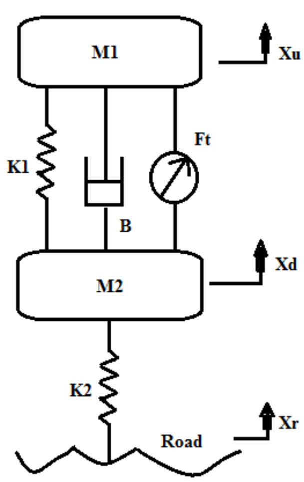


Fig. 1. Mechanical Model of Landing Gear with MR Damper

$X = [X_1, X_2, X_3, X_4]^T$ Eq.1

Where,

$X_1 = X_u - X_d$; $X_2 = \dot{X}_u$;

$X_3 = X_d - X_r$; $X_4 = \dot{X}_d$;

The output variables can be seen as:

$Y = [Y_1, Y_2, Y_3, Y_4]$ Eq.2

$Y_1 = X_1$; $Y_2 = \dot{X}_2$;

$Y_3 = K2X_3$; $Y_4 = X_4$;

Here the output parameters are:

$Y_1$ = dynamic deflection of landing gear

$Y_2$ = acceleration of fuselage

$Y_3$ = tire dynamic load

$Y_4$ = vertical velocity of the tire.

The state equation of the mechanical model can be obtained as in Eq.3 [11].

$$\mathbf{X} = \mathbf{A}\ \mathbf{x} + \mathbf{B}\ \mathbf{u} \qquad \text{Eq.3}$$
$$\mathbf{Y} = \mathbf{C}\ \mathbf{x} + \mathbf{D}\ \mathbf{u}$$

Where,

$$\mathbf{A} = \begin{bmatrix} 0 & 1 & 0 & -1 \\ \frac{-K1}{M1} & \frac{-B}{M1} & 0 & \frac{B}{M1} \\ 0 & 0 & 0 & 1 \\ \frac{K1}{M2} & \frac{B}{M2} & \frac{-K2}{M2} & \frac{B}{M2} \end{bmatrix}; \mathbf{B} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{M1} \\ -1 & 0 \\ 0 & \frac{-1}{M2} \end{bmatrix}$$

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \frac{-K1}{M1} & \frac{-B}{M1} & 0 & \frac{B}{M1} \\ 0 & 0 & K & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \ \mathbf{D} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{1}{M1} \\ 0 & 0 \\ 0 & 0 \end{bmatrix};$$

## IV. Design Of Fuzzy PID Controller

Fuzzy Logic Controller (FLCs) is used for simulating the linearized landing configuration of an aircraft. FLCs rule base are implemented as a function of the inputs i.e. the error '$e$' and the rate of change of error '$e_c$'. The FLC outputs i.e. the Proportional '$K_P$', Integral '$K_I$' and the Derivative '$K_D$' coefficients are determined by the Centroid method.

### A. *Fuzzification of the Inputs and Outputs*

The actual variation of Vibration Error '$e$' and its rate '$e_c$' lies in the range of [$e$,$e$] and [-$e_c$, $e_c$]. The domains of vibration error $e$ and its change rate $e_c$ on fuzzy sets by the quantity factors $K_e$ and $K_{ec}$ is defined by Eq.4:

e, ec = {-10,-9,-8…,0,1, 2…,8,9,10} Eq.4

Inputs and outputs linguistic variables can be defined on fuzzy subsets as:

$e$, $e_c$ , u = (NB, NM, NS, Z, PS, PM, PB)

where, the linguistic description of subset are: *NB*=negative large, *NM*=negative medium, *NS*=negative small, *Z*=zero, *PS*=positive small, *PM*=positive medium, *PB*=positive large.

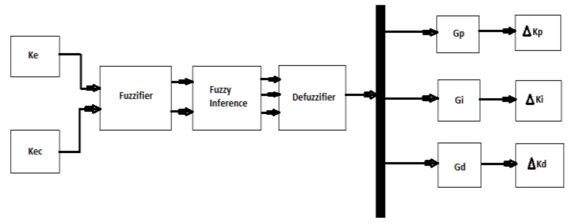


Fig. 1. Fuzzy Controller Block Diagram

The design principle of fuzzy controller is shown in Fig.1. The membership functions of the input i.e. the error and the rate of change of error of the vibration and the output i.e. the appropriate values of Proportional ($K_P$), Integral ($K_I$) and Derivative ($K_D$) coefficients are defined as in triangular form, can be viewed in Fig.2-3 and Fig.4-6 respectively.

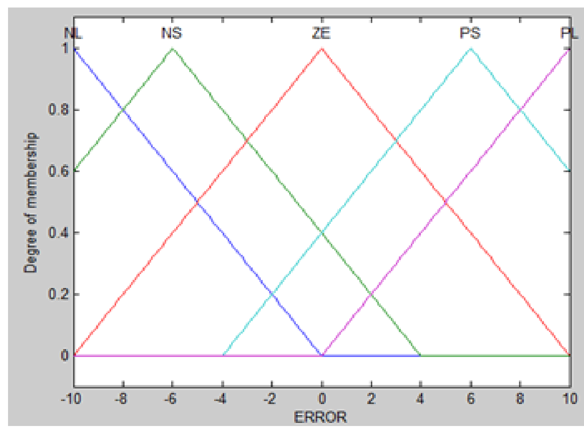


Fig. 2. MF of Error as an input to FLC

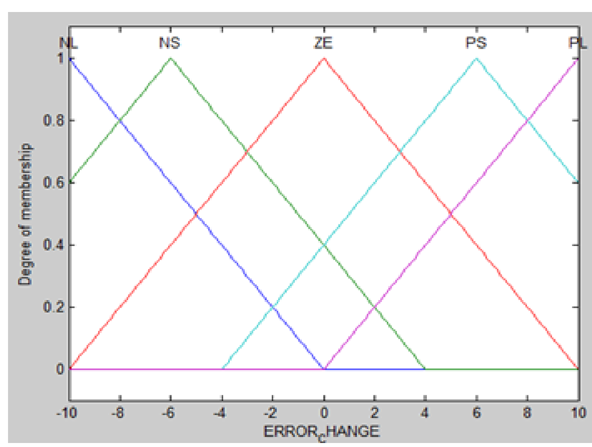


Fig. 3. MF of rate of change of error as an input to FLC

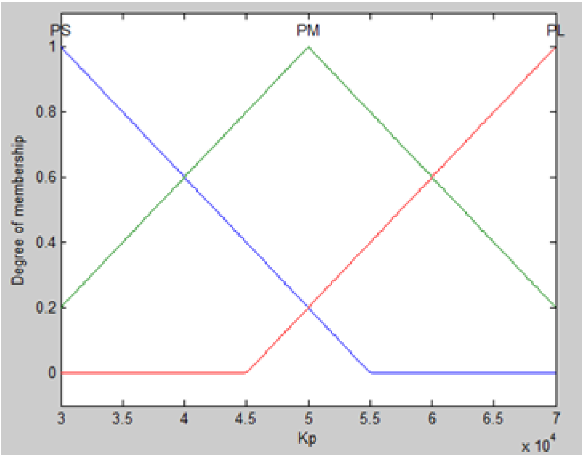


Fig. 4. MF of $K_P$ as an output from FLC

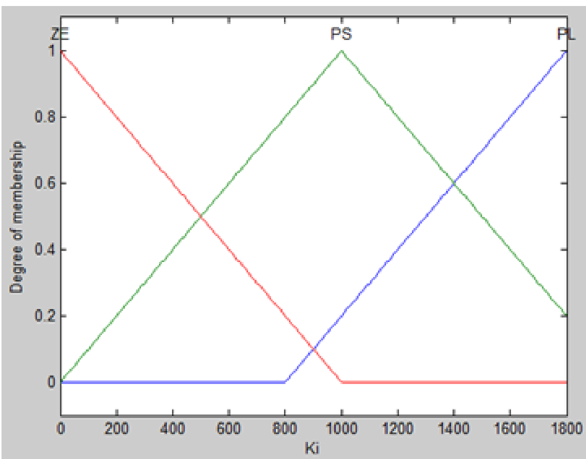


Fig. 5. MF of $K_i$ as an output from FLC

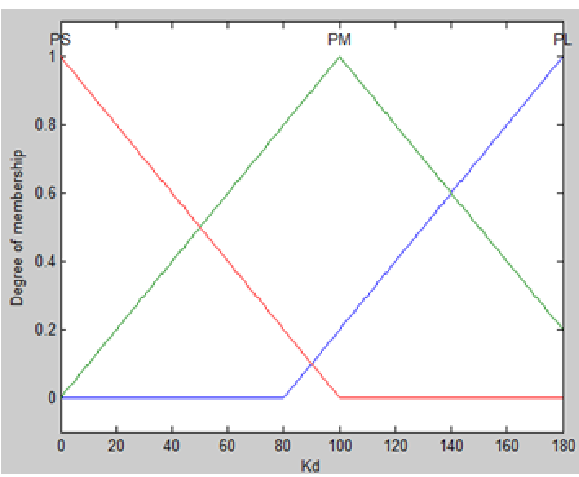


Fig. 6. MF of $K_d$ as an output from FLC

## *B. Fuzzy Inference*

Fuzzy inference is used to put together fuzzy rules. The influence of the parameters $K_e$ and $K_{ec}$ on the output characteristics of landing gear with MR damper can be summarized as follows:

*1) In order to speed up the response of the MR damper, larger values of |e| are essential, which prefer larger proportional coefficient i.e. Kp and smaller derivative coefficient i.e. Kd. In order to avoid the large overshoot of landing gear due to integral saturation, the integral coefficient i.e. Ki = 0.*

*2) The value of |e| is taken middle large to control the response time and smaller overshoot of the MR damper; for which middle values of proportional, integral and derivative coefficients are adopted.*

*3) The smaller values of |e| are used to ensure a good steady-state performance; for which the larger values of proportional and integral coefficients are necessary. If rate of change of error is small then derivative coefficient is large and vice-versa. Usually, middle values are taken for the derivative coefficient to ensure the anti- interference performance of the whole system.*

Depending upon the vibration error '*e*' and the change rate of error '$e_c$' of MR damper landing gear, triangular membership functions are used to build fuzzy rules of the order as shown in Table.1.

TABLE I. RULES FOR THE LANDING GEAR SYSTEM

| | | Rate of Change of Error | | | | |
|---|---|---|---|---|---|---|
| | | NL | NS | Z | PS | PL |
| Error | NL | PL/ZE/PS | PL/PS/PS | PL/PS/PS | PL/PS/PS | PL/ZE/PS |
| | NS | PM/PS/PM | PM/PS/PS | PM/PS/PM | PM/PS/PM | PM/PS/PM |
| | Z | PL/PL/PS | PL/PL/PM | PL/PL/PL | PL/PL/PM | PL/PL/PS |
| | PS | PM/PS/PM | PM/PS/PM | PM/PS/PM | PM/PS/PM | PM/PS/PM |
| | PL | PL/ZE/PS | PL/PS/PS | PL/PS/PS | PL/PS/PS | PL/ZE/PS |

The pictorial overview of the rule bases can be depicted as in Fig.7. These rules can also be written in the form of **IF – THEN** statements and the simulink model is given in Fig.8.

The parameters of landing gear with MR damper are taken into account, which are selected in simulation as shown in Eq.5:

$$M1 = 250000kg;\ M2 = 800kg;$$
$$B = 50000Ns/m;\ K1 = 6 \times 10^5\ N/m;$$
$$K2 = 3.2 \times 10^6\ N/m; \qquad \text{Eq.5}$$

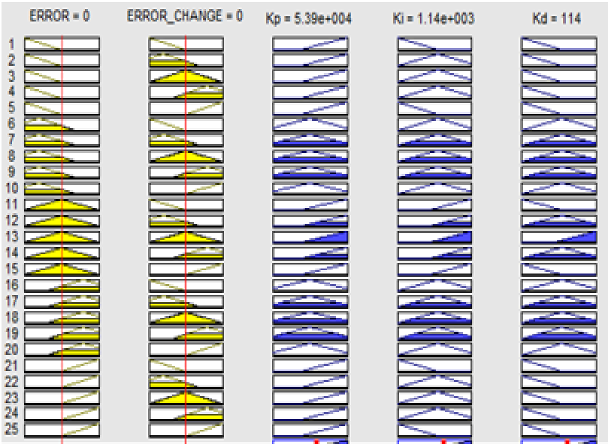


Fig. 7. Rule Viewer

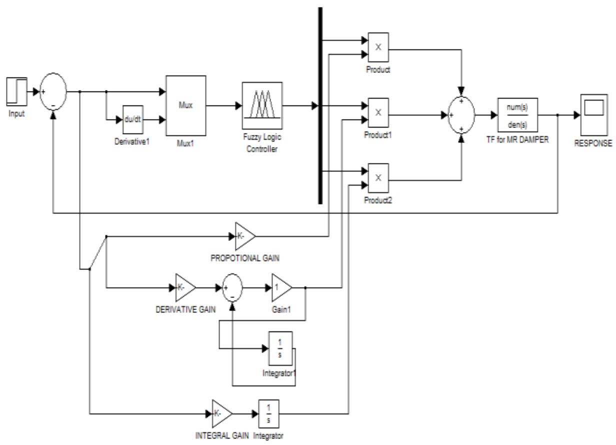


Fig. 8. Simulink Block Diagram

Fuzzy toolbox of Simulink is utilized to build the different control models of MR damper and their comparison, including PID and Fuzzy PID control model. The simulation results indicate the smooth response of the system during the process of take-off and landing. Under the arbitrary road surface input, different properties of MR damper can be examined.

## V. GRAPHS OBTAINED

The Surface Viewer has a special capability to study two (or more) inputs and one output at very same time. The Fuzzy Logic Controller outputs i.e. $K_P$, $K_I$ and $K_D$ can also be studied using surface viewer as shown in Fig.9-11.

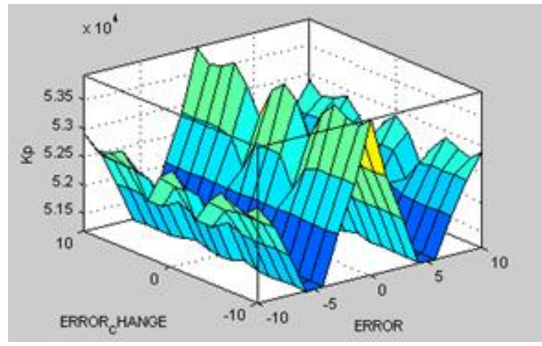


Fig. 9. Surface View for $K_P$

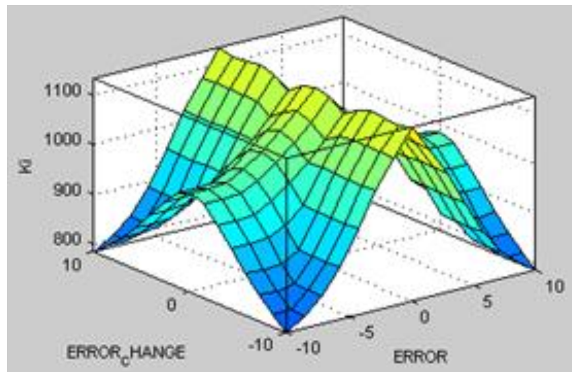


Fig. 10. Surface View for $K_i$

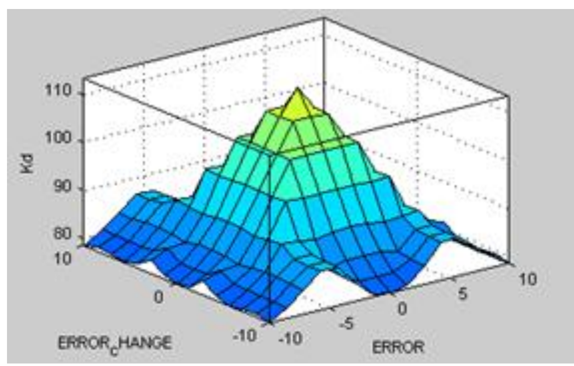


Fig. 11. Surface View for $K_d$

## VI. RESULTS AND CONCLUSION

By comparison and analysis, the simulation results show that Fuzzy PID control action is superior as compared to that of PID controller, that can effectively reduce the vibration of the fuselage and improve the smooth landing response of the aircraft. The simulation analysis of the system noticeably indicates the usage of MR damper in aircraft landing gear. Fuzzy PID control approach has a vital influence on the optimization control for MR damper. The output response of the MR damper based Landing gear system using PID controller and Fuzzy PID controller can be shown as in Fig.12 and Fig.13 respectively.

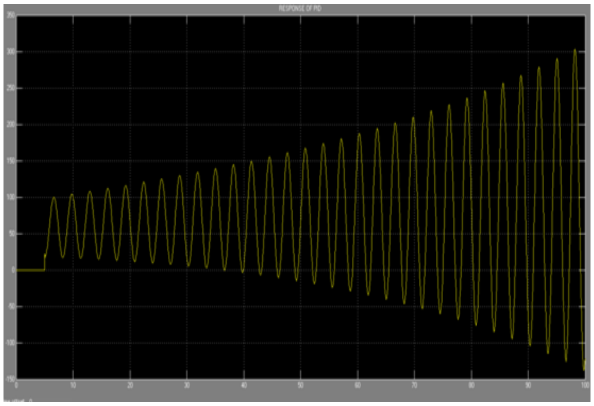

Fig. 12. Waveform for PID Controller

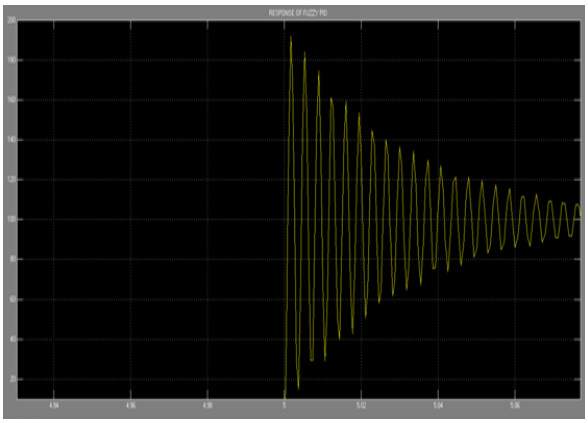

Fig. 13. Waveform for Fuzzy PID Controller

Here, we observe that due to the non-linearity of the MR Damper, the response of the PID controller is unstable whilst, when we make use of a Fuzzy PID controller, a steady output is achieved. The oscillations that are continuous and increasing in amplitude using PID controller are being replaced by damped oscillations tending to a finite value, resulting in the attenuation of the undesired vibrations in the landing phase.

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