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Active landing gear behaviour on heavy landing

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ABSTRACT

In this paper,the active landing gear two degree of freedom mass model of the aircraft has been developed.The dynamic equations of the active landing gear has been written to study the landing behaviour of the aircraft on heavy landing condition.The dynamic response of the active landing gear developed model landing on higher sink velocity with uncetainities simulated numerically.The active landing gear system provides an effective actuation mechanism by generating the required damping force, air spring force to suppress the fuselage vibrations significantly at touch down and other disturbance occurring during landing like runway roughness. The Proportional, Integral, Derivative (PID) controller is designed to actuate the servo controller to generate active control force in the landing gear system. The active landing gear system reduces the aircraft vibration levels than the passive system and takes considerably less time to stabilize the aircraft after landing impact. Thus, the aircraft fitted with active landing gears have improved passenger safety and comfort during the landing phase. The reduction of vibration levels and shock strut forces improves the fatigue life of the aircraft fuselage structure and the components of landing gear system.

KEY WORDS: Landing, Passenger Safety.

1. INTRODUCTION

Landing is the most critical operational phase of an aircraft.Landing performance of an aircraft can be directly deteriorated by the factors such as excessive sink speed,approach speed,ground effects,undesireable wind,runway uneveness and pilot errors.When an aircraft lands,large amplitude of vibrations transmitted to the fuselage from the runway thereby causing passenger safety and comfort problems.Hence the vibrations need to be suppressed quickly. Landing gear is the critical assembly of the aircraft and the centre part of the landing gear assembly is called shock strut which plays an important role in absorbing the shocks and vibrations during landing and taxying on runway.The aircraft,during its life time, is subjected to varying operating conditions in the air as well as ground.As landing is the most efficient critical phase amongst all the operational phases, there is a need to design the most efficient landing gears.Though the existing shock absorbers are the most efficient till date,they are not able to meet the variable damping requirements to cope with the varying operating conditions.The problems such as bad wether conditions,runway uneveness and pilot inaccuracies might arise during the aircraft operation which could lead to accidents,sometimes In such critical scenarios,it is necessary to have the most efficient and the robust damping system which wouuld prevent the aircraft from the potential accidents.The active suspension with robust control strategies could prove to be a solid solution for preventing the potential accidents of the aircraft during the time of landing.The passive system demerits are overcome by the development of active landing gear system. The limitation of ground loads transfer to the fuselage structure and benefits of building active system in the aircraft investigated by (Bender and Beiber, 1971; McGehee and Garden, 1979).

The advantages of decreasing landing loads and vibration levels demonstrated on different runway configurations theoretically and experimentally by (Ross and Edson, 1983; Freymann and Johnson, 1991; Freymann, 1937). The performance evaluation of active damping control for a different taxying speeds and moving on various random roughness surfaces by (Sheperd, 1992; Catt, 1992; Haitao Wang, 2008), have shown improvement in the performances of single landing gear active system with robust PID controller than the passive system. Jian-Da Wu (2008). Experimentally tested proportional-integral-derivative (PID) controller and fuzzy controller for reducing vibration levels of a semi active vehicle suspension system using an adjustable shock absorber. Atta Oveisi (2013), presented that the PID controller is tuned with Ziegler-Nichols rules for both robustness and vibration suppression performance aspects. The present study analyzed the vibration analysis of active landing gears under heavy landing condition with uncertainties. The roughness is also associated with unpaved air field and bomb-damaged runways. Ageing of concrete runways causes the plates that settle unevenly leading to runway bumps of long wave length, gap become steps in the runway and different level of rough damage surfaces.

Feng Tyan (2009), studied shape filter method and method of sinusoidal approximation for developing one-dimensional random profiles. Jai-Hyunk (2000), studied the response of aircraft landing gear over a random runway can be modelled by a non-classically damped system subject to non-stationary random excitations. Dynamic response of cars with uncertain parameters measuring acceleration, displacement on discrete inputs and excitations by random surfaces are investigated by Jun Dai (2011).

In this study, the active landing gear system mathematical model is formulated to analyse the dynamic response of active landing gear system during landing impact.

Landing gear model formulation: The mathematical model consists of the aircraft body mass and parts of the landing gear indicated by the sprung mass m_1 and wheel components indicated by the un-sprung mass m_2. The linear spring with stiffness k_1 and a damper with a viscous damping coefficient c_1 is denoting shock strut of the landing gear takes the load of aircraft structure. The spring of stiffness k_2. and damping coefficient c_2 denotes the tire mass comes in contact with the runway as shown in the figure 1. In the model y_1 , y_2 be the vertical motion of the sprung mass and un sprung mass. y_g is the ground excitation. Assuming the model has small motions which are in the vertical directions. Springs, dampers and tire behavior are assumed linear. In this model tire damping is also considered and the ground contact is maintained. The active landing gear system components are low pressure reservoir, hydraulic pump, high pressure accumulator, servo actuator and electronic controller. The shock strut travel depends on the runway undulations and the payload of aircraft during landing. In the active landing gear system, the sensors fitted in the upper and lower side of the landing gear and obtained signal input to the PID controller. The regulation of hydraulic fluid flow in the shock strut is controlled by the electronic controller. It generates the force required to actively control the vibration level and limit the loads transferred to the airplane.

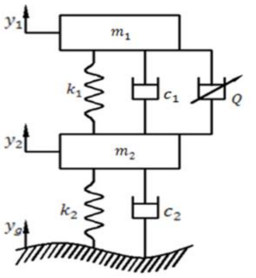

Figure.1. Vibration model of active landing gear system

By New tonics method, the dynamic equations are written as (1-4)

$$m_1\ddot{y}_1 = -k_1(y_1 - y_2) - c_1(\dot{y}_1 - \dot{y}_2) - Q \tag{1}$$

$$m_1\ddot{y}_1 = -F_a - F_d - Q \tag{2}$$

$$m_2\ddot{y}_2 = k_1(y_1 - y_2) + c_1(\dot{y}_1 - \dot{y}_2) - k_2(y_2 + y_g) - c_2(\dot{y}_2 + \dot{y}_g) + Q \tag{3}$$

$$m_2\ddot{y}_2 = F_a + F_d + F_g + Q \tag{4}$$

Where Q is the active control force from the servo actuator, the matrix representation of equation (2) & (4) becomes

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{Bmatrix} \ddot{y}_1 \\ \ddot{y}_2 \end{Bmatrix} = \begin{bmatrix} -F_a \\ F_a \end{bmatrix} + \begin{bmatrix} -F_d \\ F_d \end{bmatrix} - \begin{bmatrix} 0 \\ F_g \end{bmatrix} + \begin{bmatrix} -Q \\ Q \end{bmatrix} \tag{5}$$

Proportional-integral-derivative (PID) controller: PID controller is commonly applied in many industrial applications. It represents proportional, integral and derivative gains of the controller. This is simple and easy to tune for various devices. The adjustments can be done as per the usage requirements. In this article, the electronic controller is traditional PID considered and dynamics of the controller is formulated to evaluate performance of the active landing gear system.

The controller design is defined by eqn (6)

$$G_c = k_p e(t) + k_i \int_0^t e\,(t) + k_d \frac{de(t)}{dt} \tag{6}$$

G_c is the current input from the controller.k_p is the proportional gain, k_i andk_d is the integral and derivative gain of the PID controller. The error function in eqn (7) is the difference between the reference signal and the feedback signal measured from the sensors fitted in the landing gear.

i. e., $e(\mathrm{t}) = \dot{\mathrm{r}}(\mathrm{t}) - (\dot{\mathrm{y}}_1 - \dot{y}_2)$ (7)

The output signal of the PID controller will change in response to a change in measurement signal or reference signal. The displacement of the landing gear servo valve is written as eqn (19)

$$l_1(t) = k_p\{r(t) - [\dot{y}_1(t) - \dot{y}_2(t)]\} + k_i\{r(t) - [y_1(t) - y_2(t)]\} + k_d\{r(t) - [\ddot{y}_1(t) - \ddot{y}_2(t)]\} \tag{8}$$

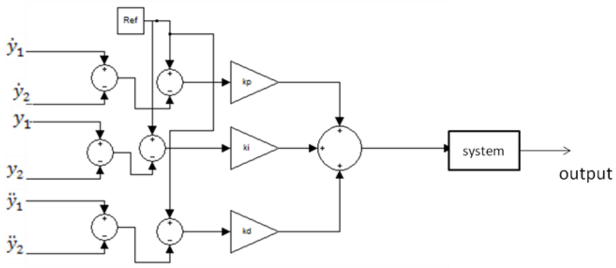

Figure.2. Simulink model of PID controller

The dynamics of PID controller is as shown in figure (2).Here the feedback coefficients k_p proportional gain, k_i an integral gain and k_d a differential gain. These are adjusted by Ziegler-Nichols tuning rules. From the body displacement curve of the landing gear, the gain margin and phase margin values are obtained. The obtained values are used to find the tuning values of the PID controller. The gains of the controller as described depend on the transient behavior of the landing gear system. The tuning process is done by Ziegler-Nichols tuning method. In this method, initially zero is set for integral and derivative gain. The k_p value raised from 0 to a critical value k_{cr} at that time the output first exhibits stable oscillations. By this critical gain k_{cr} and the corresponding period p_{cr} calculated. The tuning values of the parameters k_p,t_i and t_d is set by Ziegler-Nichols method as given in table (1).

Table.1. Zeigler –Nichols tuning values

Type of controller	k_p	k_i	k_d
P	$0.5k_{cr}$		0
PI	$0.45k_{cr}$	0.83	0
PID	$0.6k_{cr}$	$0.5p_{cr}$	$0.125p_{cr}$

The control gains $k_p = 0.584$,$k_i = 0.00412$ and $k_d = 0.0001$ has been tuned by the above tuning method to obtain the maximum control efficiency. The active control force Q generated by servo actuator is directly proportional to the flow output of the servo valve. The empirical formula described by eqns (9) and (10) are taken from Sharp 1988.

$$Q = k_a Q_{flow} \left| Q_{flow} \right| \tag{9}$$

The flow quantity Q_{flow} is calculated by

$$Q_{flow} = C_d w l \sqrt{\frac{|p_{accum} - p_{res}|}{\rho}} \tag{10}$$

The servo valve travel distance $l(t)$ is controlled by the PID electronic controller. Time delay is inevitable in the active control system because of the involved dynamics of servo actuators, filters and sensors, to generate active control force. In future study, the intentional time delays into the feedback loop will be investigated by compensation methods.

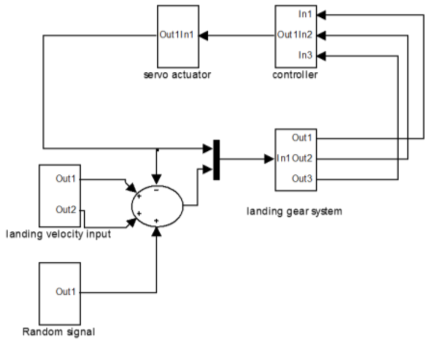

Figure.3. Simulink model of active landing gear system

Numerical simulations: The analysis presented in section 2 and 3, the acting landing gear system dynamic model has been developed in the Matlab-Simulink environment as shown in figure.3. The landing performance of active landing gear system with high sink velocity has been simulated in a Matlab-Simulink. The parameters used for numerical simulation are tabulated in Table.2.

Table.2. Aircraft Parameters for numerical simulations

Description	Symbol	Value	Units
Aircraft fuselage mass	m_1	8800	kg
Landing gear tire mass	m_2	260	kg
Landing gear shock strut stiffness	k_1	4.08e5	N/m
Landing gear tire stiffness	k_2	4.08e5	N/m

Landing gear shock strut damping coefficient	c_1	41944	N.s/m
Landing gear tire damping coefficient	c_2	37411	N.s/m

The sink velocity 3.6 m/s and runway unevenness is considered for simulating the worst landing. The landing scenario is depicted in figure.4.

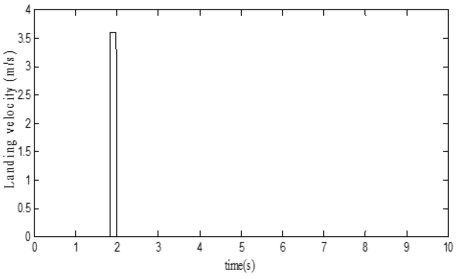

Figure.4. Input for sink velocity of 3.6 m/s

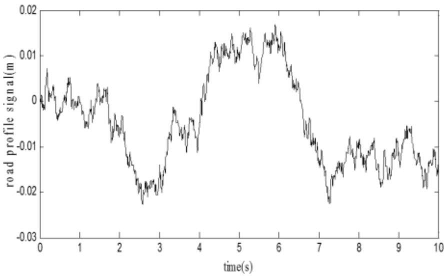

Figure.5. Random signal for grade E random runway

For the worst landing scenario, it is assumed that the aircraft lands with a sink velocity of 3.6m/s on a rough air strip. A disturbance signal is applied as an input to the landing gear in the form of Grade E random road profile. The road profile is generated in the mat lab simulink environment. The Grade E road profile is very poor roughness road and has a road roughness variance of 0.032.The velocity of the aircraft is considered as 3.6*m/s* and roughness coefficient α=0.127.The generated grade E road profile is as shown in figure.5. In realty, the aircraft might exceed the regulation limits of the sink velocity during landing because of pilot inaccuracies. Moreover the strip is not always smooth because of weather conditions which may cause excessive vibrations and sometimes a crash at the time of landing.

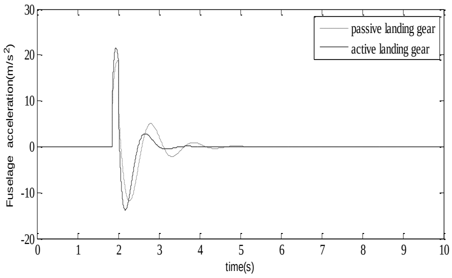

Figure.6. Fuselage acceleration response for sink velocity of 3.6m/s

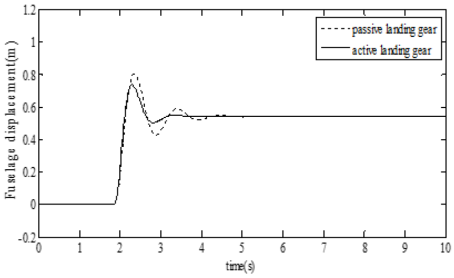

Figure.7. Fuselage displacement response for sink velocity of 3.6m/s

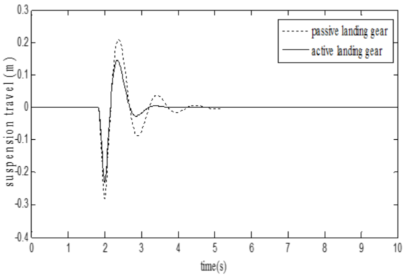

Figure.8.Suspension travel for sink velocity of 3.6m/s

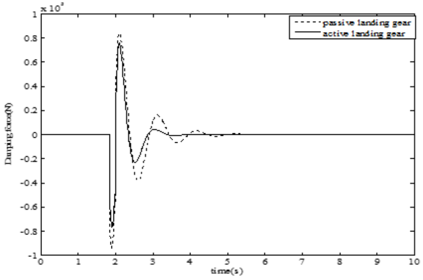

Figure.9. Damping force for sink velocity of 3.6m/s

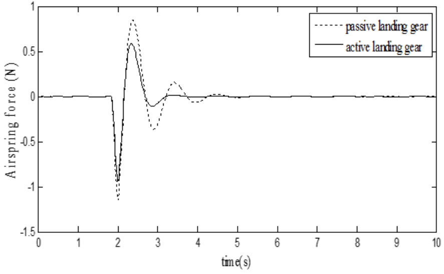

Figure.10. Airspring force for sink velocity of 3.6m/s

From figure (6), even though the peak value of active landing gear acceleration is slightly greater than passive but the settling time of active system is 2.892 s less than the passive landing gear system. The fuselage displacement of passive is 0.8071m and the active system is 0.7358m.which shows the 8.83% reduction by the active system as shown in figure (7).shock strut travel of active system is less than the passive system as shown in figure (8). Even though it is a minimum value it greatly improves the life of the aircraft structure and the landing gear system.The air spring force developed by the passive landing gear is 84750 N and the active landing gear system is 59040 N. The damping force developed by the passive landing gear is 84350 N and the active system is 75630 N. which indicates that the shock strut force developed by the active system is less than the passive landing gear system as in figure (9) & (10). The results indicate that the effectiveness of the designed active system for the adverse landing conditions.The amplitude of peaks increased as the aircraft landed on a rough airstrip with higher landing impact. However, for the worst case landing also,the active system could damp out the vibrations getting transmitted to the fuselage effectively.moreover the aircraft takes considerably less time to stabilize after the initial impact.

2. CONCLUSION

The formulation of mathematical vibration model of active landing gear system has been done and numerically simulated in the MATLAB-SIMULINK for heavy landing condition. The vibration levels show that reduction in the magnitude of fuselage acceleration and displacement by the active landing gear system than the passive system during landing with the uncertainties. The aircraft takes considerably less time to stabilize after the landing impact. It is also observed that the designed system is able to suppress the fuselage vibrations significantly not only for higher sink velocities but also in case of other disturbance occurring during landing like runway roughness. Thus, the aircraft fitted with active landing gears have improved comfort level of passengers due to vibrations and safety during the landing phase. The reduction of vibration level and shock strut forces improves the fatigue life of the aircraft fuselage structure and components of the landing gear system.

REFERENCES

Atta Oveisi, Mohammad Gudarzi ,Adaptive sliding mode vibration control of a nonlinear smart beam:A comparison with self-tuning ziegler-nichols pid controller, Journal of Low Frequency Noise, Vibration and Active Control, 32, 2013, 41-62.

Bender EK, Beiber M, A feasibility study of active landing gear, U.S. Air force flight dynamics lab, Wright Patterson air force base, AFFDL TR, 1971, 70-126.

Catt T, Cowling D, Shepard A, Active landing gear control for improved ride quality during ground roll, AGARD Smart structures for aircraft and spacecraft, 1992.

FengTyan, Yu-Fen Hong, Shun-Hsu Tu and Wes S. Jeng, Generation of Random road profiles, Computational Dynamics and control lab, Tamkang University, Tamshui, Taipei County, Taiwan, 2009.

Freymann R, Actively damped landing gear system, Landing Gear Design Load Conference, AGARD CP-484, 20, 1991.

Freymann R, An experimental–analytical routine for the dynamic qualification of aircraft operating on rough runway surfaces, AGARD R-731, 1937.

Freymann R, Johnson W, Simulation of aircraft taxi testing on the AGILE Shaker Test Facility, Second International Symposium on Aero elasticity and Structural Dynamics, sponsored by Deutsche Gesellschaft fur Luf–und Raumfahrt e.V.in Aachen, W.Germany, 1985.

Gopalakrishnan K, Sundar Raj M, Saravanan T, Multilevel inverter topologies for high-power applications, Middle - East Journal of Scientific Research, 20 (12), 2014, 1950-1956.

Haitao Wang, Xing JT, Price WG, Weiji Li, An investigation of an active landing gear system to reduce aircraft vibrations caused by landing impacts and runway excitations, Journal of Sound and Vibration, 317, 2008, 50 -66.

Jai-Hyuk Hwang and Jung-Soo Kim, on the approximate solution of aircraft landing gearunder nonstationary random excitations, KSME International Journal, 14 (9), 2000, 968-977.

Jasmin M, Vigneshwaran T, Beulah Hemalatha S, Design of power aware on chip embedded memory based FSM encoding in FPGA, International Journal of Applied Engineering Research, 10 (2), 2015, 4487-4496.

Jian –Da Wu, Chih-jer Lin, Kun-Yin Kuo, A study of semi active vibration control for vehicle suspension system using an adjustable shock absorber, Journal of Low Frequency Noise, Vibration and Active Control, 27 (3), 2008, 219-235.

Jun Dai, Wei Gao and Nong Zhang, Random displacement and acceleration responses of vehicleswith uncertainty”, Journal of mechanical science and technology, 25 (5), 2011, 1221-1229.

Kanniga E, Selvaramarathnam K, Sundararajan M, Kandigital bike operating system, Middle - East Journal of Scientific Research, 20 (6), 2014, 685-688.

Kanniga E, Sundararajan M, Modelling and characterization of DCO using pass transistors, Lecture Notes in Electrical Engineering, 86 (1), 2011, 451-45.

Karthik B, Arulselvi, Noise removal using mixtures of projected gaussian scale mixtures, Middle - East Journal of Scientific Research, 20 (12), 2014, 2335-2340.

Karthik B, Arulselvi, Selvaraj A, Test data compression architecture for lowpower vlsi testing, Middle - East Journal of Scientific Research, 20 (12), 2014, 2331-2334.

Karthik B, Kiran Kumar TVU, Authentication verification and remote digital signing based on embedded arm (LPC2378) platform, Middle - East Journal of Scientific Research, 20 (12), 2014, 2341-2345.

Karthik B, Kiran Kumar TVU, EMI developed test methodologies for short duration noises, Indian Journal of Science and Technology, 6 (5), 2013, 4615-4619.

Karthik B, Kiran Kumar TVU, Vijayaragavan P, Bharath Kumaran E, Design of a digital PLL using 0.35Î¼m CMOS technology, Middle - East Journal of Scientific Research, 18 (12), 2013, 1803-1806.

McGehee J.R and Garden H.D, Analytical Investigation of the Landing Dynamics of a Large Airplane with a Load-Control System in the Main Landing Gear, NASA Technical, 1979, 1555.

Philomina S, Karthik B, Wi-Fi energy meter implementation using embedded linux in ARM 9, Middle - East Journal of Scientific Research, 20 (12), 2014, 2434-2438.

Ross I, Edson R, Application of active control landing gear technology to the A-10 aircraft, NASA CR-166104, 1983.

Saravanan T, Sundar Raj M, Gopalakrishnan K, Comparative performance evaluation of some fuzzy and classical edge operators, Middle - East Journal of Scientific Research, 20 (12), 2014, 2633-2633.

Saravanan T, Sundar Raj M, Gopalakrishnan K, SMES technology, SMES and facts system, applications, advantages and technical limitations, Middle - East Journal of Scientific Research, 20 (11), 2014, 1353-1358.

Sharp JJ, Basic fluid Mechanics, London Butterworths, 1988.

Sheperd A, Catt T, Cowling D, The simulation of aircraft landing gear dynamics ,18th Congress of the International Council of the Aeronautical Sciences, Beijing, China, 1992.

Sivakumar S, Haran AP, Mathematical model and vibration analysis of aircraft with active landing gears, Journal of Vibration and Control, 21 (2), 2015, 229-245.

Vijayaragavan SP, Karthik B, Kiran Kumar TVU, A DFIG based wind generation system with unbalanced stator and grid condition, Middle - East Journal of Scientific Research, 20 (8), 2014, 913-917.

Vijayaragavan SP, Karthik B, Kiran Kumar TVU, Effective routing technique based on decision logic for open faults in fpgas interconnects, Middle - East Journal of Scientific Research, 20 (7), 2014, 808-811.

Vijayaragavan SP, Karthik B, Kiran Kumar TVU, Privacy conscious screening framework for frequently moving objects, Middle - East Journal of Scientific Research, 20 (8), 2014, 1000-1005.