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Conceptual Design Of Single-Acting Oleo-Pneumatic Shock Absorber In Landing Gear With Combined Method

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K E Y W O R D S: landing gear, vibration, fluid, gas, shock absorber, hydro pneumatic shock absorber;

ABSTRACT: Landing gear is a structure that is mounted under the fuselage and helps the aircraft in takeoffs and landings. The most important duty of landing gear is the control of vibration exerted on the system through the shock absorber which is a common component to all the landing gear. Considering the importance of this issue, the necessity of investigating shock absorber with features such as high efficiency, reliability and maintenance, etc. is undeniable. In the present study In addition to choosing hydro pneumatic shock absorber its relationships arising from oil and gas liquids have been studied. This research was conducted with the aim of reducing the force variations and vibrations, with a focus on liquid gas. Thus, according to the gas laws, initially gas flow in the case of practical modes of isotherms during the taxi and poly trophic during landing has been studied. Considering that in the shock absorber only one mode can be used and Isotherms mode despite less vibration is not responsible for the landing phase and poly trophic mode exerts a lot of vibration on the fuselage, therefore a situation that can meet both needs in a way that have both phases of taxing and landing and at the same time reducing vibrations to be followed is the combination mode that its relation has been extracted at the end.

Introduction

In each plane shock absorber mechanism which applied during landing and take-off and guides the aircraft on the ground is particularly important. (Michalowski, 2007; Anon, 1994) shock absorber is one of the most important components of all landing gear as all existing aircraft doesn't have a Tires, wheels, brakes and … but all of them have somehow shock absorber. The main duty and function of a shock absorber, as its name implies, is absorbing and damping kinetic energy of the impact to the extent that acceleration imposed on the fuselage reduced to the minimum tolerable (Currey, 1988). In general, there are two main types of shock absorber depending on the type of spring used in it. A kind of shock absorber, which is called mechanical shock absorber, composed from solid spring steel or rubber and other type is formed from a gas spring or oil or a mixture of them which the latter type is known respectively pneumatic, hydraulic and hydro pneumatic shock absorber. According to research carried out it can be realized that hydro pneumatic shock absorber in terms of high efficiency and optimum weight (Currey, 1988; Bauer, 2011) features spring, damping characteristics, level control, design space and cost in comparison with the other shock absorbers listed have very tangible advantage. That is why in various industries wide acceptance of this type dampers are made. The study focused on the design of this type shock absorber.

Types of shock absorber

As mentioned in the introduction mechanical dampers are one of shock absorbers. This type of shock absorber have lost their capability in various applications due to the very high weight, low efficiency which is about 60% (Currey,1988), monotonic and fixed flexibility ratio in the move as well as unavailability of the control level (Currey,1988). Another type of the shock absorber is formed from a gas flow or oil or a mixture of them. The gas flow mode which is referred to pneumatic shock absorber has been used less in recent years because of heavy weight, low efficiency and reliability (Michalowski, 2007). And also the need to a relatively large design space compared to hydro-pneumatic system (Currey, 1988; Bauer, 2011). The oil mode which is the hydraulic shock absorber, despite the high efficiency of about 75 to 90%, which compete in this respect with hydro pneumatic shock absorber, but need to bear the high pressure fluid, weight increase and its performance has changed. As well as changes in the volume of fluid at low temperatures has affected the efficiency of the shock absorber. The mixture of oil and gas mode which is known as hydro-pneumatic shock absorber, created a revolution in landing gear growth in the United States in 1950 (Bauer,2011). These shock absorbers for having both fluid and gas flow can benefit from the advantages of both previous states. Such a way that by gas absorbs energy and by the oil damped it (Currey, 1988). Therefore, due to increase flexibility coefficient (Currey, 1988; Bauer, 2011) and the highest level of friction and damping (Currey, 1988), have the highest efficiency between 80 to 90% and also have the highest energy dissipation (Michalowski, 2007; Anon, 1994).

Table 1 compares these shock absorbers so that the efficiency of hydropneumatic suspension system was clear.

Table 1. Comparison of shock absorbers (Bauer, 2011)

	Mechanical spring and damper	Pneumatic spring and damper	Hydro pneumatic system
Spring characteristics	0	++	++
Damping and friction characteristics	++	++	+
Control level	-	+	++
Cost	++	0	-
Design space requirement	0	-	+
Reliability + robustness	+	0	+
Service requirements	+	0	0

Single-chamber hydro-pneumatic shock absorber

According to Figure 1, in these shock absorbers, shock absorber cylinder is two chambers. Upper and lower chambers are separated by orifice plate which orifice in which is embedded. When the force is applied to shock absorber, fluid through the orifice move between the upper and lower chamber. By moving hydraulic fluid from the lower chamber to the upper, the gas pressured which increases its pressure and thus produces a force as gas spring force. When this gas which can be dry air or nitrogen compressed serves as a spring.

Oil passing through the orifice causing a pressure drop that this pressure drop across the orifice produces a force which referred to it as hydraulic damping force. After initial impact and compression of the gas, phase of returning is carried out by air pressure which puts pressure on the oil to flow back into its chamber.

Orifice along with metering pin that provides changes in the size of the orifice, control the damping characteristics of the shock absorber when the metering pin through the orifice moves. Therefore, it is essential two independent conditions to be formulated.

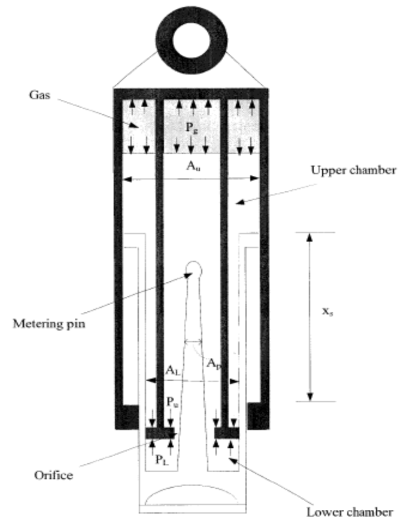

Figure 1. sketch of a hydropneumatic shock absorber

Formulation of the forces

According to the expressed contents shock absorber force, F_S, can be calculated by the following equation.

Equation (1)

$$F_S = (P_u - P_L)A_L + P_g(A_u - A_L) = F_p + F_g$$

Where P_L And A_L are respectively pressure and the upper lower area, P_u and A_u pressure and the upper chamber area and P_g the Reservoir pressure which is $P_u = P_g$.

In Equation (1) the shock absorber force is considered as a combination of the force caused by the pressure drop in the orifice and gas spring force. F_P Force can be a linear relationship between the force and pressure and a nonlinear relationship between Force and speed which by considering the law of conservation of mass for an incompressible fluid is as follows (Currey, 1988; Batterbee et al, 2007).

Equation (2)

$$F_P = (P_u - P_L)A_L = \Delta P A_L$$

Given that pressure drop in the orifice, ΔP, depends on the factors such as flow rate, orifice geometry, orifice size and density of the hydraulic fluid therefore, at first it is necessary to find a logical relationship between the pressure difference and the mentioned factors that it would be achieved through the following equation:

Equation (3)

$$\Delta P = Q^2 . K_B$$

Where Q is the volumetric flow rate which directly related to the flow rate, K_B a constant value which depends on the geometry, orifice size and density of the hydraulic fluid and through the following relations are defined:

Equation (4)

$$Q = A_L \dot{x}_s$$

Equation (5)

$$K_B = \frac{8\,\rho}{{\alpha_D}^2\,\pi^2\,{d_{orifice}}^4}$$

Where $\dot{x}_s$ is flow rate, ρ fluid density, $d_{orifice}$ the diameter of the orifice and α_D flow coefficient which depends on the geometry of the edge. Note that this flow rate is the relative speed of the shock absorber. Thus, by replacing

Equation and
Equation 5) at

Equation and then

Equation we have: **(**Bauer,2011**)**

Equation (6)

$$\Delta P = (A_L \dot{x}_s)^2 . \frac{8\rho}{\alpha_D^2 \, \pi^2 \, d_{orifice}^4}$$

Equation (7)

$$F_p = {A_L}^3 \, {\dot{x}_s}^2 . \frac{8\rho}{\alpha_D^2 \, \pi^2 \, d_{orifice}^4}$$

Figure 2 shows that Minimum flow rate α_D can be 1 and here because of drawing charts and conclusions for selected shock absorber, 1 is considered.

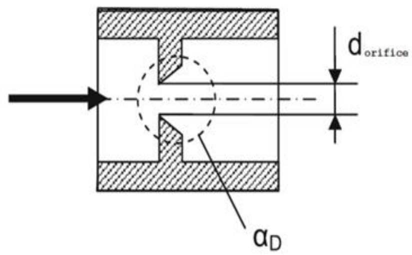

Figure 2. geometry of Inlet edge of the orifice (Bauer, 2011)

Gas spring force is also F_g which is as follows:

Equation (8)

$$F_g = P_g(A_u - A_L)$$

To obtain the relationship between gas pressures the polytropic gas law for a closed system can be used (Currey, 1988).

Equation (9)

$$P_{gx}V_{gx}^n = P_{ge}V_{ge}^n = C$$

Where P_{gx} And V_{gx} are respectively pressure and gas volume in each stroke, $P_{ge}$and V_{ge} are pressure and gas volume at full extension, C is a constant and n is an exponent which depends on the rate of compression.

Since the volume, V_{gx}, can be written as a function of stroke, S_x, So:

Equation (10)

$$V_{gx} = V_{ge} - A_u S_x$$

So in each stroke, x, we have:

Equation (11)

$$P_{gx} = P_{ge}\left(\frac{V_{ge}}{V_{gx}}\right)^n \qquad P_{gx} = P_{ge}\left(\frac{V_{ge}}{V_{ge} - A_u S_x}\right)^n \qquad 0 \le S_x \le S_{tot}$$

By replacing P_{gx} into the equation (3) we have:

Equation (12)

$$F_{gx} = (A_u - A_L)\, P_{ge}\left(\frac{V_{ge}}{V_{ge} - A_u S_x}\right)^n \qquad 0 \le S_x \le S_{tot}$$

For the normal ground handling, when the compression is low, the process is isothermal and n = 1 and for dynamic (fast) compression cases such as landing impact, where the compression is high, polytropic process is applied in which n> 1. In this process, n = 1.1 or n = 1.35 can be considered. The former is used when the gas and oil are separated and the latter when they are mixed during compression (Michalowski, 2007; Currey, 1988).

So it can be concluded:

Equation(13)

$F_{g\ poly} = F_{gx} \quad n > 1 \qquad F_{g\ iso} = F_{gx} \quad n = 1$

Since there is only one shock absorber in any aircraft for the normal ground handling and dynamic modes such as landing phase, so such a shock absorber should be designed to meet both needs. For this purpose it would be more appropriate to design based on the polytropic to include the normal mode too.

It is important to note to maximum pressure (pressure at full compression) in polytropic mode. If this pressure is smaller than the allowable pressure at this point, the polytropic method will be the basis of design.

But if in computing, a greater allowable pressure at this point is achieved, the best method is combined method that's mean using the polytropic and Isotherm at the same time (Currey, 1988).

When using this method (combined method), it is better to use isotherm method from the fully extended point to static point and use polytropic method from the static point to Fully compressed point. Therefore, we have the following relationship:

Fully extended to static:

Equation (14)

$$P_{gx} = \frac{P_{ge}V_{ge}}{V_{gx}} \qquad P_{gx} = \frac{P_{ge}V_{ge}}{V_{ge} - A_u S_x} \qquad 0 \le S_x \le S_{static}$$

Equation (15)

$$F_{gx} = (A_u - A_L)P_{gx} \qquad F_{gx} = (A_u - A_L)\frac{P_{ge}V_{ge}}{V_{ge} - A_u S_x} \qquad 0 \le S_x \le S_{static}$$

And static to fully compressed:

$$P_{g\acute{x}} = P_{static}\left(\frac{V_{static}}{V_{g\acute{x}}}\right)^n, \quad P_{g\acute{x}} = P_{static}\left(\frac{V_{static}}{V_{ge} - A_u S_{\acute{x}}}\right)^n, \quad S_{static} \le S_{\acute{x}} \le S_{tot} = S_{compress}$$

Equation (16)

$$F_{g\acute{x}} = (A_u - A_L)P_{g\acute{x}} \qquad F_{g\acute{x}} = (A_u - A_L)\, P_{static}\left(\frac{V_{static}}{V_{ge} - A_u S_{\acute{x}}}\right)^n \qquad S_{static} \le S_{\acute{x}} \le S_{tot} = S_{compress}$$

So it can be concluded:

Equation (17)

$$F_{g\ comb} = F_{gx} + F_{g\acute{x}}$$

Equations of motion

In order to investigate the vibrations on the fuselage in three modes of isotherms, polytropic and combinations, the equations of motion of the landing gear with two degree of freedom is obtained in which the whole aircraft body is assumed as a rigid body mass (the upper mass) and tire is modeled by a rigid body mass (The lower mass), spring and damper.

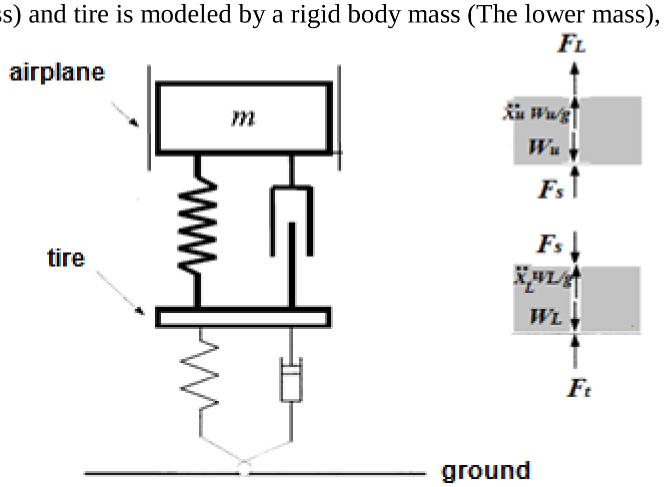

Figure 3. Two-DOF model of the landing gear system and the free body diagram of the Upper and lower mass.

Equation (18)

$$\frac{W_u}{g}\ddot{x}_u + F_s - W_u + F_L = 0$$

Equation (19)

$$\frac{W_L}{g}\ddot{x}_L - F_s + F_t - W_L = 0$$

Where W_u is the airframe weight and W_L is the wheel tire weight. It is noted that x_u and x_L are measured from the positions of W_u and W_L at the instant $t = 0$ when the tire first contacts the ground. $\ddot{x}_u$ and $\ddot{x}_L$ are the upper and lower mass accelerations respectively and g is the gravitational acceleration.

F_t is the tire force which represented here as:

Equation(20)

$$F_t = \begin{cases} k_t x_L + c_t \dot{x}_L & x_L \geq 0 \\ 0 & x_L < 0 \end{cases}$$

Where k_t is the tire stiffness and c_t is damping coefficient of the tire. F_L Is the lift force exerted from the air on the aircraft body and has upward direction. During the landing, the lift force varies and can be expressed as a function of time by an equation given by Choi and Wereley.(Choi,2003)

Equation(21)

$$F_L = [1.2 - 0.9\tanh(3t)](W_u + W_L)$$

Where $t \geq 0$ is the time in seconds.

Table 2. values of selected shock absorber

upper chamber	A_u: m^2	0.0182	Fluid density	ρ:m^3/s	2000
Lower chamber	A_L:m^2	0.0165	weight of the airframe	M_u:kg	1139.1
fully extended gas pressure	P_{ge}: kpa	662.3	weight of the tire	M_L: kg	16.45
fully extended gas volume	V_{ge}:m^3	0.06	tire stiffness	K_t:KN/m	1080
Orifice diameter	$d_{orifice}$: m	0.0074	tire damping coefficient	C_t:N.s/m	5000

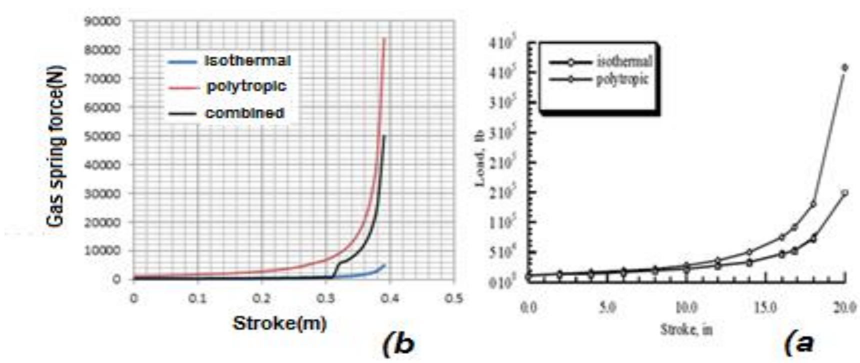

Figure 4. force-stroke curve a) experimental test (Khani,2010) b) Numerical test

Table 3. Optimal results of shock absorber force at fully compressed point

	polytropic	combined	allowable pressure force	Improvement of combined to polytropic
Force at fully compressed point of shock absorber	84200	50300	60000	%40.26

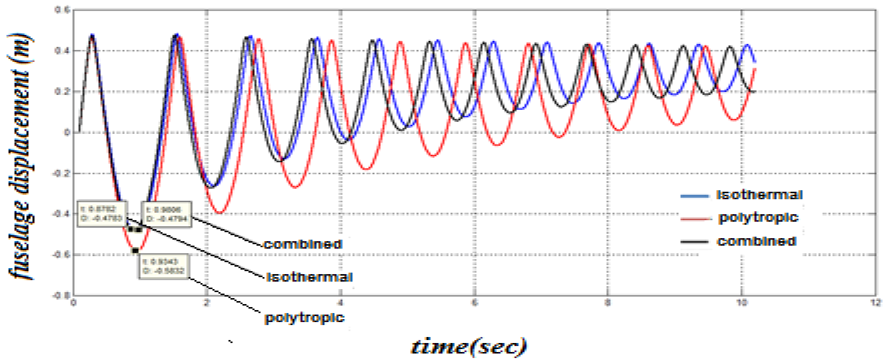

Figure 5. upper mass or fuselage displacement (isothermal, polytropic and combined)

Table 4. Optimal results of fuselage displacement

	isotherm	polytropic	combined	Improvement of combined to polytropic
upper mass or fuselage displacement (m)	- 0.4783	0.5832-	- 0.4794	17.8%

Conclusions

According to the values considered for selected shock absorber in Table 2 and force-stroke curve plotted in isotherm, polytropic and combined modes in Figure 4, It is concluded that polytropic mode due to its larger force from the permissible force shown in Table 3 cannot be used in such a landing gear therefore the combined mode is substituted. Figure 5 illustrates that when using combined mode, not only the pressure required at the time of taxing and landing is provided, but also the vibration and dynamic loads attenuate and consequently decrease the acceleration transmitted to the fuselage during the touch-down impact in landing. In other words, pressure is the pressure required in landing phase while the vibrations are as taxi phase which its results can be seen Table 4.

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