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Abstract

An ideal oleo strut must perform optimally during widely different landing conditions of an aircraft and Unmanned Aerial Vehicle (UAV). These landing conditions may impose different requirements such as controlling vertical acceleration in a desired manner. Depending on the atmospheric conditions, the axial load on the strut changes during compression and the ability to control the damping force as function of time would be of great advantage. In this paper, it is shown that by using MR fluid in the oleo strut, it is possible to achieve optimal damping performance in every particular landing situation. Three different forces act along a conventional oleo strut which are: that due to the compression/expansion of gas, that due to the passing of fluid through the orifice and that due to the viscous force. The first is the spring force while the second and the third are the damping forces. The second is proportional to the square of compression/extension rate and the third is proportional to just the rate of compression/extension. Incorporating a metering pin that can change the orifice diameter in a prescribed fashion can change the damping force to some extent within limits. By using MR fluid in a conventional oleo strut the damping force can be altered in a desired manner. A simulation model for a SDOF aircraft system is developed and a landing scenario at a particular sink velocity is simulated. The parameters controlling the behavior of MR fluid damper are tuned to get the optimal performance during landing.

Keywords: MR dampers, Oleo pneumatic dampers, Simulink model

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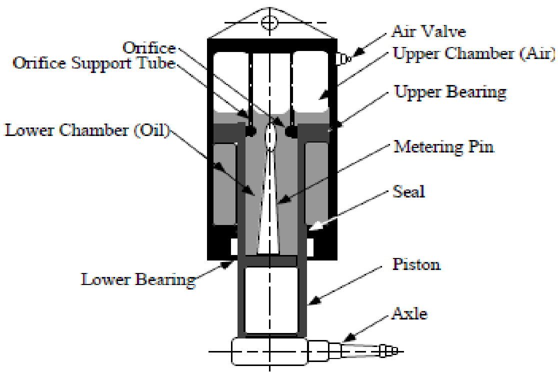
Introduction

Aircraft structure is a complex combination of a number of different components and sub-assemblies. All the systems that are involved during landing, take off, cruising and taxiing are very critical. Amongst all, landing gear is considered one of the most critical sub-assemblies (Howe, 2004). Landing gear plays a vital role during landing and take-off of aircrafts by absorbing and dissipating the impact energy. A good shock absorber should absorb most of the impact kinetic energy during landing and taxiing of an aircraft. Today, oleo-pneumatic shock absorbers are the most commonly used shock absorbers in aircraft landing gears because of their high efficiency and ability to absorb shocks and dissipate energy effectively (Currey, 1988).

Oleo-pneumatic Shock Absorbers

The constructional features of an oleo-pneumatic shock absorber are shown in Fig.1. It consists of an upper chamber with dry air or nitrogen and a lower chamber with oil. The strut operates by pushing the chamber of oil against the chamber of dry air or nitrogen. The dissipation of energy takes place when oil flows through one or more orifices. A landing aircraft inevitably rebounds after the initial impact. During this phase, the pressurized air forces the oil back to the lower chamber through the recoil orifices. The rate of flow of oil through the recoil orifices determines the amount of rebound. If oil flows too quickly through the orifice, aircraft rebounds upwards rapidly. On the other hand, if oil flow is too slow, the oscillations will not be damped out effectively during soft landing and taxiing phase (Currey, 1988).

Figure 1. *Oleo-pneumatic Shock Absorber*



The spring force in an oleo strut is provided by the compression and expansion of gas and the damping force by the fluid passing through the orifice. The orifice area changes as the metering pin moves up and down through the orifice. By appropriately designing the metering pin, it is possible to achieve required damping force (Hall, 1966). The oleo-pneumatic struts with orifice control follow conventional square law. When oil flows through orifice, a pressure difference is created inside the chamber which produces a highly resistive force and consequently a very high damping. Because of the small size of the orifice, the oil flows with a very high velocity creating turbulence inside, producing a tremendous damping force proportional to square of the strut velocity. The efficiency of this type of strut is high for the large velocities which occur during landing but is greatly reduced for low velocities during taxiing phase. Therefore, for low velocities, only the linear damping regime of the damping devices needs to be considered (Hall, 1966). The corresponding damping force is directly proportional to the velocity which provides good damping efficiency during both taxiing and landing phases. Also, the rapid fall off in the efficiency can be avoided using a linear damper (Hall, 1966).

In this paper, an oleo strut is filled with MR fluid instead of oil. When there is no current applied, the strut operates as a conventional strut and both the linear and the non-linear damping terms are considered. When it is applied with current and operates as a MR damper, the viscosity of the MR fluid changes accordingly, and the damping characteristics of the oleo strut are improved significantly. Moreover, such a change in the viscosity of the MR fluid is accomplished by changing the applied current as needed in a given landing situation. The equations of motion are solved to obtain the response of UAV upon landing with a particular sink velocity.

Need for Magnetorheological (MR) Fluids

MR fluids are a class of smart materials that can change their viscous characteristics when external magnetic field is applied. Upon application of a magnetic field, these fluids change from free flowing state to a semi-solid state changing their damping properties significantly. The change of state is rapid and can follow an applied current signal. This ability has given them tremendous importance in engineering applications, particularly in control systems (Wang & Liao, 2011).

Mathematical Modeling of MR Dampers

Magnetorheological fluids have high operating temperature range and low voltage requirements, making them ideally suitable for the landing gear applications. Batterbee, et al. (2007) suggested a methodology to optimize the performance of MR landing gear by considering the packaging constraints for the aircrafts. The hysteretic cycle followed by the MR fluids with the cyclic application of varying currents makes it very difficult to model their damping behavior. Several theories have been developed over the years in order to approximately model the hysteretic behavior. The different models describing the characteristics of MR fluids play a vital role in the development of MR fluid devices. The different approaches for hysteresis modeling can be classified as the Bingham model based dynamic models, biviscous model, the Dahl hysteresis operator based dynamic models, the sigmoid function based model, the viscoelastic plastic models and a few others (Wang & Liao, 2011). The present study uses the nonlinear biviscous hysteretic model (Werely, et al., 1998; Wang & Liao, 2011) because of its simplicity.

Nonlinear Biviscous Hysteretic Model

A four parameter nonlinear biviscous hysteretic model is used in the present study. The equations governing the nonlinear biviscous hysteretic behavior are given as follows (Wang & Liao, 2011; Werely, et al., 1998):

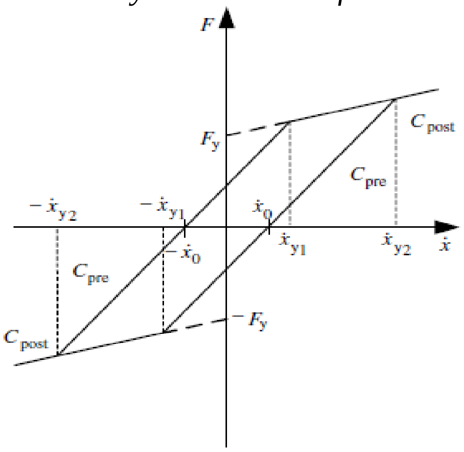
(1)

In Eq. (1) $\dot{x}_o$ is the velocity intercept at zero force and $\dot{x}_{y1}$ and $\dot{x}_{y2}$ are the compressive (decelerating) and tensile (accelerating) yield velocities, given by,

and (2)

A graphical representation of the above six equations is shown in Fig. 2. The four governing parameters which describe the damaping action of the MR damper are the pre-yield viscous damping (C_{pre}), the post yield visocus damping (C_{post}), the yield force (F_y) and the zero force velocity intercept ($\dot{x}_0$). The four factors [C_{pre}, C_{post}, F_y, $\dot{x}_0$] are sufficient to determine the damping force for a particular current excitation for which a good hysteresis can be observed (Wang & Liao, 2011).

Figure 2. *Nonlinear Biviscous Hysteretic Model for MR Damper*



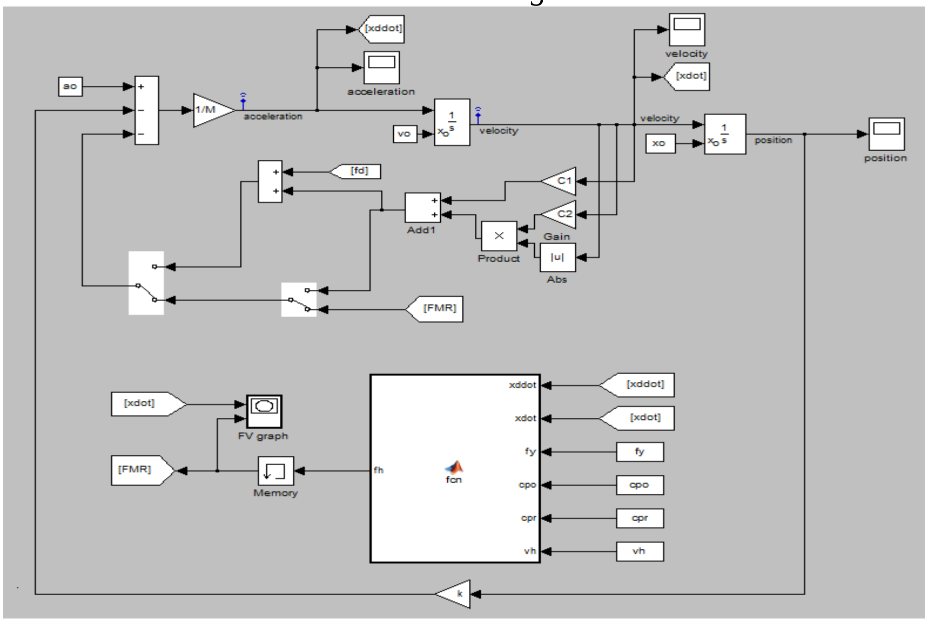
The hysteresis loop follows a counterclockwise direction when plotted against time with the motion to the right corresponding to positive acceleration and vice versa. The mean curve of the hysteresis loop approximately corresponds to the viscous damping coefficient of the MR fluid. In the pre-yield region a strong hysteresis can be observed.

The force velocity relationship is linear for larger positive velocities. When the velocity becomes negative, the force velocity relation drops of suddenly. This rapid drop is due to bleed or blow-by of fluid between the piston and the cylinder. When no current is applied, the MR damper behaves passively and behaves like a viscous damper.

Analysis and Implementation in Simulink

A Simulink model of a single degree of freedom system for UAV is shown in Fig. 3. Earlier, the SDOF system was modeled without including the damping force proportional to the square of the velocity (Asthana and Bhat, 2012). In the present model both the linear and nonlinear damping are considered when no current is applied and when current is applied MR damping is considered. The damping coefficients C_1 and C_2 represent the linear and the nonlinear damping effects, respectively. The MR damper behaves as a passive damper when the applied current is zero. In the present simulation model, a manual switch is provided in order to run the model either as a passive damper when no current is applied or as a MR fluid damper. A Matlab function block is used which contains the equations describing the behavior of nonlinear biviscous hysteretic model and the damping force, F_{MR}, associated with it. The nonlinear biviscous hysteretic model describes the dynamic behavior of the MR fluid damper by taking into consideration four governing parameters namely, the pre-yield viscous damping (C_{pre}), the post yield visocus damping (C_{post}), the yield force (F_y) and the zero force velocity intercept ($\dot{x}_0$). By optimally selecting the range of the values for these governing parameters, the potential advantage of using MR fluid in the oleo damper can be realized.

Figure 3. *Simulink Model For SDOF Landing Gear*



The parameters used to develop a SDOF model of UAV are obtained from reference (Wilson & McKay, 1968). The landing weight is considered as 20000 kg. The maximum stroke length of nominal oleo damper is taken as 0.3048 m. The optimal values of the four governing parameters which control the behavior of the MR fluid damper are taken as, C_{pre}=550000 N-s/m, C_{post}=70000 N-s/m, F_y=200000 N and $\dot{x}_0$= 0.01. A conventional oleo damper design is considered with a nominal damping ratio of 0.2. The corresponding damping coefficient is calculated from the standard equation, $C_1=2*M*\omega_n*\zeta$. A value of ω_n=3π rad/s is assumed as the natural frequency of the aircraft in vertical vibrations. For simplicity, the magnitude of the orifice damping coefficient C_2 is taken approximately equal to C_1.

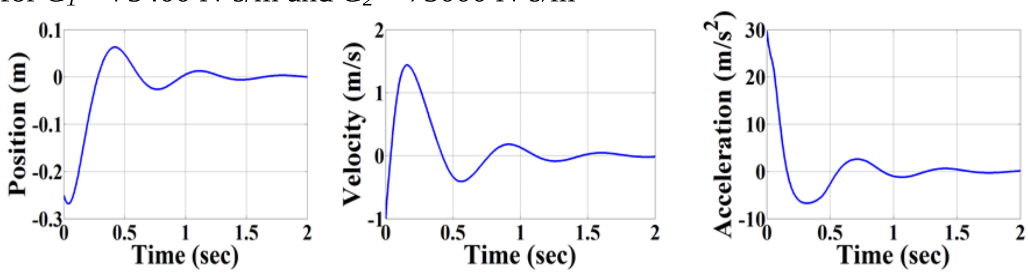
The response of the nominal oleo incorporated with MR fluid is analyzed for three different cases of sink velocities which are 1 m/s, 2 m/s and 3 m/s, and compared with the same oleo damper acting passively when current applied is zero.

Results

Initially, for the chosen parameters of a nominally designed oleo damper incorporated with MR fluid, the response is plotted for three different sink velocities taking into consideration the different landing scenarios which are presented in Figs. 4-6. Each figure compares the response of the passive oleo damper to the one when it acts as controllable MR damper upon the application of a current. It can be observed from Figs. 4-6 that when the viscosity of the MR fluid inside the oleo-pneumatic damper is changed optimally, by controlling the four governing parameters, a smoother response is obtained as compared to the passive oleo damper. For soft landing scenarios, where the sink velocity is between 1 m/s to 2 m/s, the overshoot in the damping response is removed completely. Also, the vehicle comes down to the initial position immediately after the impact in the shortest possible time.

Figure 4. *Comparison of Passive and Active Oleo-Pneumatic Damper Incorporated with MR Fluid for Sink Velocity Of 1.0 M/S*

(a) Response of passive oleo-pneumatic damper incorporated with MR fluid for C_1 = 75400 N-s/m and C_2 = 75000 N-s/m



(b) Response of active oleo-pneumatic damper incorporated with MR fluid for *Cpre* = 550000 N-s/m, C_{post} = 70000 N-s/m, F_y = 200000 N, $\dot{x}_0$ = 0.01

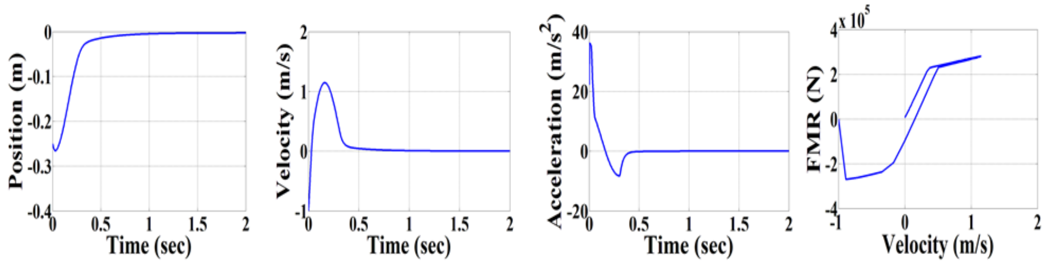
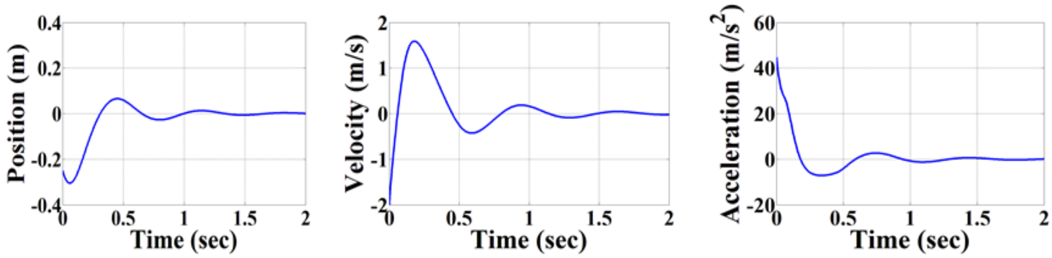


Figure 5. *Comparison of Passive and Active Oleo-Pneumatic Damper Incorporated with MR Fluid for Sink Velocity of 2.0 M/S*

(a) Response of passive oleo-pneumatic damper incorporated with MR fluid for C_1 = 75400 N-s/m and C_2 = 75000 N-s/m



(b) Response of active oleo-pneumatic damper incorporated with MR fluid for *Cpre* = 550000 N-s/m, C_{post} = 70000 N-s/m, F_y = 200000 N, $\dot{x}_0$ = 0.01

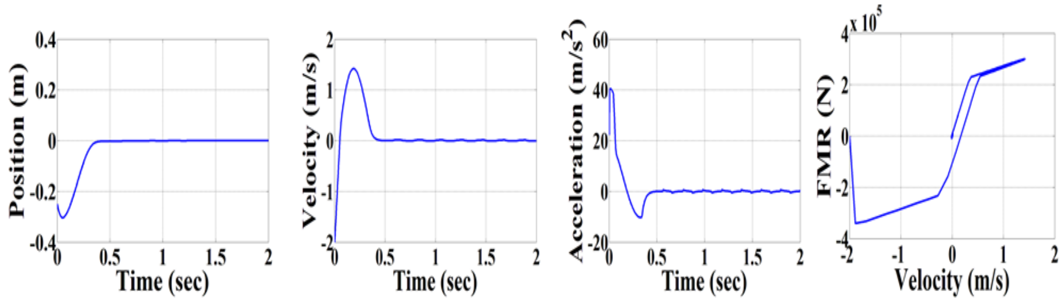
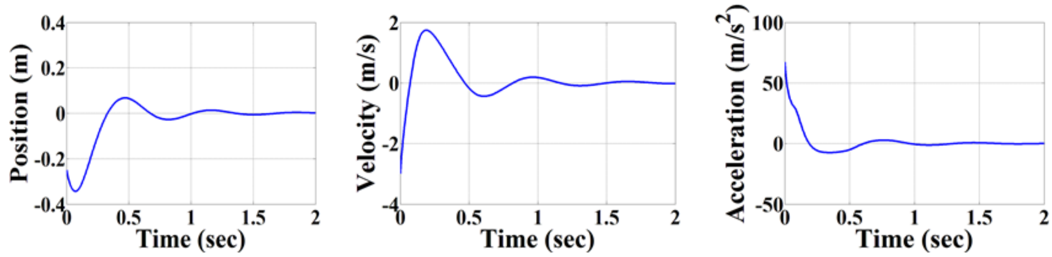
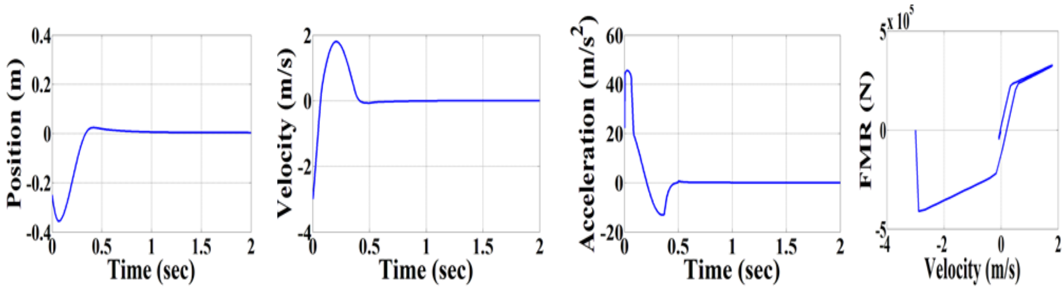


Figure 6. *Comparison of Passive and Active Oleo-Pneumatic Damper Incorporated with MR Fluid for Sink Velocity of 3.0 M/S*

(a) Response of passive oleo-pneumatic damper incorporated with MR fluid for C_1 = 75400 N-s/m and C_2 = 75000 N-s/m



(b) Response of active oleo-pneumatic damper incorporated with MR fluid for *Cpre* = 550000 N-s/m, C_{post} = 70000 N-s/m, F_y = 200000 N, $\dot{x}_0$ = 0.01



Similar results are obtained for hard landing scenario where a sink velocity of 3 m/s is considered. Fig. 6 takes into account the hard landing scenario. It can be observed that even when the sink velocity is high, the response of the vehicle after landing is smooth and it is possible to remove the overshoot in the response which is normally encountered when only passive damper is acting.

It can be seen from the results that it is advantageous to use MR fluid in the oleo-pneumatic dampers to improve their performance significantly. By optimally controlling the viscosity of the MR fluid used in the nominal oleo, it is possible to improve the damping performance and bring down the vehicle to its initial position in the shortest possible time after it lands even for hard landing conditions.

Conclusions

Oleo-pneumatic dampers incorporated with the MR fluid are studied in order to examine their effectiveness during each landing condition. In an earlier study, MR fluid was added to the nominally designed oleo strut which improved the performance of the landing gear considerably. In the present study, a realistic model of the oleo strut is formulated that includes the non-linear damping term proportional to the square of the oleo compression/ extension velocity in addition to the linear damping force in order to compare with that of a strut filled with MR fluid. By changing into MR fluid in the oleo strut, the damping can be improved considerably. The smooth interface between the electrical signal and the mechanical behavior of the MR fluid damper makes it very convenient to be used in a control system that can achieve an optimal performance under any landing conditions.

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