Piezoelectric Crystals Application on Landing Gears for Harvesting Energy

J. C. C.Pereira*, J. V. P Silva**

* Department of Mechanical Engineering, Federal University of Santa Catarina, Campus ReitorJoão David Ferreira Lima, 88040-900, Florianópolis, BR
(E-mail: *carlosp@emc.ufsc.br)*
** Department of Mechanical Engineering, Federal University of Santa Catarina, Campus ReitorJoão David Ferreira Lima, 88040-900, Florianópolis, BR
(E-mail: *joaovictorpsilva@gmail.com*)

INTRODUCTION

Piezoelectric materials are known to have the electromechanical coupling effect. This property has a large range of applications in engineering. Nowadays they are extensively used as sensors and actuators in vibration control systems. As a sensor, when bonded to a flexible structure, it can monitor the vibrations (Tzou and Tseng 1990; Kumar and Narayanan 2008). As an actuator, it can control the vibration level by introducing a restored force or by adding damping into the system (Hagood et al 1990; Baz and Poh 1988). In days when new resources of energy are being investigated theconversion ofmechanical deformation intoelectric potential in order to power devices that request a low level of energy could be a good alternative.There is significant work (Anton and Sodano 2007; Priya 2007) in applications for cantilevered energy harvesters with a common conclusion covering the restrictive use for lower power systems. In a typical operation,many mechanical systems have components in constant deformation. One of these systems is a landing gear.Landing gear dynamics have been thoroughly studied (Pritchard 1976; Moreland 1951; Chang 1995) providing models for the time domain analysis. Results have shown (Ertuk et al 2008; Magoteux 2007) the potential use of piezoelectric materials in these configurations under different geometries, with positive outcome for unmanned air vehicles (UAVs). So, this study aims to investigate the potential of the energy absorption whena landing gear responds to a load of impact and compare the power generated by a range of piezoelectric crystals. The finite element method and the modal method are used to obtain the time response domain.

THE MATHEMATICAL FORMULATION OF THE SYSTEM

Two bar elements, two rigid rods, one viscous damping, one spring, one lumped mass and one piezoelectric crystal, as presented on fig 1 compose the mathematical model of the landing gear considered in this study. The piezoelectric crystal is represented by an element located between nodes 1 and2 of the discretized system.

A uniaxial finite element of a piezoelectric crystalcan be modeled as a disk with a diameter D and a thickness h with the aspect ratio $D/h \geq 10$, with two nodes on its extremity, as shown on fig 2. Over each node, there are a mechanical load and/or an electrical charge C_i associated with a mechanical and/or an electrical displacement d_i. The Young's modulus is E, the piezoelectric constant is C_p and dielectric constant is C_d.

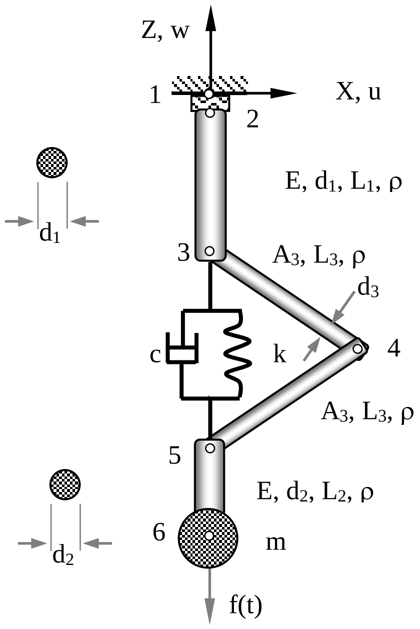

Figure 1: Landing gear model.

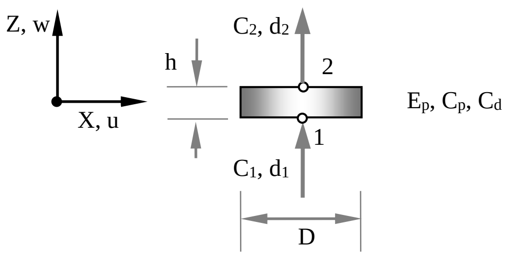

Figure 2: The uniaxial finite element of a piezoelectric crystal.

The electromechanical coupling effect of the piezoelectric material can be described using a set of basic equations as given in the IEEE Standard on Piezoelectricity, ANSY (1987):

$$\sigma = E_p.\frac{\partial w}{\partial z} - C_p.\frac{\partial V}{\partial z}$$
$$Q = C_p.\frac{\partial w}{\partial z} + C_d.\frac{\partial V}{\partial z} \qquad (1)$$

Where σ is the normal stress, Q the electric displacement, w the axial displacement and V the electric potential.
The mechanical strain energy U_m and the electric energy U_e of the piezoelectric material element are written as:

$$U_m = \frac{1}{2}\int_V \sigma.\frac{\partial w}{\partial z} dV = \frac{1}{2}\int_V \left(E_p.\frac{\partial w}{\partial z} - C_p.\frac{\partial V}{\partial z} \right) \frac{\partial w}{\partial z} dV$$
$$U_e = \frac{1}{2}\int_V Q.\frac{\partial V}{\partial z} dV = \frac{1}{2}\int_V \left(C_p.\frac{\partial w}{\partial z} + C_d.\frac{\partial V}{\partial z} \right) \frac{\partial V}{\partial z} dV \qquad (2)$$

If the linear approximation of the axial displacement w and the electric potential V over the thickness h is considered, stiffness matrices of the piezoelectric finite element can be obtained by Lagrange equations:

$$[k_m]=\frac{E_p.S_p}{h}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix}$$

$$[k_{m\_el}]=-\frac{C_p.S_p}{2.h}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix} \quad (3)$$

$$[k_{el}]=\frac{C_d.S_p}{h}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix}$$

Where $[k_m]$, $[k_{m\_el}]$ and $[k_{el}]$ are mechanical stiffness, electromechanical coupling stiffness and electric stiffness elementary matrices, respectively, and S_p is the cross section area of the piezoelectric crystal. After the assemblage of elementary matrices the differential equation of motion of this system is as:

$$[M]\{\ddot{P}\}+[C]\{\dot{P}\}+[K]\{P\}=\{F(t)\} \quad (4)$$

Where [M], [C] and [K] are global matrices of mass, damping and stiffness, respectively. Vector<P>is composed by mechanical displacements U and electric potentials V as degrees of freedom.

The nodal force applied on node 6is an impulsive force F_o due to an impact on the sprung mass during a short period of time Δt. These data are used to obtain the velocity as an initial condition in solving eq. (4) on a time response domain, Paultre (2010).

Firstly, the modal analysis is performed and after that, the modal method is used to calculate the time response domain with the first two modes.

RESULTS AND DISCUSSIONS

Geometrical properties are of a commercial Boeing 747, dimensions and masses are obtained through the manufacturer (Boeing, 2012) and loads estimated as in Majumder (2008). The bar elements and the rigid rods are made of steel with Young's modulus E = 200 GPa and density ρ = 7800 kg/m^3. The geometrical properties of the upper bar are L_1= 0.5842 m and d_1 = 292.1 mm, the geometrical properties of the lower bar are L_2 = 0.3338 m and d_2 = 292.1 mm and the geometrical properties of the rigid rods are L_3 = 0.64262m and d_3 = 137.4 mm. The spring constant is k = $1x10^7$ N/m and the viscous damping constant is c = 70000 N/m/s. The lumped mass is 1165.72 Kg. Different piezoelectric crystals were experimented and its properties are shown in Table 1.

Table 1. Properties of piezoelectric crystals.

	BaTiO3	PbTiO3	PbZrTiO3	PZT-5A	PZT-5H
Piezoelectric constant – e [C/m^2]	17.5	2.96089	10.5714	15.08	23.3
Dielectric constant – ε [F/m]	$1.12x10^{-8}$	$1.24\ x10^{-9}$	$2.39x10^{-9}$	$7.35x10^{-9}$	$1.30x10^{-8}$
Density – ρ [kg/m^3]	5700	7870	7700	7750	7500
Young's modulus – E [GPa]	150	143.3	160.9	121	126

The impulsive force is F_o= 400 N and the period of time is Δt = 1s. Fig 3 shows the time response domain of the system in respect to the displacement of node 6 while figs 4-8 show the electrical power generated in the crystal in a range of 1s.

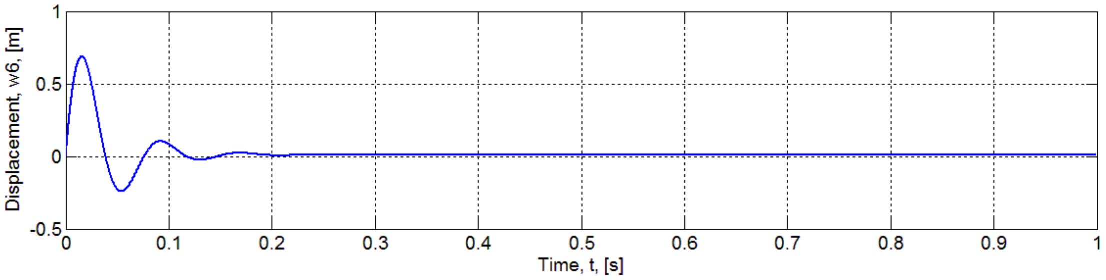

Figure 3: Time response domain: displacement of node 6.

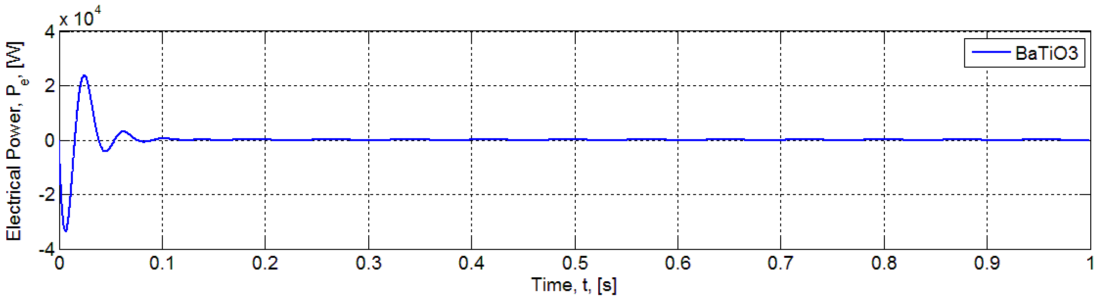

Figure 4: Electrical Power of BaTiO3.

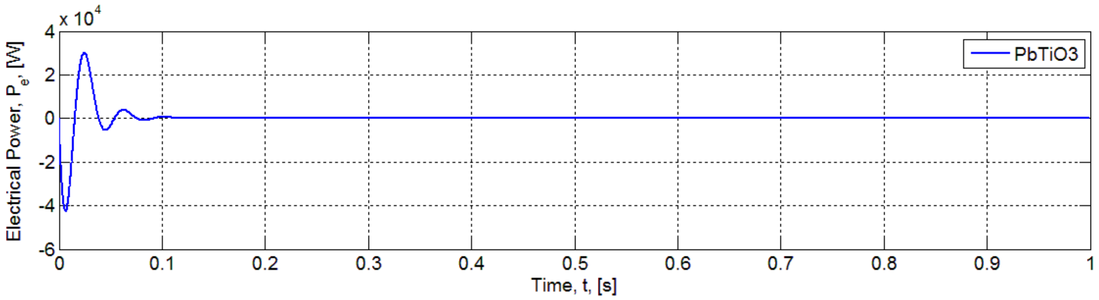

Figure 5: Electrical Power of PbTiO3.

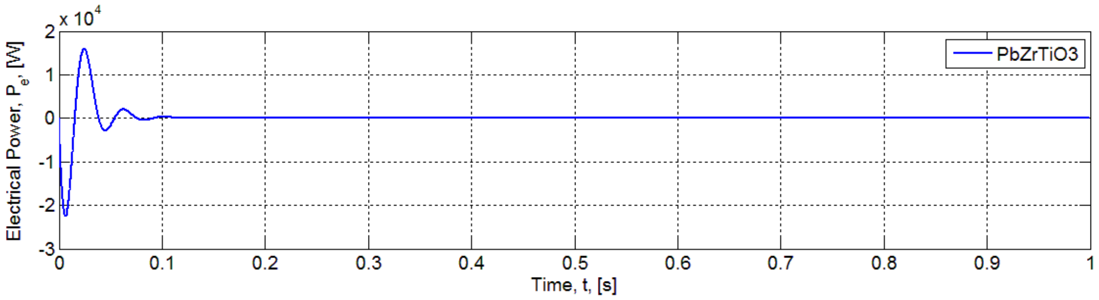

Figure 6: Electrical Power of PbZrTiO3.

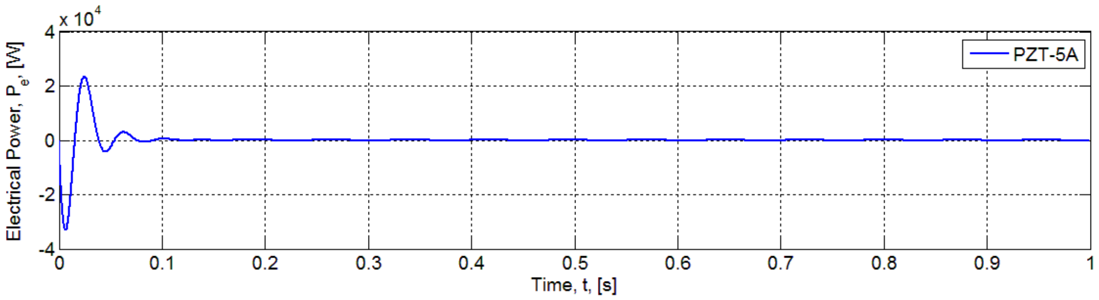

Figure 7: Electrical Power of PZT-5A.

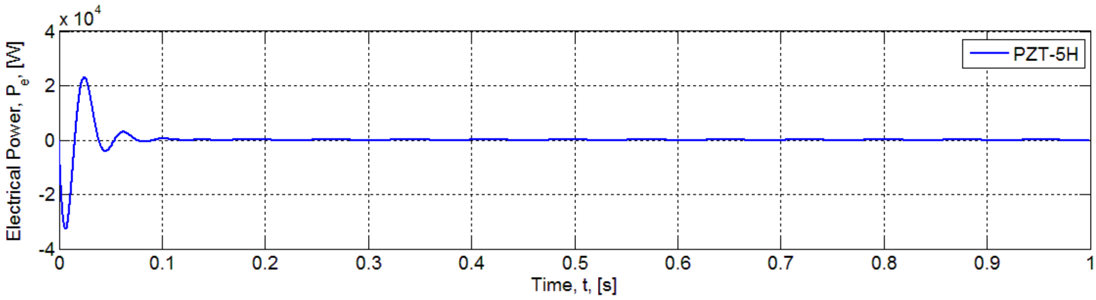

Figure 8: Electrical Power of PZT-5H.

By the observation of fig 3 through fig 8, it can be confirmed the coupling between the displacement and the electric power as presented by the constitutive relations on equation 1. It can also be observed that the peak of the electric power generated can vary by up to 70% from one piezoelectric material to another.

CONCLUSIONS

From this initial study on the application of piezoelectric material in landing gears, it can be concluded the energy absorption in this system could be a good alternative for powering on-board devices that need low level of energy to operate. It is also possible to infer that the material with the highest generation in this analysis can convert roughly double the amount of energy as the lowest, which implies a substantial gain for conceivable self-powered control systems or other on-board setups.

REFERENCES

Journal: Anton S.R., Sodano, H.A. 2007A Review of Power Harvesting using Piezoelectric Materials.*Smart Materials and Structures*, **16**:R1–R21.

Journal: Baz A., Poh S. 1988 Performance of an active control system with piezoelectric actuators.*Journal of Sound and Vibration*. Volume **126**, Issue **2**.

Report: Boeing Commercial Airplanes. 2012 *747-8 Airplane Characteristics for Airport Planning*, Revision B.

Report: Chang C. F. 1995*Dynamic Finite Element Modelling of Aircraft Landing System*, Proceedings of the ASME Design Engineering Technical Conference, Boston.

Journal: Erturk A.,Renno J. M., Inman D. J. 2008 Modeling of Piezoelectric Energy Harvesting from an L-shaped Beam-mass Structure with an Application to UAVs, *Journal of Intelligent Material Systems and Structures*.

Journal: Hagood N. W., Chung W. H., Von Flotow A. 1990 Modelling of Piezoelectric Actuator Dynamics for Active Structural Control, *Journal of Intelligent Material Systems and Structures*. Volume **1**, Number **3**.

Standard:IEEE Standard on Piezoelectricity. ANSI Std. 176-1987.

Book: Kocbach J. 2000*Finite Element Modeling of Ultrasonic Piezoelectric Transducers*. University of Bergen.

Journal: Kumar K. R., Narayanan S. 2008 Active vibration control of beams with optimal placement of piezoelectric sensor/actuator pairs, *Smart Materials and Structures*. Volume **17**, Number **5**.

Thesis: Magoteaux K. 2007*Investigation of an Energy Harvesting Small Unmanned Air Vehicle*. Master of Science Thesis, University of Dayton.

Journal: Majumder L., Rao S.S. 2008Interval-based optimization of aircraft wings under landing loads.*Computers and Structures.* Volume **87**, **225–235**.

Report: Moreland W. J. 1951*Landing Gear Vibration*. AF Technical Report Number 6590.

Book: Paultre, P.2010 *Dynamics of structures*. John Wiley & Sons.

Report: Pritchard I. J. 1999*An overview of landing gear dynamics*..NASA TM-1999-209143.

Journal: Priya S. 2007Advances in Energy Harvesting using Low Profile Piezoelectric Transducers.*Journal of Electroceramics*,**19**.

Book: Rao S.: 2009 *Mechanical Vibrations*. Prentice-Hall, 2009.

Book: Tiersten, H.F.1969 *Linear Piezoelectric Plate Vibrations*. Plenum Publishing Corporation.

Journal: Tzou H. S., Tseng C. I. 1990 Distributed piezoelectric sensor/actuator design for dynamic measurement/control of distributed parameter systems: A piezoelectric finite element approach, *Journal of Sound and Vibration*. Volume **138**, Issue **1**.

Book: Yang T. Y. 1986*Finite Element Structural Analysis*. Prentice-Hall.