Journal of Simulation and Analysis of Novel Technologies in Mechanical Engineering
13 (1) (2021) 0035~0041
HTTP://JSME.IAUKHSH.AC.IR

Research article

The dynamic response of landing aircraft at the moment of landing with regard to smart fluid dampers content MR

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(Manuscript Received --- 12 Jul. 2019; Revised --- 07 Aug. 2019; Accepted ---01 Sep. 2019)

Abstract

Dynamics and vibrations of the aircraft at the moment of impact with the ground is an important issue in aircraft design and its suspension systems. Different models for spring and damper have been used in the design of aircraft. One of the innovative ideas is MR Fluid Technology in its design. These shock absorbers are actually created a semi-active control system which by setting a magnetic field, the viscosity of the fluid can be adjusted and led to the desired damper so that the vibrations of the aircraft at the moment of landing reach the minimum amount. To achieve this purpose in the present study at First, a passive shock absorber is modeled and then an MR shock absorber which could provide the necessities of a landing gear system, have been analyzed. Finally, after writing the differential equations, the vibrational charts of the passive mode with semi active have been compared and the results confirmed and confirmed.

Keywords: Landing gear, Bumpers hydro pneumatic, Fluid MR, Semi-active damping, Dynamic plane

1- Introduction

Landing gear is the most important components of the aircraft. It should decreases the dynamic load as much as possible in terms of hard landing thereby reduce the potential damage. Nowadays all landing gear equipped with hydro pneumatic shock absorbers which have the highest efficiency and maximum energy dissipation.

Development and analysis of this critical system in passive mode goes back to 55 years ago. In this case, because the damper and spring of the shock absorber was ordinary and couldn't offer rapid variation in damping force, the active and semi-active dampers applied in landing gear system represent proper solution for these needs. [1] The active control of a landing gear can increase the efficiency of the landing gear system and cause significant reduction in ground loads during touch-down and taxiing. It might also result in improvement of the passenger and crew comfort. However, using such technology leads to a significant increase in size, weight and power requirements of the system. One of the variable damping concepts which was developed to overcome these limitations was to make use of semi active dampers. This system is less complex; less expensive and lighter than fully active control one. The semi-active control system offers controllable damping forces with minimal power requirements and combines the reliability and fail-safe features of passive system with adaptability of the active system. Among the semi-active control strategies, the ones based on smart fluid MR (Magneto rheological), Have attracted much attention [2].

Because of the unique characteristics of MR fluids, the extent of their use in various industries is very widespread. For example, in the automotive industry [3], the medical industry [4], civil industry [5] and the aerospace industry have been used. This essay will focus on the formulation of MR fluid shock absorbers in the landing gear.

2- MR fluid

A MR-fluid is a type of "smart" fluid made from magnetic particles in a carrier fluid, usually silicon based oil. These fluids are designed in order to apply controllable forces in practical damping problems, where a low response time, low power consumption and high reliability is needed [11]. In the absence of a magnetic field ("inactivated"), the MR fluid behaves like the carrier oil. When subjected to a magnetic field, the particles that have been normally dispersed throughout the oil align themselves along the lines of the magnetic flux. Once aligned in this fashion, the chains of the magnetic particles resist against the trend of being removed out from their respective flux lines alignment and act as a barrier to the fluid flow as illustrated in Fig 1. This causes the variation in the viscous and shear properties of the fluid which consequently yields changes in the damping force.

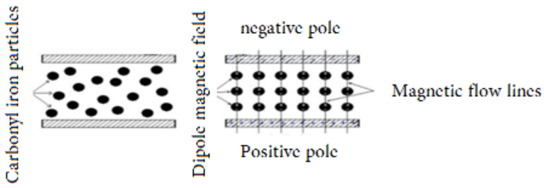

Fig. 1 The left image: particles in the absence of a magnetic field, the right image: particles in the presence of a magnetic field [9].

2-1- Modeling the semi-active landing gear

MR dampers mainly have been studied in automobile suspension systems but on the use of these shock absorbers in landing gear systems no integrated researches has been done. In this section, a semi-active shock absorber is modeled. For this propose the passive shock strut model is discussed. Then the required changes are discussed in order to generate MR shock strut model through which dynamics of the system under different conditions of land, is analyzed.

2-2 Passive hydro pneumatic system design

In these types of shock absorbers, its cylinder has two chambers that upper and lower chambers are separated by the orifice plate. When the aircraft lands, after the initial impact, oil is forced from the lower chamber to the upper chamber through the orifice. The orifice along with metering pin, which enables changes in size of the flow orifice, controls the damping characteristics of the gear as the pin moves through the orifice. When the hydraulic fluid moves from the lower chamber to the upper, gas pressurized and, therefore, generates a force which is known as gas spring force. This gas which can be dry air or nitrogen, when compressed acts like a spring [1]. In the picture (2) a view of this type of shock absorber is depicted. The upper chamber contains hydraulic fluid and the compressed gas which is represented by the light grey area in the figure.

Oil passes through the orifice creates a pressure drop which is known as hydraulic damping force. After the initial impact and compression of gas, the rebound is done by the air pressure forcing the oil to flow back into its chamber through one or more recoil orifices. Thus it can be stated that the gas spring absorbs energy and represents the stiffness properties of the shock strut while the pressure drop obtained from the oil dissipates it at the same time and represents the damping properties. Therefore two independent terms should be formulated and then summed.

2-3 Semi-active hydropneumatic system design

Now with regard to the reforms needed to the passive hydropneumatic shock absorbers model, MR semi-active mode could be modeled. This methodology is based upon replacing the orifice plate of the shock absorber shown in Fig. 2 with an MR valve. The MR fluid valve consists of annular orifices with a coil positioned in flow path.

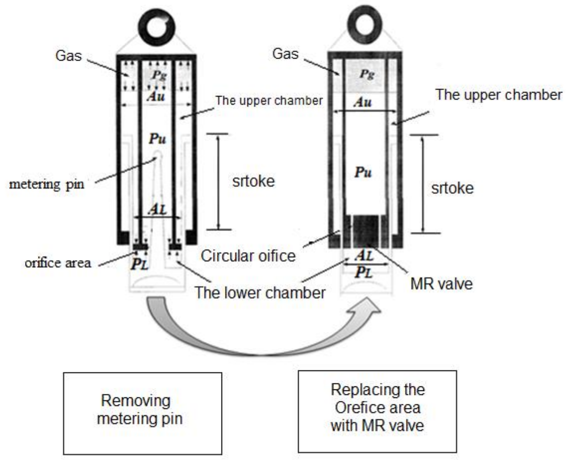

Fig. 2 The left image: Disable shock absorber, the right image: Semi-active shock absorber

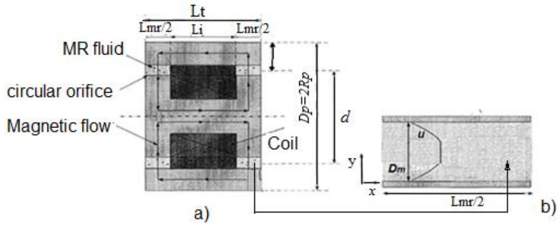

Fig. 3 (a) Schematic Valve MR, (b) velocity within circular orifice for Bingham plastic model

The MR fluid flows through the orifice and changes its apparent viscosity. Flow through the orifice causes the two regions; the region that by changing the magnetic flow, reacts to the field, is fluid active region which is characterized by l_{mr} and other region that are not affected by the field, is fluid in-active region which is characterized by l_{l_i} .

When a current is applied to the orifice, some Changes in pressure drop occur in the two regions which are shown respectively by ΔP_i and ΔP_{mr} [1].

As in image (3-a) was observed, L_t is the total length of the valve, D_P is the diameter of the piston, D_m is Height of the orifice, l_{mr} is the active length and l_i is the in-active length. It is assumed that the amount of l_{mr} is approximately half of the total length of the valve l_t.

3- Formulation of the forces

The determination of the forces generated by MR shock strut is a very important goal; because without having the proper knowledge of these forces, solving the equations of motion becomes impossible. Thus, the force of the shock absorber can be described as a combination of pressure drop across the orifice, F_h and gas spring force, F_g . That's mean:

$$F_S = \left(P_u - P_L\right)A_L + P_g\left(A_u - A_L\right) = F_h + F_g \quad (1)$$

where P_L and A_L are the pressure and the area of the lower chamber and P_u and A_u are respectively the pressure and area of the upper chamber. P_g is the pressure of the accumulator which is $P_g = P_u$.

3-1 Force due to Pressure Drop Across the Orifice

To formulate the force due to pressure drop across the orifice, the two active and inactive regions of fluids have to be modeled. Thus the force due to pressure drop across the orifice can be a linear relationship between the force and pressure which is written as follows:

$$F_h = \left(P_u - P_L\right)A_L = \Delta P_i A_L + \Delta P_{mr} = F_i + F_n \quad (2)$$

Therefore, the overall pressure drop across the orifice can be expressed as a combination of the pressure drop across the inactive length of orifice, F_i and the pressure drop across the active region of the orifice, F_{mr}.

Pressure drop across the inactive region of the orifice, AP0, can be related to the volumetric flow rate using well-known Poiseuille equation for incompressible laminar flow between two stationary parallel plates as:

$$F_i = \frac{12\mu l_i A_L{}^2 \dot{x}_s}{\pi d D_m^3} \quad (3)$$

In above equation, d and $\dot{x}_s$ are respectively Diameter of MR valve and the flow rate.

Pressure drop across the active region of the orifice, F_{mr}, can be related to the volumetric flow rate using Buckingham equation for incompressible laminar flow as:

$$4\left(\frac{l_{mr}A_L}{D_m F_{mr}}\right)^3 \tau_y^3 - 3\left(\frac{l_{mr}A_L}{D_m F_{mr}}\right)\tau_y + \left(1 - \frac{12\mu_p l_{mr} A_L{}^2 \dot{x}_s}{a D_m^3 F_{mr}}\right) = 0 \quad (4)$$

Generally:

$$F_{mr} = f\left(\dot{x}_s, \tau_y\right) \quad (5)$$

So in the case of zero fields, the yield stress is zero too. Thus Eq. (4) is reduced to Eq. (5). In fact, semi-active shock absorbers operate like passive shock absorber; in other words, semi-active system could act like a passive system In the case of failure and have fail-safe mode of operation [1].

3-2 Gas Spring Force

As previously discussed, the force of the shock absorber consists of the gas spring force and the force due to the pressure drop across the orifice. Gas spring force is F_{gx}, which can be written as follows:

$$F_{gx} = \left(A_u - A_L\right)P_{ge}\left(\frac{V_{ge}}{V_{ge} - A_u S_x}\right)^n, \ 0 \le S_x \le S_{tot} \quad (6)$$

For normal ground handling activity, when the rate of compression is low, the process is isothermal meaning that $n = 1$ and in the case of dynamic and fast compression such as impact phase, polytropic process is applied in which $n > 1$. In this process, n is either $n = 1.1$ or $n = 1.35$. The former is used when the gas and hydraulic fluid are mixed and the latter is used when they are separated and the gas is located in an accumulator [2]. Therefore formulation should be made based on the polytropic mode in the landing phase through which the normal mode included too.

4- Equations of Motion

The two-DOF model of the main landing gear system including MR shock absorber model and the free body diagram of the lower and upper masses are presented in Fig 4.

Considering free-body diagram in Fig 4 the governing equations of motion for the main landing gear model can be expressed as:

$$\frac{W_u}{g}\ddot{x}_u + F_S - W_u + F_L = 0$$
$$\frac{W_L}{g}\ddot{x}_L - F_S - W_L + F_t = 0 \tag{7}$$

It is noted that x_u and x_L are measured from the positions of W_u and W_L at the instant $t=0$ when the tire first contacts the ground.

In the above equation F_L is the lift force exerted from the air on the aircraft body and has upward direction [10].

$$F_L = \left(1.2 - 0.9\tanh(3t)\right)\left(W_u + W_L\right),\ t \ge 0 \tag{8}$$

F_t is the tire force and is represented here as:

$$F_t = \begin{cases} k_t x_L + c_t \dot{x}_L & x_L \ge 0 \\ 0 & x_L < 0 \end{cases} \tag{9}$$

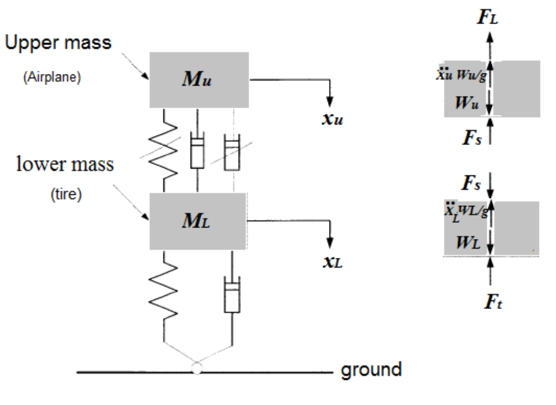

Fig. 4 Two-DOF model of the landing gear system and the free body diagram of the upper and lower mass.

Table 1: Selected value of a sample shock absorber

	Parameter	Symbol / unit	values
MR shock absorber	upper chamber	$A_u : m^2$	0.0182
	Lower chamber	$A_L : m^2$	0.0165
	fully extended gas pressure	$P_{ge} : Pa$	662324.17
Aircraft and tire	Aircraft weight	$M_L : kg$	16.45
	tire weight	$M_u : kg$	1139.1
	Landing speed	$V : m/sec$	3.2
MR valve	valves length	$l_{tot} : m$	0.048
	Active and passive length	$l_i = l_{mr} : m$	0.024
	Orifice Diameter	$D_m : m$	0.0078
	Valve Diameter	$d : m$	0.05
MR Fluid	Shear stress	$\tau_y : Pa$	50000
	Fluid viscosity	$\mu_p : Pa.s$	0.1

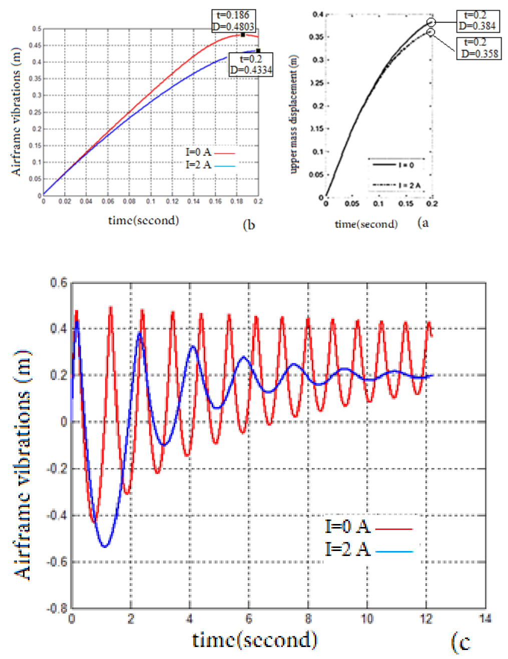

Fig. 5 Airplane vibration curve with landing speed of v= 3/2.a) The results of the fall test in the landing phase [11]; (b) results of landing phase; c) results after the landing phase.

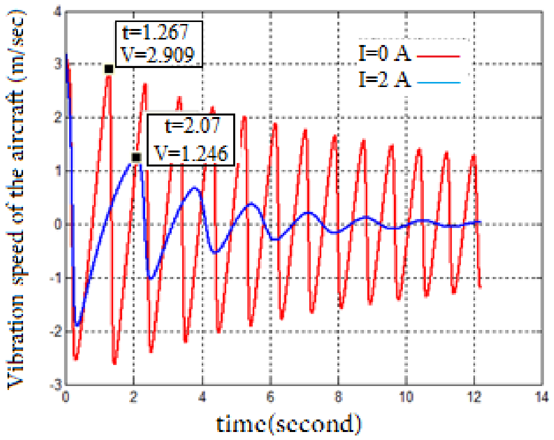

Fig. 6 The vibration velocity curve of the aircraft after the landing phase with a landing speed of v= 3/2

Table 2: Comparison of vibrations and speed of the inactive and semi-active systems

velocity Displacement	inactive systems	semi-active systems	The improved
Maximum vibration of numerical results	0.4803	0.4334	%9
Maximum vibration of the fall test	0.384	0.354	%7
Maximum speed of numerical results	2.909	1.246	%57

5- Conclusion

In this paper, an MR shock absorber model was created based upon changing the passive shock absorber. According to the values selected in the table (1) and expressed Relations confirmed that MR shock absorber model is much better than passive shock absorber because MR shock absorber increases the damping force and consequently reduces the vibration due to landing impact which is shown in Figs. 5 and 6. Table 2 has been shown that semi-active shock absorber is optimized more than passive mode.

References

[1] Currey, N. S. (1988). *Aircraft landing gear design: principles and practices*. Aiaa.

[2] Batterbee, D. C., Sims, N. D., Stanway, R., & Wolejsza, Z. (2007). Magnetorheological landing gear: 1. A design methodology. *Smart materials and Structures*, *16*(6), 2429.

[3] Lindler, J. E., Dimock, G. A., & Wereley, N. M. (2000, June). Design of a magnetorheological automotive shock absorber. In *Smart Structures and Materials 2000: Smart Structures and Integrated Systems* (Vol. 3985, pp. 426-437). International Society for Optics and Photonics.

[4] Carlson, J. D. (2001). Smart Prosthetics Based on MR Fluids. In *Proc. 8th Ann. symposium On Smart Structure And Mat. SPIE*.

[5] Yang, G., Spencer Jr, B. F., Carlson, J. D., & Sain, M. K. (2002). Large-scale MR fluid dampers: modeling and dynamic performance considerations. *Engineering structures*, *24*(3), 309-323.

[6] Ahmadian, M., & Norris, J. A. (2008). Experimental analysis of magnetorheological dampers when subjected to impact and shock loading. *Communications in Nonlinear Science and Numerical Simulation*, *13*(9), 1978-1985.

[7] Mikułowski, G. (2008). Adaptive impact absorbers based on magnetorheological fluids. *IPPT PAN*.

[8] Wereley, N. M., Cho, J. U., Choi, Y. T., & Choi, S. B. (2007). Magnetorheological dampers in shear

mode. *Smart Materials and Structures*, *17*(1), 015022.

[9] Abu-Ein, S. Q., Fayyad, S. M., Momani, W., Al-Alawin, A., & Momani, M. (2010). Experimental investigation of using MR fluids in automobiles suspension systems. *Research Journal of Applied Sciences, Engineering and Technology*, *2*(2), 159-163.

[10] Choi, Y. T., & Wereley, N. M. (2003). Vibration control of a landing gear system featuring electrorheological/magnetorheological fluids. *Journal of aircraft*, *40*(3), 432-439.

[11] Khani, M. (2010). *Magneto-rheological (MR) damper for landing gear system* (Doctoral dissertation, Concordia University).