Numerical Characterization of Magnetostrictive Response of GalFeNol Samples for Energy Harvesting

G. Canciello[1], A. Cavallo[1], C. D'Avino[2], D. Tornese[2], C. Visone[3]

[1]Dipartimento di Ingegneria Industriale e dell'Informazione, Seconda Università degli Studi di Napoli, Caserta CE, Italy

[2]Teoresi Group S.p.A, Torino, Italy

[3]Dipartimento di Ingegneria, Università del Sannio, Benevento BN, Italy

Abstract

INTRODUCTION:
Multifunctional materials are increasingly more used in energy harvesting from ambient vibrations. Nowadays, the most common materials used for this purpose are Piezoelectrics [1,2,3] but innovative approaches are based on Giant Magnetostrictive Materials (GMM). Magnetostriction occurs in most ferromagnetic materials and is due to Joule and Villari effects [4,5]. The former is a transformation from electrical to mechanical energy, the latter is the reverse, i.e., mechanical stress drives magnetization the sample. Recent studies recommend the use of Terfenol-D (Tb0.3Dy0.7Fe2) provided by ETREMA Inc. as it has a high magnetostriction value (up to 2000 ppm at saturation) [6]. A new magnetostrictive material (with saturation magnetostriction of about 400 ppm) is GalFeNol [7]. However, the advantage of GalFeNol is its Ultimate Tensile Strength (UTS) of 360 MPa rather than 28 MPa of Terfenol-D. Moreover, GalFeNol is lighter (density 7800 kg/m3) and, differently from Terfenol-D, thanks to its high UTS, it can work in tensile conditions widening mechanical reliability and application range of these materials. In this study a characterization in COMSOL of this new material is provided.
USE OF COMSOL MULTIPHYSICS®
A 3D-model of a GalFeNol rod stressed by a time varying force of 1000 N, directed on the longitudinal direction, is presented. The study has been carried out for two shapes, a solid and hollow cylinder (Figure 1). For both the shapes, physical dimensions (inner and outer radius) are parametrized in order to evaluate the best combination of them. In the model, a new material (GalFeNol) has been created starting from the indications of the supplier (ETREMA Inc.).
The physics interfaces involved in the COMSOL model are Solids Mechanics from Structural Mechanics Module and Magnetic Fields and Electrical Circuit from AC/DC module. The model also includes a multiple wire coil and a resistive load (100 Ω) to evaluate the electrical power generated by the energy harvesting. Simulations have been performed both in Time Dependent and in Frequency mode (1-500 Hz) to evaluate transient and stationary phenomena.
RESULTS:
Results in mechanical terms show that the maximum longitudinal strain is 80.0 ppm for the solid cylinder, and 36.0 ppm, for the hollow cylinder. In both cases the maximum internal stress is

below 10 % of UTS of GalFeNol (5.18 MPa for the solid cylinder and 2.19 MPa for the hollow cylinder).
In terms of magnetic energy conversion, both from the parametric results for solid cylinder (Figure 2) and for hollow cylinder (Figure 3), it can be concluded that the smaller the transverse section, the higher the converted electrical power.
CONCLUSION:
The results of the study show that GalFeNol is able to convert mechanical energy into electric one and at the same time to resist to mechanical stress. The maximum computed internal stress is below 10 % of UTS, i.e. even in the worst mechanical stress condition no permanent deformations happen. Future studies will deal with more complex 3D-models, taking into account the actual nonlinear behavior of such alloys, and more efficient electric circuits to improve energy conversion efficiency.

Reference

[1] G.W. Kim, Piezoelectric energy harvesting from torsional vibration in internal combustion engines, International Journal of Automotive Technology, Vol. 16, No. 4, pp. 645−651 (2015)
[2] N. Makki,R. Pop-Iliev, Piezoelectric power generation in automotive tires, International Workshop SMART MATERIALS, STRUCTURES & NDT in AEROSPACE, Montreal, Quebec, Canada (2011)
[3] R. Elfrink, et. al., Shock induced energy harvesting with a MEMS harvester for automotive applications, IEEE International Electron Devices Meeting (2011) [4] D. Davino et al., Experimental analysis of vibrations damping due to magnetostrictive based energy harvesting JOURNAL OF APPLIED PHYSICS 109, 07E509 (2011)
[5] F. Claeyssen et. al.,, Magnetostrictive actuators compared to piezoelectric actuators, European Workshop on Smart Structures in Engineering and Technology (2003)
[6] A. Matsui, Y. Yamamoto, M. Hanazawa , Energy Scavenging Using Giant Magnetostriction Material: Prototype Development IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society, pp 873 - 877(2011)
[7] E. Clark et. al., Magnetostrictive Properties of Galfenol Alloys Under Compressive Stress, Material Transaction, Vol. 43, No. 5, pp 881 – 886 (2002)

Figures used in the abstract

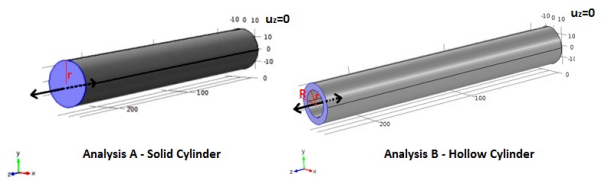

Figure 1: Figure 1: Test articles

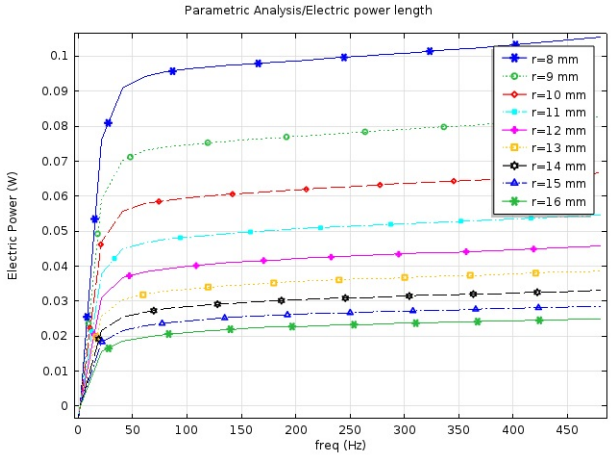

Figure 2: Figure 2: parametric analysis, solid cylinder

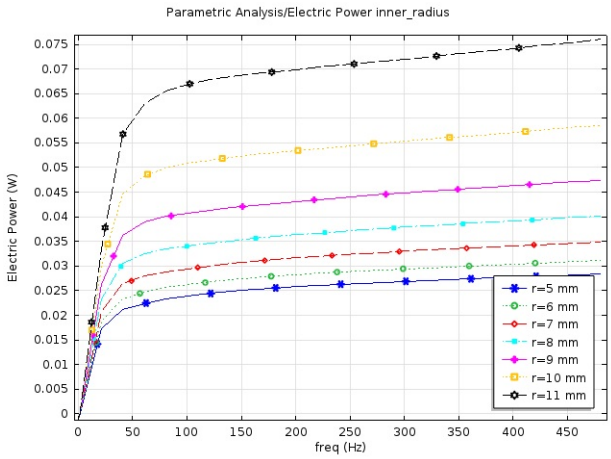

Figure 3: Figure 3: parametric analysis, hollow cylinder