XL CILAMCE
IBERO-LATIN AMERICAN
CONGRESS ON
COMPUTATIONAL
METHODS IN
ENGINEERING
NOVEMBER
11-14, 2019
Praiamar Natal Hotel & Convention
Natal, RN-BRAZIL

IMPACT ABSORBERS FOR APPLICATION TO THE CASING OF EXPERIMENTAL ROCKETS

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Abstract. This project had an intent to research and determine materials with good damping characteristics that serve as impact absorber.The materials determined here can serve as the inner casing of experimental rockets, minimizing the damage caused by impacts to the ground to the ejected capsules, aiming the reuse of internal components. A mathematical model with a degree of freedom was used, which shows the spring, the damping and the mass of the capsule. The dynamic loading was due to the impact on the ground. The elastic, damping and inertial forces were considered. The goal was to minimize the acceleration of the part through the use of materials that could serve as the inner lining of these rockets. Several materials were researched, with the objective of determining its modulus of elasticity, coefficient of internal damping and density. A material with a high density, or a low damping factor, is not desirable. Once these properties were determined, they were introduced in the mathematical model to verify the ones that produce the most acceleration reduction after impact.

Keywords: Impact Absorbers, Dynamic of Structures, Experimental Rockets

1 Introduction

In 1926 the first rocket, made by Dr. Robert Hutchings Goddard, considered the father of modern rocket propulsion, built and tested, and over time the rockets were being refined and developed, creating new types and models, arriving to this wide variety of rockets known today. Many of the rockets use couplings that serve as propellants to carry this load to the desired altitude. Many times these elements, when decoupling and falling to the ground, suffer a great impact and end up being destroyed, having the need to be rebuilt, and these elements can't be reused and having several parts being thrown away because it is no longer possible to use them by impact between him and the ground. But if it is possible to design a material as a casing that has the function of absorbing part of the impact, it can save many components that would be damaged, resulting in the economy of the replacement of objects. Once the replacement costs are reduced, there is a potential for this cost reduction to be applied to the improvement in the design, fabrication and launching process of the rockets. The objective of the present work was to carry out a research and analysis of materials, available in the market, that serve as impact absorbers. The results of the present study can also be extrapolated to applications in other areas that require these devices.

2 Theoretical Bases

2.1 Conceptual Aspects

The basic characteristics of the dynamic analysis of a structure are: loads, reactions, displacements, deformations and internal stresses vary over time, with velocities and accelerations that is not negligible; in addition to the applied loads, reactions and internal forces (which are balanced in a static situation), inertial forces (related to the mass of the structure) and forces that dissipate energy (damping) also take part in the equilibrium, to a single (static) result, but to a response history.

In that specific case the dynamic analysis considering the characteristics of the problem and the high accelerations generated in the impacts against the ground is crucial. In order to solve a dynamic impact problem, such as the one in question, it is necessary to construct a mathematical model. Once a mathematical model is constructed, there are three main ways of solving it.

In the case of the dynamics of structures, the mathematical model that is arrived at is composed of systems of differential equations in which time plays a fundamental role. This is quite different from the static case, where it falls into systems of algebraic equations. Table 1 shows the difference between the systems of dynamic and static analysis equations:

Table 1 - Difference of the systems of equations of the dynamic and static problem

Dynamic	Static
System of Ordinary Differential Equations	System of Algebraic Equations
$M\ddot{u} + C\dot{u} + Ku = f(t)$	$Ku = f$

In the above equations M, C and K are respectively mass, damping and stiffness matrices, whereas the vectors $\ddot{\boldsymbol{u}}$, $\dot{\boldsymbol{u}}$, u, and f are respectively the acceleration, velocity, displacement and external force vectors. The independent variable is time t. It is observed that the main difference between the two cases is that in the static the independent variable time does not appear and the accelerations and velocities are despised. When the equations are linear, it is a linear dynamic or static and when the equations are non-linear, it is nonlinear dynamics and static.

In the present work, linear dynamics was used, that is part of a more general discipline called Dynamical Systems.

2.2 Damped Free Oscilations

The model to be used in the present work (Figure 1) is the free-floating oscillation. Once the ejected capsule collides with the ground, it introduces an initial velocity into the system, whereas from this moment no more external forces acting on the system exist, only elastic, damping and inertial forces, where the application of the forces is done slowly, with negligible velocities, it is usual not to take into account the appearance of forces of inertia, therefore a force-free and damped oscillation.

The mathematical model must be developed by using the laws of mechanics. The external force applied in a dynamic system is designated by P (t), however null in the case in question. The resilient restorative force, which tends to bring the mass into its zero-displacement position, is proportional to the displacement. In this case, K is the elastic constant and u is the displacement.

Due to the friction, always present in the real structures, a dissipation (damping) force appears, which is considered proportional to the velocity (the point on the variable u represents the first derivative in time, that is, the velocity), while C is the damping constant. By Newton's second law, the sum of the forces applied to a mass corresponds to a force of inertia equal to the product of mass by acceleration (the two points on the variable u represent second derivative in time, that is, the acceleration) in the opposite direction.

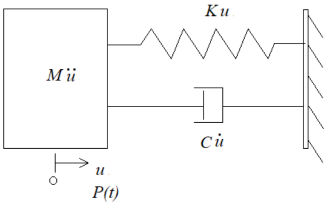


Figure 1 - Mathematical model with a degree of freedomSo,

$$f_i = P(t) - f_e - f_d \,,$$

which, re-arranged, falls into the known form of the Equation of Motion of a system of a degree of freedom, the ordinary differential equation (ODE):

$$M\ddot{u} + C\dot{u} + Ku = P(t) \,.$$

Considering the presence of the damping, as it is necessary in the real structures, and considering the external force null, it happens to have the homogeneous ODE given by

$$M\ddot{u} + C\dot{u} + Ku = 0 \,, \text{ or } \ddot{u} + 2\xi\omega\dot{u} + \omega^2 u = 0 \,,$$

where $\omega2 = K / M$ is the natural frequency of vibration and the "damping rate" is given by

$$\xi = \frac{C}{2M\omega}\ .$$

In the case of the dynamics of the structures, the systems have subcritical buffers with the value of ξ generally well below 1.

The ODE solution is

$$u(t) = e^{-\xi\omega t}\rho\cos(\omega_D t + \theta)\ ,$$

with damped frequency and amplitude of vibration given respectively by

$$\omega_D = \omega\sqrt{1-\xi^2} \qquad \text{e} \qquad \rho = \sqrt{u_0^2 + \left(\frac{\dot{u}_0 + \xi\omega u_0}{\omega_D}\right)^2}\ ,$$

and phase angle

$$\theta = -\tan^{-1}\left[\left(\frac{\dot{u}_0 + \xi\omega u_0}{\omega_D u_0}\right)\right].$$

It id noted that the resulting harmonic motion (Figure 2) rapidly decreases in amplitude due to the negative exponential that multiplies and its frequency is slightly decreased by the damping, that is the corresponding period is slightly increased.

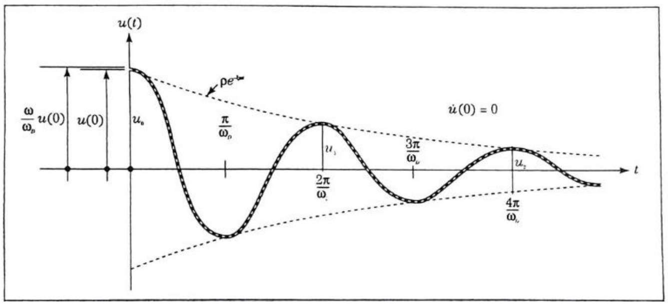


Figure 2 - Response to free vibration of a system with subcritical damping

The equations shown in this section are programmed into a Microsoft Excel spreadsheet and then provided with data so that it gets the system's dynamic response.

3 Methodology

The research started with a bibliographical revision in order to base the mathematical formulation of the dynamic problems to be solved. Right after this step, the formulated problems was programmed in Microsoft Excel. The spreadsheets were then tested in order to verify the performance and effectiveness of the programming by comparing the results with theoretical data. Once the spreadsheets present adequate data, the process was applied with the use of different types of materials, with different characteristics of elastic constants and damping. The materials with the best impact absorption capacity were identified and then sorted in order of efficiency. To measure the efficiency, an instant of time was defined common to all the materials and this was measured the displacements and accelerations so that one can have a parameter of comparison. The best impact-absorbing materials are those with a lower value (in absolute value) of displacement and acceleration at the instant of time considered.

Laboratories, equipment and programs: Computers, laboratories, libraries and other facilities were used in the Undergraduate Program in Aerospace Engineering of the Federal University of ABC.

3 Results

Inside of that research a lot of compounds were founded, as well as their respective modulus of elasticity. Around that materials the polymers and rubbers had the best materials for lower acceleration, that is they have the best perform to be inside the rocket and have the greatest chance of surviving and finally be reused. For the rocket was used for 5% of coating material, coating thickness of 2 cm, contact area between payload and the coating of 10 cm2, object mass (payload) of 0, 2 kg and maximum speed of 40 km / h (approximately 11.11 m / s)

About these materials:

- Elastomer, with modulus of elasticity founded with 1000 kpa and your acceleration of 527 g

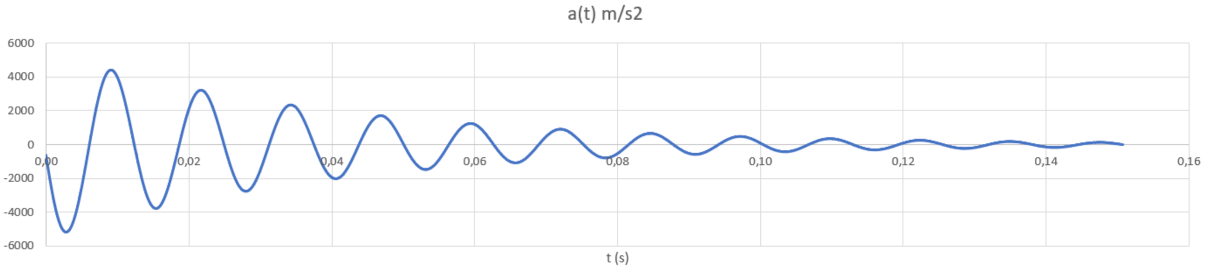
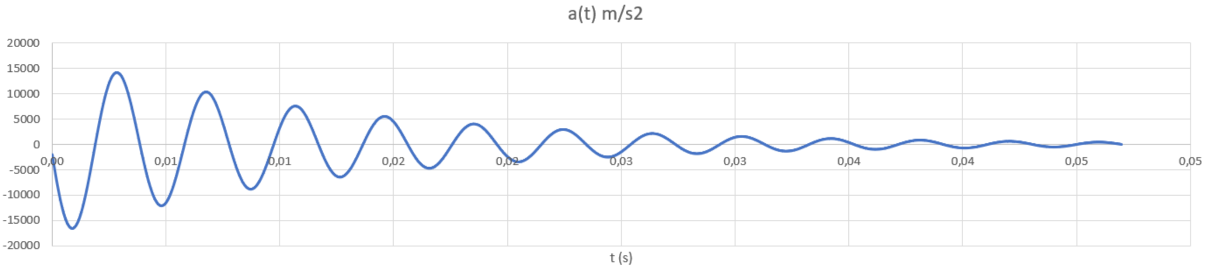


Figure 3

- Polypropene, with modulus of elasticity founded with 10300 kpa and your acceleration of 1693 g



Figue 4

- Silicone rubber, with modulus of elasticity founded with 1000 kpa and your acceleration of 527 g

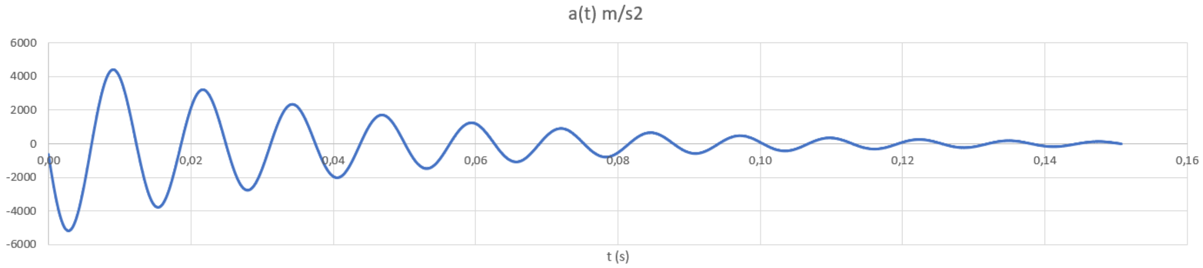


Figure 5

- Poli-3-Hidroxibutirato (PHB), with modulus of elasticity founded with 1185 kpa and your acceleration of 574 g

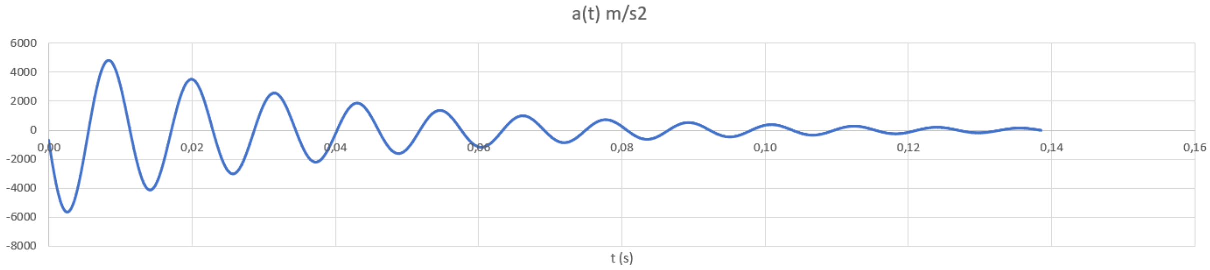


Figure 6

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Acknowledgment

I would like to thank Professor Marcelo Araujo da Silva for the opportunity to work on the Researching from the First Day (PDPD) project and for his great help and patience throughout the research.

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