Experimental Studies of Application Passive Momentum Exchange Impact Damper (PMEID) on UAV’S Landing Gear

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Abstract. Unmanned aircraft or UAV (Unmanned Aerial Vehicle) is a future technology that continues to be developing. This research examines the structural vibration acceleration response of the aircraft’s nose landing gear. The landing gear is the part of the aircraft that receives the most significant shock load during landing. This is due to the magnitude of the maximum acceleration of the landing gear vibration when experiencing shock loads. This phenomenon causes the landing gear damaged due to excessive vibration. Therefore, uncontrolled shock loads can damage the landing gear structure and even pierce its frame structure. A momentum transfer method was applied to the landing gear design to reduce the maximum acceleration amplitude of vibration due to experiencing shock loads during landing. The research experiment was carried out using the principle of passive momentum transfer; the test was carried out by dropping the landing gear at a certain height. When the landing gear experiences a shock load, kinetic energy and momentum will be transferred to the PMEID system so that the landing gear remains in a stable condition. The experiment gives an output in the form of the vibration acceleration amplitude of the landing gear measured by the accelerometer sensor on the landing gear’s main mass. The vibration response will then be sent to the voltage amplifier and forwarded to the digital signal processing and displayed on a computer monitor. The test results prove the application of the momentum transfer method in the landing gear design can reduce the maximum amplitude of vibration acceleration when landing.

1. Introduction
UAV (Unmanned Aerial Vehicle) is a future technology that is continuously has been developing. The use of drones is currently widely used in various fields, such as agriculture, military, industry, the arts, and other areas. The deficiencies in unmanned aircraft design continue to develop, not a few studies and studies have been carrying out with different studies. In this study, an analysis of shock vibration control in unmanned aircraft during landing was conduct. When landing, the aircraft receives a shock load due to the influence of the aircraft; the shock load is magnified by the acceleration of the aircraft when it hits the ground. When landing, the landing gear supports the aircraft's entire weight; thus, the aircraft hits the ground hard and receives a huge shock load. This large shock load produces uncontrollable shocks, causing damage to the landing gear itself and the unmanned aircraft structure, in conditions large enough to affect the safety of the environment around the vehicle [1]. Control of shock vibrations in the landing gear is carrying out to reduce vibrations so that when the plane lands, the vibrations that propagate the airframe will not cause damage due to excessive vibrations [2]. In addition to causing damage to the fuselage, excessive shock vibrations can cause loss of sensitivity to aircraft electronic components. The aircraft's electronic components that lose the sensitivity make the aircraft difficult to control and lose orientation in carrying out the mission. The thing that is feared by the shock vibration is the high amplitude of the maximum acceleration of the vibrations that occur when receiving the shock load. The amplitude is the maximum displacement measured from the equilibrium point of the wave. The magnitude of the shock force determines the magnitude of the maximum acceleration amplitude of the vibration. Various methods of controlling shock vibrations on geological landing have been implementing to reduce the maximum acceleration amplitude. A new
method used to reduce the vibration amplitude due to shock loads on the landing gear is to use the passive momentum transfer method. The use of PMEID (Passive Momentum Exchange Impact Damper) in vibration control has been carrying out because the system receives a huge shock vibration. This huge shock vibration causes vibration control to be damaged. This is due to the high maximum amplitude of acceleration that occurs before the vibration is damped. PMEID is a method used to reduce shock loads by reducing the amplitude of the maximum acceleration that occurs in the system. This method uses the principle of momentum transfer on the third pendulum swing; in this case, PMEID is analogous to the third ball, which absorbs energy and momentum from the second ball after being hit by the first ball [3]. In previous studies, the application of PMEID to floor dampers has been showing to reduce the shock vibration response by 25% [1]. In this final project, the method applied to the experimental model of unmanned aircraft gearing. The energy and momentum received by the landing gear will be transferred to the PMEID system so that it can reduce the maximum acceleration amplitude due to the shock force that occurs in the landing gear system.

PMEID (Passive Momentum Exchange Impact Damper) is a shock vibration control method using passive momentum transfer. The basic concept of PMEID comes from MEID (Momentum Exchange Impact Damper), where MEID uses the three pendulums swing [3]. The following shows the basic working principle of MEID momentum transfer in figure 1.

![Figure 1 Analogy of the 3 Pendulum Swing System.](image)

Figure 1 shows that when the collision occurs between the first pendulum and the second pendulum, the first pendulum's momentum and kinetic energy have transferred to the second pendulum. The same condition applies to the collision that occurs between the second pendulum and the third pendulum. It can conclude that the momentum and kinetic energy in the first pendulum has transferred to the third pendulum; this energy and momentum transfer mechanism causes the second pendulum to be maintained in a stable condition. In designing a landing gear system using PMEID, the first pendulum is analogous to the shock load's excitation force. The second pendulum is analogous to the main system in the form of a U-profile spring, and the third pendulum is analogous to the mass of the PMEID system.

In designing shock absorbers based on landing gear momentum changes, the PMEID system's mass and spring characteristics affect the vibrations to has moved. Following is the working principle of PMEID on landing gear can be seen in figure 2.

Figure 2 shows the PMEID system landing gear mechanism, which is considered to have linear rigidity. When a landing made and a collision, momentum and kinetic energy on the wheel were transferred to a U-shaped leaf spring. The same thing happens to the U profile and the second mass because the U profile and the second mass are in contact with each other when the collision occurs momentum and the profile's kinetic energy. U is transferred to the second mass. In contrast to the 3 pendulums swing principle, when a collision occurs due to the shock load, the U profile experiences a deflection because the leaf springs have stiffness. The transfer of energy and momentum in the landing gear can be maximized by designing a U spring with linear stiffness and low deflection. In the second mass, a spring is attached, which gives the second mass a tendency to move because personal frequencies influence it due to the stiffness and the second mass's influence quickly. The contact
spring stiffness value determines the contact time between the U profile and the second mass. The amount of energy and momentum transfer was determined by the value of the second mass used [3].

![Image](a) Nose Landing Gear  (b) PMEID System

**Figure 2** PMEID Nose Landing Gear Mechanism

2. Materials and methods
In this research, the experimental was conducted to prove the effect of kinetic energy transfer and momentum on reducing shock vibrations in unmanned aircraft's landing gear. The initial step is designing the landing gear main spring (U profile). The U profile is designed with high stiffness to produce an elastic impact on the system. The vibration would maximally transfer to the PMEID system before being absorbed by the nose landing gear.

The next step is designing a PMEID shock absorber system. In this stage, all aspects that can affect the damper's performance were considered, such as contact mass and spring stiffness. In addition, at this stage, the PMEID system's position against the excitation force due to the collision is calculated.

For the next stage, a test instrument is made based on the design that has been making. After the test equipment was complete, a test was carried out to see the PMEID system's performance on the landing gear. Tests are carried out for several parameter configurations of the mass of the contact springs and the excitation force's magnitude, which is determined by the height of $H = 100$ mm. The test results are then analysed and compared with the designed contact mass configuration.

3. Results and discussion

3.1. Personal Frequency Test Results

3.1.1 Personal Frequency Testing with Simulations
The landing gear response dynamics in personal frequency and vibration mode were simulated with the finite element method using Autodesk Inventor software. The use of a finite element simulation method and modal analysis showing in figure 3.

The calculation of the personal frequency in modal coordinates determined by applying the four lowest nose landing gear modes was obtained from the simulation. See the lowest mode simulation results on the nose landing gear in the form of a U profile, where the lowest mode occurs at the first personal frequency of the system at 47 Hz. The value of the first private frequency in the simulation then used as a parameter for testing the personal frequency experimentally.
3.1.2 Personal Frequency Testing with Experiments
A personal frequency calculation performs in the experiment obtained from the FRF (frequency response function) graph. Figure 4.2 is the FRF graph from the comparison of the measured landing gear acceleration response to the magnitude of the impulse force exerted by the impact hummer.

Figure 4. FRF Nose Landing Gear Graph.

Figure 4, it is seen that the results of experimental testing that have been carried out provide the lowest four-mode values for the nose landing gear system, namely 51.50 Hz in the first mode, 85.51 Hz in second, 98.51 Hz in the third mode, and 109.50 Hz in the fourth mode.

The differences in simulated and experimental personal frequency testing results can be analysed on the first personal frequency. The experiment result is 4 Hz higher. It can be due to the higher system stiffness in the experiment because it is influenced by the bolt stiffness and the test equipment’s slider stiffness.

3.2 The Result of U Profile Spring Stiffness Testing
3.2.1 Stress Testing with Static Analysis
Static simulation of nose landing gear aims to find the PMEID strut nose landing gear component's stiffness value. A stress analysis simulation performed using Autodesk Inventor software to determine the nose landing gear's stiffness value. The simulation carried out using static analysis of U-profile springs by looking at the deflection that occurs when a force applied to the U-profile spring. The deflection and force parameters are used as input values for the strength calculation in the excel. This stiffness value is needed as a basic parameter for PMEID landing gear design. The material in the strut
nose landing gear is assumed to be isotropic. In this simulation, an E-fibre glass composite was used with a Young modulus of 25 GPa [12]. The U-profile landing gear strut nose element model when applied loading is shown in figure 5.

![Figure 5. U Profile Spring Finite Element Model.](image)

Based on the simulation results, it obtained that the U profile spring stiffness is 194,924 N/m, the U profile spring stiffness value used as a comparison with the stiffness of the experimental results.

![Figure 6. First Vibration Mode FRF Graph.](image)

3.2.2 Stress Testing with Dynamic Analysis

Figure 6 shows the experimental results of the FRF (frequency response function) graph. As a parameter in determining the first personal frequency of the landing gear system. The first personal frequency value from the experiment is 51.50 Hz. The personal frequency value used to find the U profile spring stiffness and the U profile spring stiffness obtained of 209,201 N/m. The U profile spring stiffness value is the main parameter in the nose landing gear shock design absorbers on changes of momentum. Based on the results of stiffness calculations by simulation and experiment, the stiffness value of the static analysis simulation results is 194,924 N/m, while the value from the experimental test results is 209,201 N/m, with the measurement accuracy (error) of the simulation and experiment of 7.3%.

3.3 Test Results Without PMEID System

The experiment shows the results of the measurement of the maximum acceleration amplitude on the landing gear without using the PMEID system. Measurements were carried out in five tests with a
system drop height of 100 mm. The acceleration value of the nose landing gear (U profile) can be seen in figure 7.

![Graph showing acceleration values](image)

**Figure 7. Test Results Without PMEID**

In figure 7, it can be analysed that the maximum acceleration amplitude value of the nose landing gear in the form of a U profile spring is around 170 m/s². Significant acceleration occurs when the landing gear hits the ground at a very short contact time. A negative acceleration value indicates that the landing gear lifted upwards, the landing gear is lifted three times for 0.4 seconds before the condition is stable. The average landing gear maximum acceleration amplitude without PMEID is 168.22 m/s².

3.4 Test Results with PMEID

PMEID testing was carried out by varying the contact mass of PMEID, namely 125 g, 165 g, and 185 g. This test was conducted to see the decrease in the maximum acceleration amplitude response of the nose landing gear on the influence of the PMEID system's personal frequency due to variations in contact mass. The following result is a landing gear test with PMEID mass variations to the maximum acceleration amplitude landing gear.

3.4.1 PMEID Mass Contact 125 g

In tests with PMEID, a contact mass of 125 g was used. The experiment was carried out five times, with the landing gear falling height of 100 mm. So that it can be seen the landing gear maximum acceleration amplitude response with the PMEID system in figure 8.

![Graph showing acceleration values](image)

**Figure 8. PMEID Test Results for Contact Mass 125 g**
In Figure 8, it can be analysed that the maximum acceleration amplitude of the nose landing gear for the PMEID system with a mass of 125 g is around 130 m/s². A negative acceleration value indicates that the landing gear lifted upwards, the landing gear is lifted three times for 0.4 seconds before the condition is stable. The mean of the maximum acceleration amplitude of 125 g of PMEID is 144.90 m/s².

3.4.2 PMEID Mass Contact 165 g
In the experiment, it can be seen that the landing gear acceleration response after testing five times the variation of the contact mass of 165 g. The effect of landing gear acceleration after being dropped 100 mm on the nose landing gear's acceleration amplitude can be seen in Figure 9.

In Figure 9, it can be analysed that the value of the maximum acceleration amplitude of the nose landing gear with the PMEID system contact mass of 165 g tends to decrease. The acceleration's negative value indicates that the landing gear lifted upwards, the landing gear is lifted three times for 0.4 seconds before the condition is stable. The mean of the maximum acceleration amplitude of the contact mass of the PMEID system 165 g is 130.51 m/s². It can be analysed that the variation of the PMEID contact mass of 165 g can reduce the maximum acceleration amplitude by 22.41% of the landing gear acceleration without the PMEID system.

3.4.3 PMEID Mass Contact 185 g
In the test, the total addition of contact mass increased to 85 g. This mass is the last condition to determine the effect of mass variation on the decrease in landing gear acceleration amplitude. The effect of landing gear acceleration after a contact mass variation of 185 g is given to the nose landing gear’s acceleration amplitude when receiving a shock load can be seen in Figure 10.

In Figure 10 can be analysed that the value of the maximum acceleration amplitude of the nose landing gear with PMEID contact masses around 130 m/s². A negative acceleration value indicates that the landing gear lifted upwards, the landing gear is lifted three times for 0.4 seconds before the condition is stable. The average maximum acceleration amplitude without PMEID is 128.50 m/s². It can be analysed that the addition of the PMEID contact mass of 185 g can reduce the maximum acceleration amplitude by 23.06% of the landing gear acceleration without the PMEID system.
3.5 Comparison Result of Landing Gear Shock Response without PMEID (U Profile) and PMEID Landing Gear

Figure 11 shows the performance of each test condition. The test result compares the amplitude value of the maximum landing gear acceleration without PMEID with the mass variation of PMEID landing gear.

In Figure 4.9, it can be analysed that the maximum acceleration amplitude of the landing gear using the PMEID system has decreased with each additional contact mass. The decrease in the response of the maximum acceleration amplitude of the vibration at the mass variation of 125 g is 13.86%. The mass variation of 165 g resulted in a decrease of 22.41%, the mass of 185 g, and a decrease of 23.06%. This result explains that the PMEID method effectively reduces the shock load on the nose landing gear.

4. Conclusion

Based on the results of experiments that have carried out, several conclusions obtained, namely:

a. It has obtained an experimental model of shock vibration control with a passive momentum change method in an unmanned aircraft’s landing gear, which can reduce the shock vibration response by up to 23.06%.

b. It found that the comparison of the shock vibration response in a landing gear structure without a damper that has a higher maximum acceleration amplitude response than a landing gear structure with a passive momentum change damper.
References

[1] Lovely Son, Makoto Kawachi, Hiroshi Matsuhisa. 2007. “Reducing Floor Impact Vibration And Sound Using A Momentum Exchange Impact Damper”. Journal of system design and dynamics. Vol 1, no.1.
[2] RikiArdiansyah, Donny Hidayat, Dan AfidNugroho. “Design and Analysis of Main Landing Gear Frame of LSU-05By Finite Element Method”. LembagaPenerbangandanAntariksa Nasional (LAPAN).
[3] Lovely Son, Mulyadi Bur, MeifalRusli. 2016. “A New Concept For UAV Landing Gear Shock Vibration Control Using Pre-Straining Spring Momentum exchange damper” Journal of vibration and control.
[4] WillyantoAnggon, Ian HardiantoSiahaan, dkk. “AnalisaDistribusiTeganganPadaModifikasi Axle Sleeve Landing Gear PesawatTerbangDenganMetodeElemenHingga”. Surabaya : Mechanical Engineering Universitas Petra Christian.
[5] Rajesh,A., Abhay,BT., 2015. “Design and Analysis Aircraft Nose and Nose Landing Gear”. Journal of Aeronautics & Aerospace Engineering Vol.4, Issue 2.
[6] LembagaPenerbangandanAntariksa Nasional."LapanPamerkanPesawat LSU-02 NGLD”. Lapan.go.id (diakses pada 22/10/2019)
[7] Thomson, William T., &Marrie Dillon Dahleh. 1998.“Theory Vibration With Applications5th Edition”. Prentice Hall. United States of America.
[8] Ferdinand P. Beer, E. Russel Johnston, Jr. “Mechanics for Engineers, Dynamics”. Singapore : Mc-Graw Hill.
[9] Mulyadi Bur.1999.“Diktat PenuntunKuliahGetaranMekanik”. Padang :UniversitasAndalas.
[10] Mohammad Sadoraey, Daniel Webster College. 2013. “Air craft Design A systems Engineering Approach”. New Hampshire, USA : Wiley.
[11] GusmanArifPandy “AnalisisStruktur Landing Gear DenganPatran PadaPesawatNirawak LSU-05”. Padang :TeknikMesinUniversitasAndalas.
[12] Muhammad AdiKusnanda, Dony Hidayat.2018. “Simulasi Drop Test Nose Landing Gear Lsu-02 MenggunakanPendekatan Multi-Body Simulation (Mbs) Rigid Models”. PustekbangLapan, Rumpin : Bogor.