CONTROLLABLE STUDY OF ELECTRO-RHEOLOGICAL FLUID APPLIED TO LANDING GEAR BUMPER

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Abstract

Electro-rheological fluid takes many advantages to suppress mechanical vibration or impact, because of its electro-mechanical coupled effect and low energy controllability. This paper develops an idea to use such a medium for shock-energy absorbing of aircraft's landing gear, and the mathematical model for it has been constructed*. For the oil-air bumper of single-cavity, an appropriate controllable law to improve dynamic quality of landing gear subjected to impact has been presented in this paper.*

1 Introduction

Electro-rheological fluid (ERF), as a novel energy saving technology of electro-mechanical conversion, has been received more and more application in many industrial fields recent years, which possesses of reversibility, quick response, easy control, low energy dissipation and widely varying range. Many research institutes of the America, England, Japan, Germany and Russia, etc. have developed a large number of technical products such as base-mounts, valves, clutches and dampers for use of vibrating suppression and improvement of dynamic quality in supporting bases and movable articulations of automotive engine, bridge, robot and other mechanical engineering[1~3]. Electro-rheological damper makes full use of controllable resistance and remarkable electro-mechanical coupled effect in vibrating suppression, and many theoretical researches with advanced technical applications have been recently reported for aeronautical engineering[4], for example, ERF is experimentally added into rotary wing structure of helicopter to control its bending and twisted vibration.

In view of its excellent electro-mechanical coupled effects and potential to use in flight vehicle technology, this paper theoretically attempts to explore ERF as a variable damping medium to actively control aircraft's landing-gear bumper such that it alleviate high speed landing impact. The mathematical model and numerical solution have been studied for this idea, and a mathematical control law has been presented in this paper.

2 Mathematical Model

Fig.1 shows the simplified oil-air mixed construct and its model of a typical single-cavity landing gear[5], structural mass of which consists of two parts, one is elastic, m_1, composed of airframe, bumper wall, oil and air cavities, etc. and the other is non-elastic, m_2, composed of bumper piston-rod, wheel and its tire, etc. For the modeling simplicity, we take some assumptions as follows:

1.the movement of landing gear is confined along the direction perpendicular to ground;

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2.the elastic deformations of bumper cavity, bracing strut and wheel are neglected, and damping oil is considered non-compressive; and 3.m_1 can be accounted into an equivalent elastic mass around landing gear shaft, and m_2 around wheel shaft.

Based on the above assumptions, the mathematical model of a typical oil-air mixed landing gear can be written as

$$m_1\ddot{y}_1 = f_v + f_u \tag{2.1a}$$

$$m_2\ddot{y}_2 = -f_v - f_u + f_t \tag{2.1b}$$

where f_v indicates the air spring force; f_u oil drag; f_t force provided by tire; y_1 the displacement of gravity center of landing gear, and y_2 the displacement of the wheel shaft.

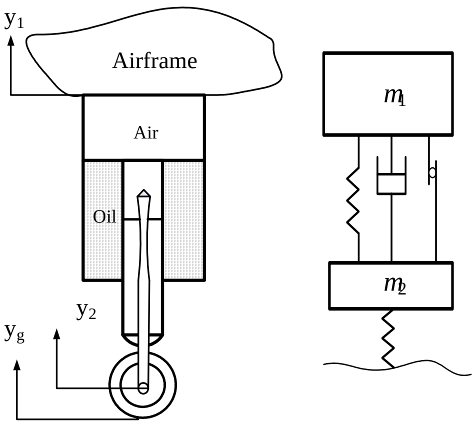


Fig.1 Simplified construct and model of a landing gear

When taking the wheel as a linear spring with stiffness coefficient K, the force f_t can be simply described by

$$f_i = K(y_g - y_2) \tag{2.2}$$

where y_g is the displacement input by ground impact. Substitution of Eq. (2.2) into (2.1b) leads to

$$m_2\ddot{y}_2 = -f_v - f_u + K(y_g - y_2) \tag{2.3}$$

It is assumed that landing impact can be considered as an adiabatic process because of very short time action and very difficult heat exchange with exterior. Hence, the air spring force is given by

$$f_v = \frac{P_0 V_0^{\,r} A_0}{(V_0 - A_0 S)^r} = \frac{P_0 A_0}{(1 - A_0 S/V_0)^r} \tag{2.4}$$

where P_0 means initial pressure of air cavity; V_0 initial capacity of air cavity; A_0 effective air compressive area; S air compressive stroke; and r air compressive variable index with value through 2.1 to 2.4.

When the oil medium of the landing gear bumper is replaced by ERF, the pressure drop of ERF flow is given to rise by viscous flow and electro-rheological shearing effect, which means that the flow drag is made up of both viscous and coulomb damping, that is,

$$\Delta P = \Delta P_\eta + \Delta P_{ER} \tag{2.5}$$

where $\Delta P_\eta = \frac{\rho k}{2}(\frac{A_0}{A_d})^2 V_0^{\,2}$, means pressure drop brought by viscous damping[6]; and $\Delta P_{ER} = C\frac{L}{H}\tau_y$, is pressure drop brought by coulomb damping.

Thereby, the total drag provided by ERF for landing gear bumper can be expressed as

$$f_u = \frac{\rho k A_0^3}{2A_d^2} V_0^{\,2} + CA_0\frac{L}{H}\tau_y = F_\eta + F_{ER} \tag{2.6}$$

where C is a proportional coefficient with values through 2 to 3; F_{ER} is usually taken as a function of the static yielding stress, τ_y of ERF， which is invariant under certain electric field intensity E, and empirically taken as an exponent function of E with relationship of

$$\tau_y(E) = 0.324 \times E^{1.876} \tag{2.7}$$

The Eqs.2.4 and 2.5 are substituted into the mathematical model 2.3, and after some real-life landing impact situation is taken into account, a simultaneous non-linear governing ordinary differential equation group for the ERF damping type bumper can be written by

$$\begin{cases} \ddot{\delta} = \overline{L}g - \dfrac{K\delta}{m_1 + m_2} - \zeta\ddot{S} \\ \ddot{S} = \dfrac{1}{m_2}\left(K\delta + \dfrac{m_2\overline{L}g}{\zeta} - \dfrac{F_s}{\zeta}\right) \end{cases} \quad (2.8)$$

where S stands for bumper stroke in compression, δ for compressive quantity of landing gear tyre, $\overline{L}$ for influencing coefficient of lift download, g for gravity acceleration, ζ for upper mass coefficient equal to

$$\varsigma = \frac{m_1}{m_1 + m_2} \quad (2.9)$$

and F_S for drag of the bumper written as

$$F_s = (1+K)\frac{P_0 A_0}{(1 - A_0 S/V_0)^r} + \frac{\rho k A_0^3}{2A_d^2}\dot{S}^2 + CA_0\frac{L}{H}\tau_y \quad (2.10)$$

3 Numerical Solution

In order to determine the initial and boundary conditions for solving Eq.2.8, we should figure out the displacement and speed of the lower mass of landing gear before the movement of bumper piston. Then, the following equation should be solved, that is,

$$(m_1 + m_2)\ddot{y} + Ky = (1+K)\frac{P_0 A_0}{(1 - A_0 S/V_0)^r} \quad (3.1)$$

And the initial and boundary conditions of Eq. 3.1 can be given as

$$Y\big|_{t=0} = \frac{\overline{L}(m_1 + m_2)g}{K} \quad (3.2)$$

$\dot{Y}\big|_{t=0}$ = the sinkage speed of aircraft.

Solve the above problem and take the displacement and speed when balancing as those of bumper piston starting to move, and also as the initial and boundary conditions of Eq.2.8, which are assumed as

$$\dot{S} = 0, \quad \ddot{S} = 0, \quad \delta = Y_1, \quad and \quad \dot{\delta} = \dot{Y}_1 \quad (3.3)$$

With help of the Rounger-kutta technique, the numerical results of the Eqs.2.8 under the initial and boundary conditions, Eqs.3.3 can be obtained.

To proceed with finial destination, the following parameters of the dynamic system are taken into account,

$m_1 = 8700$ kg , $m_2 = 100$ kg ,

$P_0 = 15.3 \times 10^5$ Pa , $V_0 = 0.831 \times 10^{-3}$ m^3,

$A_0 = 0.35 \times 10^{-2}$ m^2, $A_d = 0.33 \times 10^{-4}$ m^2,

$\zeta = 0.989$, $K = 133222$ N/m ,

$\tau_y = 0.324 \times E^{1.876}$,

$CA_0 \dfrac{L}{H}\tau_y = 250 \times A_0 \times E^{1.876}$

Substitute the above parameters into Eqs.3.1 and 3.2, and some characteristic values are solved as follows,

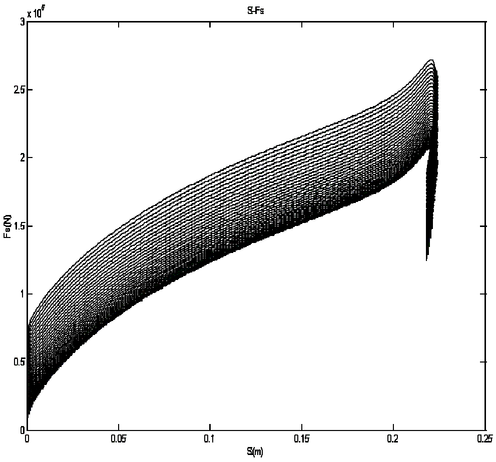
$\omega = \sqrt{\dfrac{K}{m_1 - m_2}} = 3.891$, being the natural frequency of the dynamic system,

$A = \sqrt{Y_0^2 + (\dfrac{\dot{Y}_0}{\omega})^2} = 0.788$, being the modal amplitude of the dynamic system,

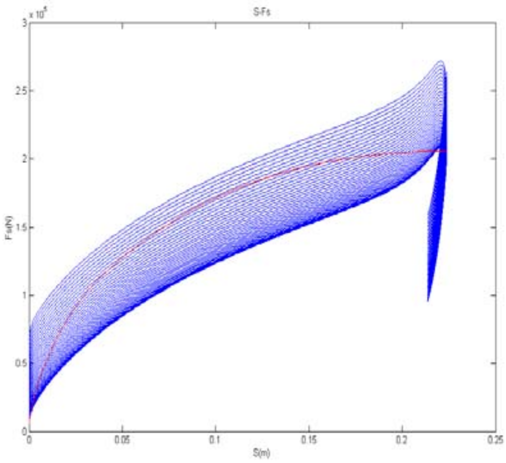
$Y_1 = 0.0439$, being the initial displacement of bumper piston starting to move, and

$\dot{Y}_1 = 3.051$, being the initial speed of bumper piston starting to move.

Now taking different electric field intensity, E and all the above concrete parameters, we can evaluate the Eqs.2.8 and 2.10, step by step under a numerically stable size, and plot all the numerical curves of the bumper stroke, S against its drag F_S, which are shown as Fig. 2a.



(a)



(b)

Fig.2 Curves of bumper stroke vs. its drag

4 Controllable Law

Each work curve in Fig.2a, under certain electric field intensity is not satisfied with the requirement of comfortableness, and so we need to vary field intensity as the function of bumper stroke. Plot a goal work curve, shown as Fig.2b, and evaluate the intersections of the curve with all the original ones, as well as plot the intersectional curves in Figs.3and 4. Then fit the intersections and we can obtain the so-needed function in the Eqs 4.1.

$$E(S) = 10^8 (1.7143S^3 + 0.0428S^2 + 0.0004S) \quad (0 < S < 0.0112) \tag{4.1}$$

$$E(S) = 10^8 (-1.7512S^6 + 1.664S^5 - 0.3104S^4 + 0.0419S^3 - 0.031S^2 + 0.0001S) \quad (0.0112 < S < 0.2012) \tag{4.2}$$

$$E(S) = 10^9 (-7.1088S^4 + 5.91S^3 - 1.8447S^2 + 0.2258S - 0.133) \quad (0 < S < 0.0112) \tag{4.3}$$

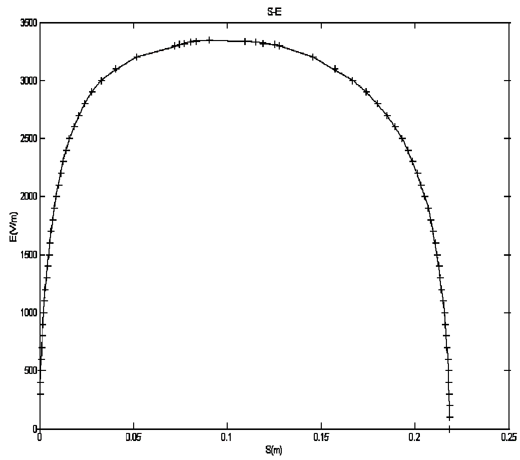


Fig.3 Curve of intensity E vs. stroke

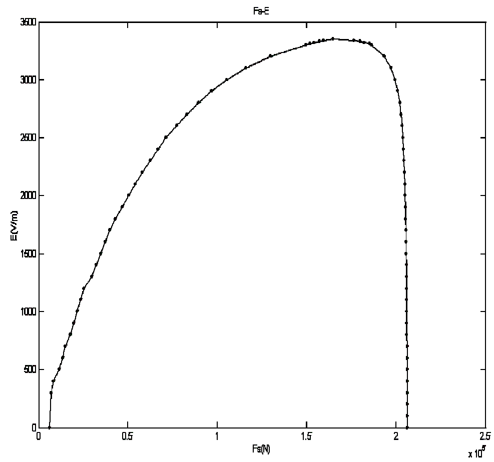


Figure 4 Curve of intensity E vs. bumper drag

Use the Eqs.4.1 and all the same physical parameters, numerically solve the non-linear dynamic system again and we can obtain final evaluations, drawn as Fig.5, which deviates the goal curve only with 4 percent of maximum relative error.

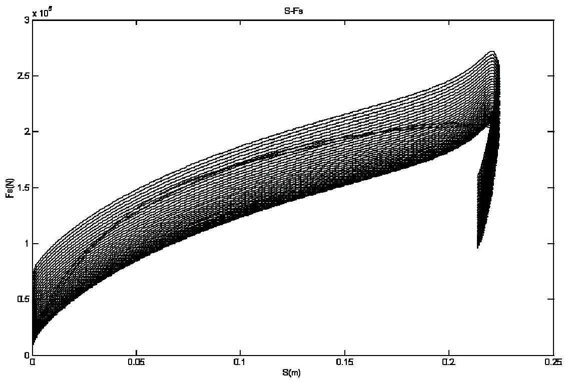


Fig.5 Goal work curve of bumper stroke vs. its drag

5 Concluding remarks

This paper has developed an idea to use electro-rheological fluid as damping medium for controlling the work curve of landing gear subjected to impact. The dynamic governing equations of landing gear under such a damping medium have been worked out and numerically solved. To find the controllable law of electric field intensity with landing gear bumper stroke, a goal work curve is plotted and the fitting relation of electric field intensity with the bumper stroke has been obtained. Based on this controllable law, the dynamic equation of the landing gear is evaluated again and an ideal shock-absorbing effect on landing gear has been achieved.

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