

ADAPTIVE AIRCRAFT SHOCK ABSORBERS

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Typically, aircraft shock absorbers are designed as passive devices with characteristics satisfying the hardest expected landing impact conditions. However, in the majority of the cases, the variation of real working conditions is below these critical levels and the passive shock absorber is too stiff to optimally perform the landing scenario. In contrast to the passive systems, the proposed approach focuses on active adaptation of energy absorbing structural elements, where the system of sensors recognizes the type of impact loading, and activates energy absorbing components realizing a pre-design strategy of optimal impact energy dissipation.

The term "adaptive shock absorbing" refers to the methodology used to formulate the laws that determine the required signal produced in response to the measured output of the sensors (e.g. radar or accelerometers). This control signal is sent to the actuators (e.g. tuning characteristics of Magnetorheological Fluid), thereby applying corrections of mechanical properties of structural members. The corresponding methodology (and the software package) will be developed in the proposed approach. As a result, the optimal distribution of non-linear material characteristics (realized through actively controlled shock absorbers) can be designed for the predicted impact scenarios.

Keywords: smart structures, magnetorheological fluid, MR Damper

1 General Introduction

For many years aircraft technology researchers have considered the possibility of introducing active control to landing gear systems. Loads that are induced during aircraft touchdown operation, as well as, loads transmitted to the fuselage during taxiing, have a very unfavourable influence on the durability of the structure. Smart solutions for controlling and limiting the structural loads on the inevitable level, would allow for increased periods between servicing the airplanes, as well as, improve the comfort of travel for the passengers and crew of passenger aircrafts. On the other hand, the technology of actively controlled, smart landing gears may be also welcomed by designers of military aircrafts. It is very important to consider the introduction of a landing system for fighters, which would enable them to land and operate on uneven landing fields, e.g. unpaved airfields or runways that were repaired after bombing.

Systems that were proposed in the seventies and were tested in the eighties were based on an idea of influencing the internal hydraulic oil pressure inside of the shock absorber chambers [3, 4]. Realization of these concepts were actualized by introducing additional hydraulic circuits that pumped additional amounts of

fluid in or out of the system, effecting the hydraulic circuits of the shock absorber with increasing or decreasing hydraulic pressure. The basis of the concept was to obtain a desired damping force, realized by the device, by monitoring the difference in hydraulic pressure levels between two internal chambers of the shock strut. In light of the fact that a touchdown instant lasts 200 ms, it was concluded that a hydraulic system with limited size was not capable of acting fast enough to control the dissipation of impact energy.

These limitations may be overcome in the case of using a faster way of influencing the damping forces generated by the shock absorber, and using predictive strategy of control. Magnetorheological dampers have capabilities of relatively quickly changing the shock strut characteristics, which in combination with predictive control system may be an efficient way of controlled dissipating of landing impact energy.

As a model for the numerical and experimental verification of the presented approach, a small MR damper 1005-3 (produced by the LORD company) was chosen.

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2 Experiments

A small drop stand was used for the testing of MR Damper RD 1005-3 under impact loading. The damper was placed in a vertical position inside of a steel frame as shown in Figure 1. The test procedure consisted of dropping variable masses on the damper. The following measurements were performed during the procedure:

1. Measuring of the damper's piston displacements by means of LVDT mounted parallel to the damper,
2. Measuring of forces generated by the damper during the dissipation process by means of a piezoelectric force sensor.



Figure 1: Experimental stand

The force sensor was placed in a series configuration between the damper and dropped mass. Process of data acquisition was triggered by a photocell

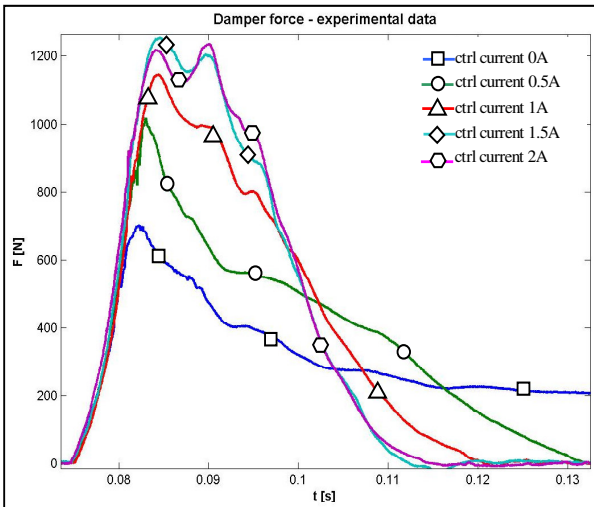


Figure 2: Damper forces under impact loading - experimental results

mounted to the frame of the stand. Data acquisition from the sensors was performed with the frequency of 20kHz per channel.

In order to make the experiment more similar to real aircraft shock absorber operation conditions, a rubber element of height equal 40 mm was mounted between the dropped mass and the damper. This element simulated a tire in the system. The rubber stiffness was identified for 250 kN/m by means of testing machine.

Figure 2 presents a set of obtained results depicting the force development generated by the MR Damper during the experiments with drop mass equal 15 kg. The height of drop was 76 mm, which was adequate to the initial impact velocity 1.22 m/s.

3 Modeling and numerical simulation

A phenomenological model of the experiment was chosen and a series of numerical simulations were performed. Figure 3 presents a scheme of the proposed

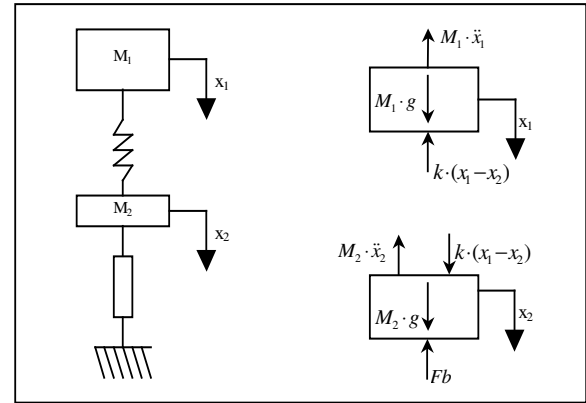


Figure 3: Scheme of experiment model

model. Upper mass M1 is associated with the drop mass in the experiment. Spring k reflects the behaviour of the rubber element mounted between the dropped mass and the damper. Mass M2 depicts the mass of the piston in the damper and F_b is the force generated by the damper. For description of the damping force, the Bingham model of MR Damper was chosen [2]. The following set of equations describes the behavior of the system:

$$M_1 \cdot \ddot{x}_1 = M_1 \cdot g - k \cdot (x_1 - x_2) \quad (1)$$

$$M_2 \cdot \ddot{x}_2 = M_2 \cdot g + k \cdot (x_1 - x_2) - F_b \quad (2)$$

$$F_b = f_b(u) + c(u) \cdot \dot{x}_2 \quad (3)$$

$$f_b(u) = f_{b1} \cdot u \quad (4)$$

$$c(u) = c_0 + c_1 \cdot u \quad (5)$$

Where:

M_1 - upper mass,

M_2 - lower mass,

x_1 - upper mass displacement,

x_2 - lower mass displacement,

k - spring stiffness,

g - gravity constant,

F_b - damper force,
 f_b - force dependent on magnetic field,
 c - damping coefficient dependent on magnetic field,
 u - parameter describing control current of the damper,

The Bingham model of the MR Damper was generalized for fluctuating magnetic fields by means of the introduction of parameters f_b and c , that were linearly dependent on parameter u - control current of the damper. The assumed model was numerically integrated with fourth order Runge Kutta method. Table 1 contains values of model parameters used during the simulation. Results that are shown in Figure 4 were compared with results obtained from the experiment. The agreement between the curves is not ideal, but the general trend was reflected.

Table 1: Model parameters

Model parameters	
$M_1 = 17.6kg$	$c_1 = 50N \cdot s / m \cdot A$
$M_2 = 0.1kg$	$k = 250kN / m$
$f_{b1} = 200N / A$	$c_0 = 1000N \cdot s / m$

4 Control strategy

The most important factor for durability of fuselages are high-energy cyclic loads causing fatigue damages in the structures. The energy transferred to the fuselage during a landing impact for a particular case is always dependent on an aircrafts mass and actual vertical velocity of approach. The mass of the aircraft is an unchangeable factor and only the vertical velocity of approach can be minimized by pilots. However, the sink speed may be decreased only to a certain critical level, which strongly depends on environmental conditions. Each time some amount of energy must be dissipated by the shock strut. The dissipation in telescopic shock absorbers generates the lowest levels of loads affecting the fuselage when it is performed over a long distance.

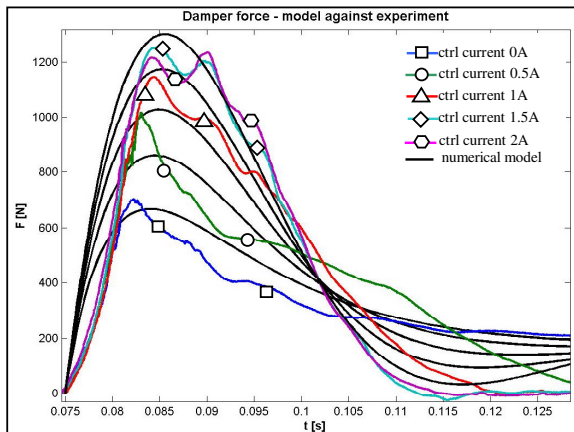


Figure 4: Damper forces - experimental and simulation results

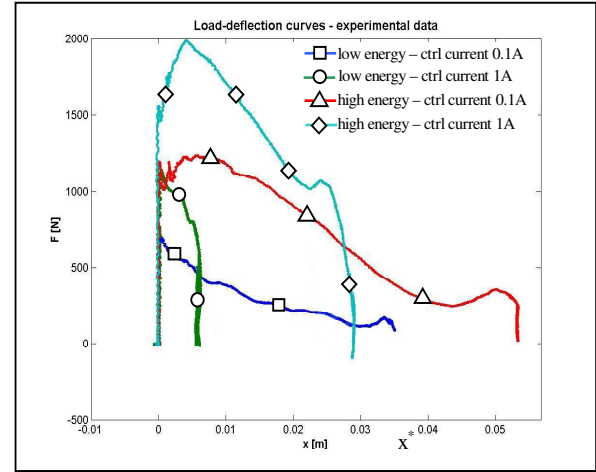


Figure 5: Experimental load-deflection data

It would be desirable to use a full stroke of the shock absorber during each touchdown.

Let us assume that Fig.5 presents two landing scenarios. The first one, with the maximal impact energy to be dissipated, leads to two options: line \diamond in Fig.5 for the MR fluid maximally hardened with current 1A and the line Δ for the inactivated MRF, with no current. Only the first landing option is acceptable due to the constrain $x^*=0.035$ imposed on maximal admissible stroke of the dissipater. On the other hand, in the case of most smooth landing scenario, two options can be considered, where the passive one, with no current (line \square), is the desired one (allowing full stroke of dissipater).

In conclusion, the methodology for design of adaptive landing gears can be proposed, satisfying the following conditions:

- Design the passive dissipater (uncontrolled case) for the lowest expected impact.
- Fit the maximally stiffed dissipater (with maximal control current) to the maximal impact expected.

4.1 Inverse dynamics concept

Control strategy for obtaining the desired loads history curve may be realized via the inverse dynamics approach. The method assumes the determining of optimal deflections, velocities, and accelerations (developed in time) of a suspended body in a vertical direction. From the optimal kinematics, forces that are required to be generated by the shock absorber can be derived.

The optimal kinematics has to meet a series of conditions:

1. Deflection of the strut during whole dissipation process should be equal to the total stroke length of the strut
2. Vertical velocity should be equal to zero at final moment of the dissipation
3. Maximal accelerations should not exceed the level determined as optimal for a defined

mass of body, initial velocity, and total stroke.

The calculation of kinematics may be realized by means of using a Fourier series. Desired accelerations during touchdown process may be described with $\frac{1}{4}$ part of a particular period of Fourier series as it is presented in Figure 6. Higher orders of Fourier series let us reflect the desired acceleration path more and more accurately. For the following approach Fourier series of seventh order was chosen as adequately reflecting the process. Analytical integration of the series lets us determine the velocities and displacements of a suspended body. The solution delivers us optimal time of dissipation and kinematics for assumed initial vertical velocity, total stroke, and mass. Figure 6 presents an example of optimal kinematics for initial impact velocity 4 m/s.

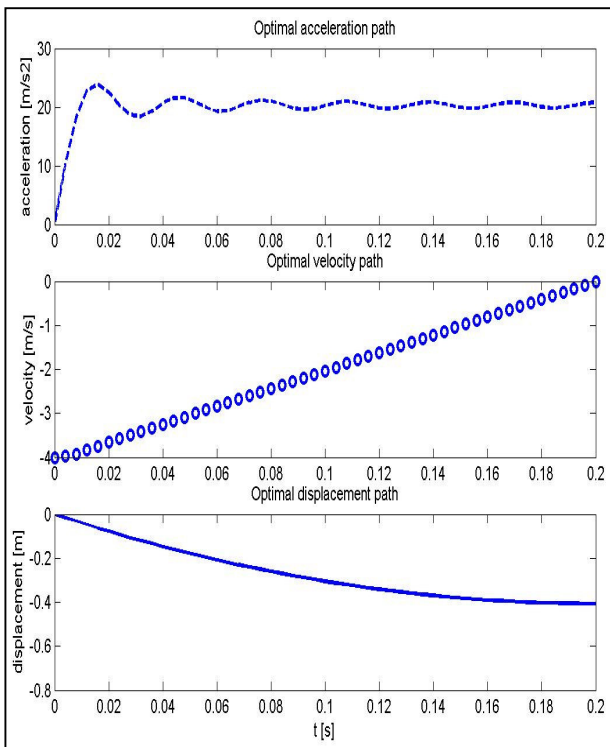


Figure 6: Optimal characteristics

5 Inverse dynamics results

The optimal kinematics obtained from the inverse dynamics approach was used as a basis for calculating the optimal force path that should be generated by the damper during impact absorption. The optimal force path was calculated in discretized routine from previously assumed equations of motion. Equations (1,2) were transformed as follows:

$$x_2 = (M_1 \cdot \ddot{x}_1 - M_1 \cdot g + k \cdot x_1) / k \quad (6)$$

$$F_b = k \cdot (x_1 - x_2) + M_2 \cdot g - M_2 \cdot \ddot{x}_2 \quad (7)$$

It was assumed that the optimal kinematics should be realized by upper mass M_1 and the rest of the system including: spring k , mass M_2 and the damper F_b should be adapted to the requirement. Figure 7 presents the

damping force path obtained for conditions compatible with the experiment conducted for initial impact velocity 1 m/s and upper mass 15 kg. On the basis of this curve, an optimal control current path may be derived by using a proper phenomenological model of the damper, or it may also be treated as an input for a fuzzy logic controller. The approach may also be used for preliminary analysis and requirements definition for telescoping shock absorbers.

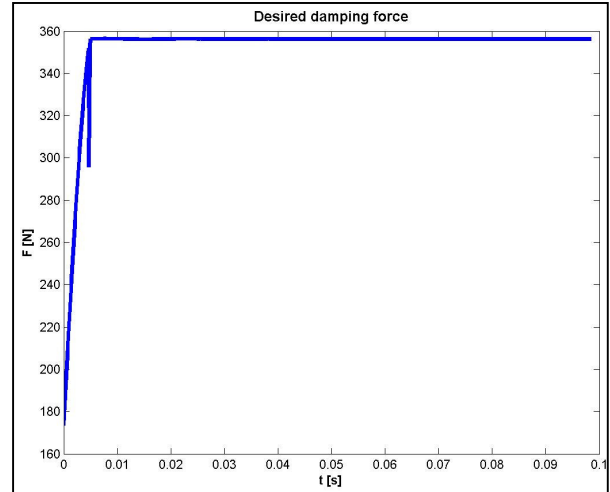


Figure 7: Desired damping force path

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