Aircraft landing gear with electromagnetic damper

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Abstract. The article describes the design and computation of the aircraft landing gear with an electromagnetic-gas shock absorber. A numerical simulation of the landing impact was carried out at different values of the initial vertical velocity. The dependence of the optimal electric current in the winding of the shock absorber electromagnet on the vertical speed is obtained.

1. Introduction
Flight safety during takeoff and landing largely depends on the aircraft landing gear. Landing gear damping system absorbs the energy of the vertical movement of the aircraft, reduces the overload acting in the airframe at the time of impact during landing, as well as when hitting irregularities during taxiing, takeoff and landing. To it should be attributed pneumatic wheels and shock absorbers. The shock absorber absorbs and dissipates the impact energy (up to 60...80%), so that the overloads occurring in the airframe are within regulated limits. These overloads should be acceptable not only for the structural elements, but also for all that is in the aircraft (passengers, cargo, weapons, avionics, etc.). The shock absorber can be an independent element, or integrated with the landing gear strut. There are many design types of shock absorbers capable of absorbing and dissipating the vertical kinetic energy of an aircraft at the time of landing. In this paper, one of the most promising landing gear schemes with an electromagnetic-gas shock absorber is considered.

2. Description of design and mathematical model
The scheme of the considered landing gear is shown in Figure 1. The landing gear consists of a wheel and a shock absorber. The shock absorber is a cylinder in which the gas is compressed by the piston. The walls of the cylinder are made of copper, and an electromagnet is built into the piston. When a piston moves in a copper cylinder, eddy current arise due to the magnetic field of the electromagnet, creating an induced magnetic field that counteracts the magnetic field of the electromagnet. Thus, during the compression of the shock absorber arises braking electromagnetic force.

The design of the electromagnetic damper is shown in more detail in Figure 2. The damper consists of winding 1 electromagnet, copper cylinder 2 and magnetic core 3. The core of electromagnet together with the steel wall 4 of the shock absorber cylinder forms a toroidal magnetic circuit. The electromagnet is mounted on the rod 5 of the shock absorber. Seals 6 seal the chamber with compressed gas. The electromagnet together with the seals 6 and the axle boxes 7 forms a shock absorber piston.
At the initial moment of time, the landing gear moves vertically with the mass at a velocity $V_y$. When the landing gear strut is compressed, a lifting force $Y$ equal in size to $2/3$ of the weight of the landing gear with the mass falling on it.

The computation model of the landing gear is presented in Figure 3. Equations of motion:

$$M \cdot \ddot{H} = -P_{sh} - Y + R,$$

$$m \cdot \ddot{h} = -P_{sh} - P_w - R,$$

where $m$ is the mass of the moving parts of the landing gear, $M$ is the mass of the load falling on the strut, except for the mass $m$, $H$ is the vertical displacement, $h$ is the reduction of the wheel, $R$ is the reaction in the piston stop when the shock absorber is not compressed, $P_w$ is the force of compression of the wheel, $P_{sh}$ is the shock absorber compression force:

$$P_{sh} = P_g + P_f + P_e,$$

where $P_g$ is the gas compression force, $P_f$ is the friction force, $P_e$ is the electromagnetic force.

Lifting force:

$$Y = \begin{cases} (M + m) \cdot g \cdot 2/3, & \text{if } H \geq 0 \\ 0, & \text{if } H < 0 \end{cases},$$

where $g$ is the acceleration of gravity.
Reaction in the piston stop is defined as follows:

\[
R = \begin{cases} 
R', & \text{if } S = 0 \text{ and } R' > 0 \\
0, & \text{otherwise}
\end{cases}
\]

\[
S = H - h,
\]

\[
R' = P_{sh} + (m \cdot Y - M \cdot P_w)/(M + m),
\]

where \(S\) is the compression of the shock absorber. In addition, if \(S = 0, \dot{S} < 0\), then \(\dot{H}\) and \(\dot{h}\) recalculated as \(\dot{H} = \dot{h} = (M \cdot \dot{H} + m \cdot \dot{h})/(M + m)\).

The force of gas compression is determined from the expression:

\[
P_g = p_0 \cdot F/(1 - S \cdot F/\Omega_0)^\chi,
\]

where \(p_0\) is the initial gas pressure, \(\Omega_0\) is the initial gas volume, \(F\) is the cross-sectional area of the piston, \(\chi\) is the polytropic exponent.

Friction force:

\[
P_f = \mu \cdot \text{sgn}(\dot{S}) \cdot P_g,
\]

where \(\text{sgn}(x) = \begin{cases} 
1, & \text{if } x > 0 \\
0, & \text{if } x = 0 \\
-1, & \text{if } x < 0
\end{cases}\)

Electromagnetic force [1, 2]:

\[
P_e = (1/a^3 - 1/b^3) \cdot 15 \cdot \mu_0^2 \cdot \sigma \cdot q^2 \cdot \dot{S}/1024,
\]

where \(a\) is the inner radius of the copper cylinder, \(b\) is the outer radius of the copper cylinder, \(\mu_0 = 1.2566371 \cdot 10^{-6}\) H/m is the magnetic constant, \(\sigma = 59500000.0\) S/m is the electrical conductivity of copper, \(q\) is the magnetic moment [3]:

\[
q = k_m \cdot I \cdot F_m \cdot n,
\]
where $k_m$ is the coefficient determined by the parameters of the magnetic core, $I$ is the electric current in the electromagnet winding, $F_m$ is the cross-sectional area of the magnetic core, $n$ is the number of turns of the winding.

Wheel compression force [4]:

$$P_w = k h/(1 - h/h_{\text{max}})^\alpha,$$

where $k$ is the stiffness, $h_{\text{max}}$ is the maximum compression displacement of the wheel, $\alpha$ is the nonlinearity coefficient.

Initial conditions:

$$H = 0, h = 0, \dot{H} = V_y, \dot{h} = V_y.$$

Model parameters: $M = 785.5$ kg, $m = 14.5$ kg, $Q_0 = 0.0021$ m$^3$, $p_0 = 176519.7$ Pa, $F = 0.00785$ m$^2$, $\chi = 1.35$, $\mu = 0.1$, $a = 0.05$ m, $b = 0.06$ m, $k_m = 16.2$, $F_m = 0.00181$ m$^2$, $n = 10000$, $k = 201279.584$ N/m, $h_{\text{max}} = 0.1158$ m, $\alpha = 0.095$.

3. Simulation results

In Figures 4–7 shows the results of numerical simulation for the parameters: $V_y = 3.05$ m/s, $I = 4.2$ A.
According to the results of numerical simulation, the optimum values of the electric current in the electromagnet winding were determined at vertical velocity from 1 m/s to 4 m/s. The optimal electric current value was considered such that the maximum force in the shock absorber during the reduction was the lowest. The diagram of the dependence of the optimal current on the vertical velocity is shown in Figure 8.

![Figure 8. Dependence of the optimal current on the vertical velocity.](image)

The resulting dependence is linearly approximated:

\[ I = K_I V_y + I_0, \]

\[ K_I = 0.551 \text{ A·s/m}, \quad I_0 = 2.51 \text{ A}. \]

The results of the calculation of cases of landing using the dependence of the optimal electric current on the vertical velocity are shown in Figures 9–13.

![Figure 9. Dependence of shock absorber force on shock absorber rod displacement.](image)

![Figure 10. Dependence of electromagnetic force on shock absorber rod displacement.](image)
4. Conclusion

According to the results obtained, we can conclude about the high efficiency of the electromagnetic-gas shock absorber. Such a shock absorber can be used in adaptive landing gear of aircraft, which allow minimizing the operational load on the airframe of the aircraft during landing. The design of the proposed electromagnetic damper is simple compared to regulated liquid dampers. When changing the control signal, the damper has no inertia, which allows you to fast change the damping force.

References

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