

Semi-Active Vibration Control of Landing Gear Using Magneto-Rheological Dampers

2011-01-2583

Published
10/18/2011Wei Liu and Wenku Shi
Jilin UniversityHao Ya
China FAW Group Corporation R&D Center

Copyright © 2011 SAE International

doi:[10.4271/2011-01-2583](https://doi.org/10.4271/2011-01-2583)

ABSTRACT

Magneto-rheological(MR) dampers are devices that use rheological fluids to modify the mechanical properties of fluid absorber. The mechanical simplicity, high dynamic range, large force capacity, lower power requirements, robustness and safe manner of operation have made MR dampers attractive devices for semi-active real-time control in civil, aerospace and automotive applications. Landing gear is one of the most essential components of the aircraft, which plays an extreme important role in preventing the airframe from vibration and excessive impact forces, improving passenger comfortable characteristics and increasing aircraft flight safety. In this paper, the semi-active system used in landing gear damping controller design, simulation, and the vibration test-bed are discussed and researched. The MR dampers employed in landing gear system were designed, manufactured and characterized as available semi-active actuators. On the basis of a large number of experimental data, a mathematical model based on the Bouc-Wen hysteresis model was adopted to predict both the force-displacement behavior and the complex nonlinear force-velocity response of the MR dampers. Using the landing gear vibration test-bed, the vibration characteristic of passive absorber was compared with the vibration characteristic of semi-active control. It is indicated that compared with passive control, the MR damper based on semi-active control can obviously restrain the displacement and acceleration response of the structure, and takes an effective performance in MR fluid absorber vibration reduction system.

INTRODUCTION

When airplane touches down and taxis on uneven runways with high speed, there is heavy ground impact and huge vertical load to the airframe. To improve safety and make passengers comfortable during landing, an effective landing gear capable of absorbing impact energy as much as possible is indispensable for modern airplane. Besides the basic function of reducing impact loads, the landing gear must also allow sufficient maneuverability during ground operation, which leads to conflicting requirements in terms of the suspension system. Traditional landing gear consists of tires and passive shock absorbers, which can only be optimized before leaving factory to ensure the landing gear having a fairly good performance in particular design operational conditions, typically hard landings. However, due to its fixed structure, the passive shock absorber cannot always work well on various ground conditions and operational conditions. A heavy landing or a coarse runway may lead to significant deterioration of its performance, which is harmful to the fatigue life of the landing gear and of the airframe.

Active control and semi-active control are widely used approach in the field of construction vibration control and vehicle suspension control. Compared with passive control, active and semi-active control has excellent tunable ability due to their flexible structure. Active control needs an external hydraulic source to supply energy for the system. The main component of semi-active landing gear system is a magneto-rheological shock absorber, which contains multidisciplinary and highly nonlinear dynamics. It is not an easy task to design an effective controller for such complex system. Ghiringhelli builds a complete aircraft landing simulation model in ADAMS software [1]. A semi-active PID

control method is used to control the orifice area. He also studies sensitivity of the complete aircraft model to the variation of control parameters and compares the results obtained in the simulated drop tests between passive and semi-active approach. Maemori proposes an optimization method for a semi-active landing gear to handle variations in the maximum vertical acceleration of an aircraft during landing caused by the variation of the aircraft mass, which is always due to the variations in the number of passengers, and the amounts of cargo and fuel[2]. Mikulowski et al. discuss the application of piezo-actuators and magneto-rheological damper in the adaptive landing gear design[3]. And there are some other researchers applying ER or MR technology in semi-active land gear system[4,5]. All of the semi-active controllers designed above do not consider the actuator saturations (limited control amplitude and rate), which may lead to significant, undesirable deterioration in the closed-loop performance and even closed-loop instability.

Model predictive control (MPC) refers to a class of control algorithms in which a dynamic model is used to predict and optimize control performance. The predictions are obtained from a dynamic model and the optimization problem is solved subject to constraints on input and output variables. So MPC is especially suited for constrained, digital control problems. Initially MPC has been widely used in the industrial processes with linear models, but recently some researchers have tried to apply MPC to other fields like automotive and aerospace [6,7], and the nonlinear model is used instead of linear one due to the increasingly high demands on better control performance and rapidly developed powerful computing systems [8]. To the semi-active landing gear control problem, the nonlinear model predictive control is a good choice considering its effectiveness to constrained control problems and continuously optimized performance. The goal of this paper is to introduce the design and the analysis of a nonlinear hierarchical control strategy, for semi-active landing gear systems in civil and military aircrafts, based on predictive control strategies.

MODEL OF LANDING GEAR

The technology of multi-body simulation (MBS) with its associated software tools has been developed to analyze complex and arbitrary mechanical systems. The aircraft landing gear is a complex multi-degree-of-freedom dynamic system which may encounter vibration modes which can be influenced by brake frictional characteristics and design features. Although equations for representing various parts of a landing gear are well established, solving the problems manually with mathematical programs can be slow and laborious. In many cases, vibration problems may not be uncovered until physical prototypes are built and tested, adding considerable time and expense to the product development cycle.

The multi-body model of a landing gear used for this work is prepared using various body elements which are connected to each other by means of joints in MBS software SIMPACK. Figure 1 shows the virtual prototype of landing gear system. In SIMPACK this multi-body system is represented by rigid body elements such as main-fitting, the shock tube, and two or four wheels, respectively. The shock absorbers are located between shock tube and main fitting. All landing gears have one translational degree of freedom for the shock absorber and one rotational degree of freedom for each wheel.

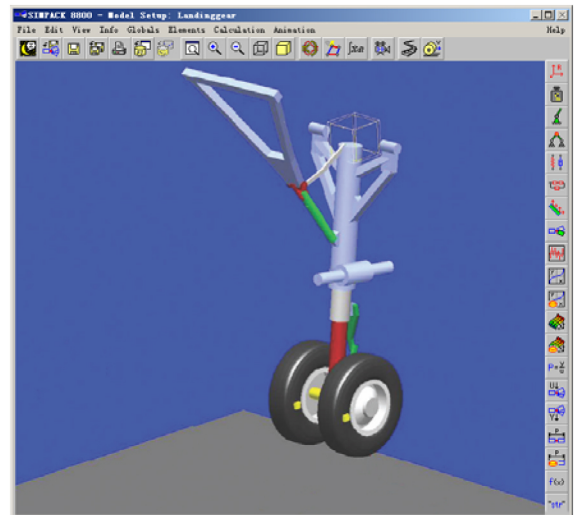


Figure 1. Virtual prototype of landing gear.

To generate a good approximation of the mass distribution of an aircraft like the Airbus A320 and the structural properties, existing and accessible data were used together with the statistical mass approximation method published by Raymer. These data were the main sources used to establish a CAD-model of all of the structures. To comply with the goal of simulating different loading cases of passengers, cargo and fuel, a balance calculation similar to those applied before each flight of the real aircraft was used. The data obtained for the air-frame structure was pre-processed to facilitate the generation of an elastic model in SIMBEAM. The elastic structure was assembled with the use of beam elements accounting for the main parts of the fuselage and the whole wings. Other elements, for example the foremost part of the fuselage in front of the nose landing gear, as well as the empennage, are considered rigid, but have the correct mass-properties and were attached to the corresponding elastic beam element. Implementing beam elements to generate elastic structures reduced the required time for simulation. Different beam elements were defined between certain markers and reflected a change in structural properties. To compensate for possible elements which have no structural influence, for example aircraft systems and fairings, the masses were equally distributed along the elastic beams between certain positions, and the mass was adjusted

accordingly. All other elements were added as rigid mass elements. This facilitated changing the loading of the aircraft and the amount of fuel for simulation of different landing mass and centers of gravity. Some of the resulting eigenmodes of the elastic aircraft model is shown in [Figure 2](#).

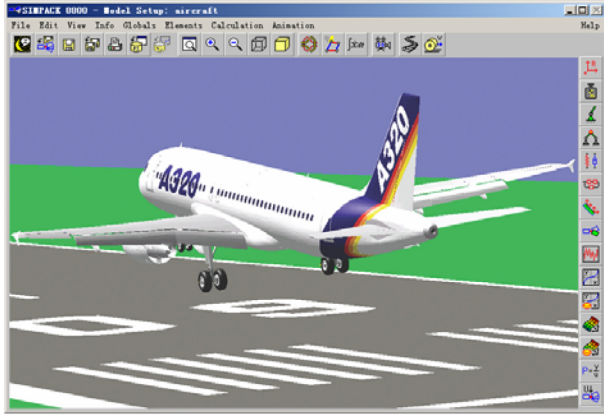


Figure 2. Elastic aircraft model.

DESIGN OF A SEMI-ACTIVE CONTROLLER

Model predictive control (MPC) is a control algorithm that solves a discrete time optimal control problem which maximizes an objective function as it designs the optimal control laws for a system. The MPC is considered to be the only advanced control technique that has had a significant and widespread impact on industrial process control, because it is the only generic control technology which can deal routinely with equipment and safety constraints. The MPC can be regarded as having three parts: model prediction, feedback correction, and rolling horizon optimization. In process control, the objective is usually to maintain a steady process. Thus, the objective function is usually of a quadratic form to minimize the error from the set point.

For the problem of semi-active landing gear control, a nonlinear model predictive control (NMPC) approach is adopted here considering its effectiveness to real-time performance and constrained control problems[5]. The basic principle of this NMPC is to obtain a nonlinear feedback control law by solving an approximate receding-horizon control problem via a multi-step predictive control formulation.

The following receding-horizon problem can be set up for providing the output-tracking control:

$$\min_u J[x(t), t, u] = \min_u \frac{1}{2} \int_t^{t+T} [e^T(\tau) Q e(\tau) + u^T(\tau) R u(\tau)] d\tau \quad (1)$$

where $e(t) = y(t) - y_d(t)$

Approximating the above receding-horizon control problem by the following multi-step-ahead predictive control formulation, define $h = T / N$, with N is control number during the prediction horizon. The output $y(t + kh)$ is approximated by the first-order Taylor series expansion

$$y(t + kh) \approx y(t) + C[x(t)] \{x(t + kh) - x(t)\}, \quad 1 \leq k \leq N \quad (2)$$

where $C = \partial c(x) / \partial x$. The desired output $y_d(t + kh)$ is predicted similarly by recursive first-order Taylor series expansions

$$y_d(t + h) \approx y_d(t) + h \dot{y}_d(t) \quad (3)$$

$$y_d(t + 2h) \approx y_d(t + h) + h \dot{y}_d(t + h) \approx y_d(t) + h \dot{y}_d(t) + h[\dot{y}_d(t) + h \ddot{y}_d(t)] \quad (4)$$

where another first-order expansion $\dot{y}_d(t + h) \approx \dot{y}_d(t) + h \ddot{y}_d(t)$, then we have

$$y_d(t + kh) \approx y_d(t) + h \left[\sum_{i=0}^{k-1} (1 + hp)^i p y_d(t) \right] \quad (5)$$

where $p = d / dt$ is the differentiation operator. Combining the predictions of $y(t + kh)$ and $y_d(t + kh)$, we obtain the prediction of the tracking error

$$e(t + kh) = y(t + kh) - y_d(t + kh) \approx h \left\{ \sum_{i=0}^{k-1} [C(I + hF)^i] f + \sum_{i=0}^{k-1} [C(I + hF)^i] g u(t + (k-1-i)h) - (1 + hp)^i p y_d(t) \right\} \quad (6)$$

where $F = \partial f(x) / \partial x$. Approximating the cost function by the trapezoidal rule, it can be written as a quadratic function

$$\bar{J} = \frac{1}{2} v^T H(x) v + r^T(x) v + q(e, x, y_d) \quad (7)$$

where $v = \text{col}\{u(t), u(t + h), \dots, u[t + (N+1)h]\}$.

The constraint is then expressed as $e(t + Nh) = 0$ which leads to

$$M^T(x) v = d(e, x, y_d) \quad (8)$$