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Design and Analysis of Mechanical Damper

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Abstract

Landing gear is used by an air vehicle during takeoff, landing, and taxiing. Its function is to offer suspension and cushioning for safe operation. The shock absorber, often known as the principal active component, is the brace. The strut may be pneumatic, hydraulic, or a combination of the two. The goal of the research was to create a revolutionary mechanical damper design that would reduce landing-related vibrations. The product will subsequently undergo testing and evaluation for consistency and effectiveness under dynamic loading. This study discusses "Mechanical Damper Design and Analysis." Additionally, it offers details on the many kinds of landing gears, dampers, and applications for each. Additionally, it provides details on the software programmes utilized to create the project. This project uses Solid Works to design, manufacture, and test a mechanical damper both theoretically and numerically and the simulations were performed in ANSYS 17.1. The simulation outcomes of a mechanical damper and a leaf spring were compared. The tests were run to ascertain the spring's displacement, kinetic, and potential energies. After comparing the data, it was discovered that the mechanical damper could absorb 71% of the energy, the leaf spring could absorb 24%, and the control spring could absorb 30%.

Keywords

Mechanical damper, Strut, Leaf spring, Landing gear

Introduction

Rotorcrafts

A rotorcraft is equipped with rotating wings or blades that provide lift by rotating around a mast or vertical shaft. A rotorcraft is described as being "supported in flight by the reactions of the air on one or more rotors" by the International Civil Aviation Organization (ICAO) [1]. Helicopter, autogyro, gyrodyne, and rotor kite are some of the several classes of rotorcrafts. An autogyro employs a non-powered rotor, whereas a helicopter has one or more motors that help with vertical takeoff and hovering. The lift is provided by aerodynamics. Single-rotorcraft (such as helicopters) and multi-rotorcraft (such as quadcopters, hexacopters, etc.) are the two primary categories of rotorcraft.

Quadcopter

A helicopter with four motors is called a quadcopter. Four-rotor helicopters and convertibles have been used for research reasons for a very long period. Typically, quadcopters have two motors rotating counterclockwise and two clockwise. The first heavier than air vehicles to successfully do a vertical takeoff and landing were quadcopters [2]. The frame and rotors are the major mechanical parts. A quadcopter's improved design offers greater capabilities. for unmanned flying.

Better endurance was achieved with the use of lithium-ion batteries and weight reduction. Ferdinand Kickinger of Germany established the record for a battery-powered quadcopter's longest flying time in 2016, which was 2 h 31 min 30 s. Unmanned air vehicles (UAVs), or drones as they are more popularly called, have increased interest in quadcopters.

UAVs

UAVs, or drones, are controlled by ground-based controllers like a remote controller, contrary to what their name implies. UAVs were first created for military usage to complete tasks that were risky and potentially endanger human life [3]. Drone use outside of military operations has increased as a result of technological breakthroughs and cost reductions. These days, drones are used for surveillance, agriculture, photography, product delivery, and monitoring of forest fires [4]. UAVs can be categorized using a variety of factors, including weight, altitude, degree of autonomy, etc. Drones can be classified as nano, micro, or mini depending on their weight [5]. According to the ICAO [6], drones can be categorized as remotely piloted aircraft or completely autonomous aircraft.

Landing gear

An undercarriage called landing gears or landing struts helps an aircraft land and take off. These are essential in absorbing impact and providing a secure landing. The various gear configurations include:

- Conventional/Taildragger: This style of landing gear features two large wheels up front and a single, tiny wheel at the back. In Piper Cub, this layout is seen.
- Tricycle: This arrangement resembles the standard design with the exception that the smaller wheel is mounted on the aircraft's nose.
- Bicycle: This set-up is sometimes referred to as tandem. A smaller wheel is placed beneath each of the wings in addition to the two larger wheels on the fore and rear of the aircraft. This kind of setup exists between the Harrier Jump Jet and the Lockheed U-2.
- Quadricycle: To enable unfettered access to the fuselage's bottom, the Aeroplane XC-120 Packplane incorporates a quadricycle gear that is housed in the engine nacelles [7].

Oleo strut 1

Oleo is simply defined as an amalgam of oil and air. Typically, a spring absorbs energy and then releases it, producing bounce. In contrast, an Oleo strut reduces the bounce during takeoff or landing by absorbing the shock. Oleo struts are made of a metering pin such that their stiffness is determined by how much they deflect. According to Engineering360 in 2019 [8], the oleo strut is the most used form of shock absorber utilized in the aircraft industry.

A strong spring

This kind of damper makes use of a solid, flexible strut. The strut is positioned at an angle to the fuselage. The strut's bending as the weight is displaced vertically provides the necessary shock absorption. Lack of shock-induced vibration damping is the major flaw. The airplane subsequently bounces upon landing as a result of this. Due to the low sink speeds, it works better for lightweight aircraft where shock absorption is not as important [9].

Pneumatic damper

Similar in operation to hydraulic dampers, pneumatic dampers absorb energy using air as opposed to oil as the operating fluid. Lightweight applications are better suited for pneumatic dampers.

Magnetorheological fluid

A magnetic fluid that may be utilized to actively alter the damper's stiffness makes up a magnetorheological (MR fluid) damper. Even the oleo strut damper includes a metering pin that can change the damper's stiffness but that also has a set shape. Because the profile may be changed based on the circumstances, the MR fluid damper is more effective [10].

Overview of problem statement

The project is addressing the straightforward problem that most dampers are made to absorb impact and damp oscillations by slowly returning to their starting positions. To accomplish this, pneumatic dampers and working fluid are often forced through a tiny hole in the piston by lubricants. This lessens vibrations.

Forces the drone encounters upon landing

The drone experiences two forces when hovering: one is the pull of gravity, and the other is the lift from its motors. The lift provided by the motors is diminished during landing, resulting in a tiny force differential and a little larger gravitational pull as the drone slowly descends. In some cases, the operator may lose control of the drone or may erroneously drop the throttle too much, causing it to fall harder than normal and perhaps damaging the drone or its cargo.

Solution overview

By locking it at its fully compressed position, the mechanical damper tries to totally remove the bounce found in the regular damper. This will allow the damper to convert all of the drone's potential energy into spring potential energy without causing a jerk since the velocity of the drone in its compressed condition will be zero. Operating in a manner similar to a ball dropping in sand, where all of the energy is absorbed by the sand and wasted as heat from friction.

Software used

Solid works is a design tool made by Dassault Systems. It is used to create and model the components for 3D printing as well as to simulate their movement using motion analysis. The team decided to model the project using Solidworks since they are familiar with its user interface. Additionally, the software's drawing sheets may import the part files. Additionally, this feature offers the tools needed to add the essential details on the fits, surface quality, measurements, and viewpoints (front, top, side, and isometric), making it simple to utilize them during manufacturing.

Finite element analysis is a technique used by ANSYS17.1 to address structural and dynamic issues. Finite element analysis divides the model into several discrete components and runs calculations on them in order to forecast how a part will behave in the actual world. ANSYS 17.1 was used to determine the stress created on the piston, cylinder, teeth, and other damper components [11].

A mechanical, hydraulic, or pneumatic device called a shock absorber or damper is used to absorb the impact loads that cause vibrations. The innovative design makes operating safer and helps to cushion the vehicle. A damper's primary purpose is to absorb oscillations to prevent damage to the vehicle's body [12]. Moving the conversation to air vehicles, most of them employ hydraulic, pneumatic, or a mix of the two types of dampers. The oleo strut is one example of a combined damper. Oleo, which means "mixture of air and oil," is utilized in both heavy and small aircraft. The patent for the first oleo pneumatic shock absorption strut is held by the British manufacturing conglomerate Vickers Armstrong [13]. The adaptive type of air craft shock absorber is another intriguing model. According to research on the adaptive landing gear article by Mikulowski and Jankowski [14], adaptive landing gear outperforms passive landing gear in peak strut force by 6.9 to 17.8%. In high energy landings, active landing gear was also able to increase the safety margin. The numerous adaptive control techniques are also discussed in this work. The three control methods of passive, semiactive, and active were discussed. The experiments were carried out to establish the maximum strut forces and the acceptable sinking speeds. To get the damping force, a test rig was constructed utilizing MR fluid, and the lift force was disregarded during the test runs. Since helicopters and quadcopters have a similar kind of aviation mechanisms, study was done on helicopter landing gears to develop one for quadcopters. The information on methods for testing was adapted from the Code of Federal Regulations [15] and the Drop Test analysis done by Anitha et al. [16].

The project's deliverables include creating simulation tools for adaptive response, developing adaptive landing technology utilizing either MR fluid or Piezo valve-based technology, and lastly creating and testing a full-scale model of the methodology of choice. On an M-28 Skytruck, they tested their shock-absorber while taxiing, taking off, and landing. Additionally, they created a shock-absorber with a piezo-activated damping valve [17].

It was discovered after reading the aforementioned publications that MR fluid may also be employed as a shock absorber. A smart fluid called MR fluid has magnetic particles contained in a carrier fluid, like oil. This fluid becomes more viscous when exposed to a magnetic field, turning it into a viscoelastic solid. This fluid's characteristic makes it an excellent choice for a damper. Powell et al.'s study [18] and Asthana and Bhat's study [10] discuss the rheological characteristics, sedimentation rate, and behavior under dynamic impact stresses.

After the numerical calculations were finished, the relationship between the pneumatic damper's size and the ideal design was noticed. The design was completed using the damper's 20 kg mass and 10 m/s^2 acceleration. After further analysis, it was determined that the size of the shock absorber restricts acceleration [19].

As the project progressed, the examination of the damper that was being produced led to the study of the report by Nagurka and Huang [20]. In this document, a spring-based ball-bouncing model was examined. It develops stiffness, damping ratio, and frequency. The performance of the spring damper system was then contrasted with that of a ping-pong ball in motion. The relationship between nanoparticle emissions as well initial rotor temperature, total energy dissipated, and braking power has been observed here. According to a driver behavior and regulatory perspective, it appears limiting harsh braking as well as braking about high speeds, possibly through improved driving techniques, road design, and traffic management [21].

Experimentation

Design development - mechanism

The mechanism is inspired from zip ties. Zip ties are plastic ties used to tie wires and other things together. A zip-tie is a very useful and simple mechanism, the strap of the zip-tie has small teeth on it and the head contains a small arm which only allows the strap to tighten but restricts it from coming undone. The same concept was used to design the mechanical damper. The ridges on the inner side of the cylinder act as the teeth on the strap of the zip-tie and the teeth on the piston act as the flexible arm in the zip-tie thus only allowing the damper to move up but restricts it moving back down. To come up with the final design it took a few iterations and changes to the original design. Figure 1 presents a helical spring.

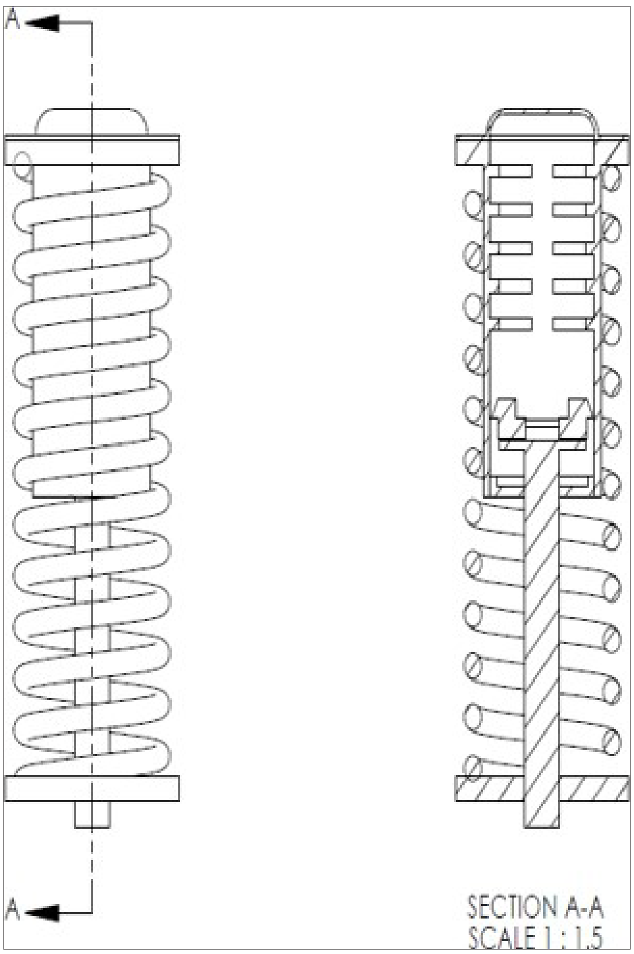

Figure 1: Helical spring [15].

Design calculations

Piston calculations: tensile

$$A = \frac{\pi}{4} 30^2 \quad (1)$$

$$A = 225\pi \ mm^2$$

$$\sigma = 1.01 \frac{N}{mm^2} \quad (2)$$

Cylinder calculations: tensile

$$A = \frac{\pi}{4} 40^2 + 36^2 \quad (3)$$

$$A = 76\pi \ mm^2 \quad (4)$$

$$\sigma = \frac{720}{76\pi} \quad (5)$$

Cylinder calculations: crushing load

$$A = 30 \ mm^2$$

$$A = 30 \ mm^2$$

$$\sigma = \frac{360}{30}$$

$$\sigma = 12 \ N/mm^2$$

Piston cap calculations: bending

$$\sigma = \frac{My}{I} \quad (6)$$

$$\sigma = \frac{360 \text{ x } 10 \text{ x } 12}{156.25}$$

$$\sigma = 46 \ N/mm^2$$

Tooth calculations: crushing load

$$A = 2.5 \ mm \text{ x } 10 \ mm$$

$$A = 25 \ mm^2$$

$$F = \frac{720}{2} \quad (7)$$

$$F = 360 \ N$$

$$\sigma = \frac{360}{25} \quad (8)$$

$$\sigma = 14.4 \ N/mm^2$$

Tooth calculations: shear

$$A = 10 \ mm \text{ x } 6.5 \ mm \quad (9)$$

$$A = 65 \ mm^2$$

$$F = \frac{720}{2} \quad (10)$$

$$F = 360 \ N$$

$$\sigma = \frac{360}{65} \quad (11)$$

$$\sigma = 5.54 \ N/mm^2$$

Nut calculations: annular plate bending

$C_9 = 0.29$

$C_8 = 0.74$

$L_9 = 0.18$

$$M = \frac{-4.77 \text{ x } 30}{0.74}\left(\frac{24 \text{ x } 0.29}{15} - 0.18\right) \quad (12)$$

$$M = -54.9 \ mm$$

$$\sigma = \frac{6 \text{ x } 54.9}{10} \quad (13)$$

$$\sigma = 3.29 \ N/mm^2$$

Bolt calculations: tensile

$$A = \frac{\pi}{4} \text{ x } 4^2 \quad (14)$$

$$A = 4\pi \ mm^2$$

$$F = \frac{720}{2} \quad (15)$$

$$F = 360 \ N$$

$$\sigma = \frac{360}{48} \quad (16)$$

$$\sigma = 28.6 \ N/mm^2$$

Helical spring calculations: springe stiffness

$$k = \frac{p}{\delta} = \frac{720}{60} = 12 \ N/mm \quad (17)$$

Helical spring calculations: material

$$S_{ut} = \frac{A}{d^m} = \frac{1753}{d^{0.182}} \quad (18)$$

$$\tau = \frac{S_{ut}}{2} = \frac{876.5}{d^{0.182}} \quad (19)$$

$$\tau = K\left[\frac{8PC}{\pi d^2}\right] \quad (20)$$

$$K = \frac{4c-1}{4c-4} + \frac{0.615}{c} \quad (21)$$

$c = 8$

$$K = \frac{(4 \text{ x } 8)-1}{(4 \text{ x } 8)-4} + \frac{0.615}{8} \quad (22)$$

$K = 1.184$

Now, substituting the value of K in Shear Stress equation:

$$\frac{876.5}{d^{0.182}} = 1.184\left[\frac{8 \text{ x } 720 \text{ x } 8}{\pi d^2}\right] \quad (23)$$

d = 5.1689 mm

$d \approx 6$ mm

Feasibility of design

$$\tau = 0.5S_{ut} = 0.5 \text{ x } 1130 \quad (24)$$

$$\tau = 565 \ N/mm^2$$

$$\tau = k\left[\frac{8PC}{\pi d^2}\right] = 1.184\left[\frac{8 \text{ x } 720 \text{ x } 8}{\pi \text{ x } 6^2}\right] \quad (25)$$

$$\tau = 482.405 \ N/mm^2$$

(b) < (a)
Hence, the design is satisfactory.

$\therefore d = 6 \ mm$

Mean coil diameter

D = c x d (26)
D = 8 x 6 = 48 mm

$\therefore D = 6 \ mm$

Number of active coils

$$\delta = \frac{8PD^3N}{Gd^4} \quad (27)$$

$$G = 81370 \ N/mm^2$$

$$60 = \frac{8 \text{ x } 720 \text{ x } 48^3 \text{ x } N}{81370 \text{ x } 6^4}$$

N = 9.932

$\therefore N \approx 10$

Total number of coils

$$N = N_t - 1.5 \quad (28)$$

$$N_t = N + 1.5 = 10 + 1.5 = 11.5$$

$$\therefore N_t = 11.5$$

Actual deflection of spring

$$\delta = \frac{8PD^3N}{Gd^4} \quad (29)$$

$$60 = \frac{8 \text{ x } 720 \text{ x } 48^3 \text{ x } 10}{81370 \text{ x } 6^4}$$

$$\therefore \delta = 60.4055 \ mm$$

Solid length of spring

Solid Length = Nt x d = 11.56 x 6 (30)

$\therefore Solid \ Length = 69 \ mm$

Gap between consecutive coil

Total gap = (N_t – 1) x Gap (31)

Total gap = (11.5 – 1) x 1

$\therefore Total \ gap = 10.5 \ mm$

Free length of the spring

Free length of spring = 60.4055 + 69 +10.5 (32)

Free length of spring = 139.9 mm ≈ 140 mm

$\therefore Free \ Length = 140 \ mm$

Pitch of spring

$$Pitch = \frac{Free \ Length}{N_t - 1} \quad (33)$$

$$Pitch = \frac{140}{11.5 - 1} = 13.33 \ mm$$

$\therefore Pitch = 13.33 \ mm$

Leaf spring calculation: load and deflection

$$Load = 720 \text{ x } \cos 30^{\circ} = 623.54 \ N \quad (34)$$

$\therefore Load = 623.54 \ N$

$$Deflection = 60 \text{ x } \cos 30^{\circ} = 51.962 \ mm \quad (35)$$

$\therefore Deflection = 51.962 \ mm$

Leaf spring calculation: thickness of springe

$$\delta = \frac{4Pt^3}{Ebt^3}$$

$$51.962 = \frac{4 \text{ x } 623.54 \text{ x } 320^3}{207 \text{ x } 10^3 \text{ x } bt^3} \quad (36)$$

$$bt^3 = 7598.6 \ mm^4$$

Assume b = 50 mm,

Gives t = 5.3 mm ≈ 5.5 mm (37)

$\therefore t = 5.5 \ mm$

$\therefore t = 5.5 \ mm$

Leaf spring calculation: Working stress of the spring

$$\sigma_b = k\left[\frac{6 \text{ x } P \text{ x } l}{b \text{ x } t^2}\right] \quad (38)$$

k = 1.1

$$\sigma_b = 1.1\left[\frac{6 \text{ x } 623.54 \text{ x } 320}{50 \text{ x } 5.5^2}\right]$$

$$\sigma_b = 870.69 \ \ N/mm^2$$

$$\therefore \sigma_b = 158.31 \ \ N/mm^2$$

$$158.31 \ \ N/mm^2 < N/mm^2$$

Hence the design is satisfactory.

Results and Discussion

The Recorded drop tests were analyzed using the tracker software. The displacement and velocities were recorded and used to calculate the potential energy, kinetic energy, and spring potential energy; these results are shown in figure 2. Figure 2 shows how the energy gets dissipated by the mechanical damper. It can be seen that 24.8 J of energy is lost in the first bounce. Most of this energy can be seen to be absorbed as spring potential and stored in the spring. It can be seen that the spring absorbs about 21 J of energy (84%) which is shown as the peak of the spring potential graph this is approximately the energy lost in the first bounce shown by A-B. Due to the pitch of the ridges the damper, it loses approximately 3 J of energy which is dissipated is the next 2-minute bounces. This brings the final energy stored in the spring to 17.7 J. This means that 17.7 J (71%) of energy was completely absorbed in the first bounce. It can be seen from the fact the spring takes 4 s to dissipate the energy. Some energy is lost in each bounce and converted to heat or lost to air friction. From the graph it can be calculated that through the first bounce 7.5 J are lost which is approximately 30% of initial energy. To check the bounce height in the leaf spring transient structural analysis was performed in Ansys. An initial velocity was given to be 3.16

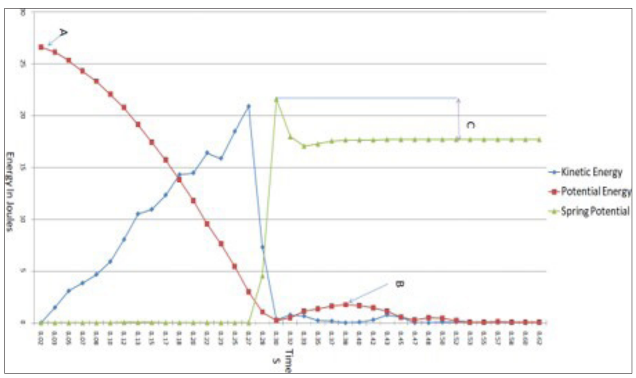

Figure 2: Energy dissipated by mechanical damper.

m/s and standard earth gravity was applied to the system. It was found that the leaf spring system would bounce to a height of 0.38 m on the first bounce. From this it can be seen that the energy lost in the first bounce is 24.5 J - 18.7 J which implies a 24% drop in energy.

Conclusion

The mechanical damper was designed, fabricated, and tested successfully. The mechanical damper was able to handle the load and no component faced any damage or deformation throughout the testing. Through experimentation and analysis, it was found that the mechanical damper was much better at absorbing the initial impact by absorbing 71% of the energy. When compared to the control spring which absorbed 30% of the energy and the leaf spring which absorbed 24% of the energy. It was also found that there would not be any sudden impulse in the mechanical damper as the velocity is relatively small when the teeth grip onto the ridges. 71% of energy absorbed by the spring is considered as plastic deformation as the energy does not rebound and stays in the spring unless released manually. After experimentation it was found that the Mechanical damper could be improved by reducing the pitch of the ridges on the inner face of the cylinder. This would result in less energy being lost and the 3 J of energy lost in the mechanical damper could also be absorbed resulting in complete elimination of any bounce.

Acknowledgements

None.

Conflict of Interest

None.

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