1er Congrès Annuel
Marseille 7-9 Juin 2023

Development of Active Composite Materials Towards Optimal Design of Energy Efficient Mechatronic Systems and Structures

Rogers K. Langat[1,2], Emmanuel De Luycker[1], Arthur Cantarel[2], Micky Rakotondrabe[1]

[1] Laboratoire Genie De Production (LGP), National School of Engineering in Tarbes (ENIT), University of Toulouse, Tarbes, France

[2] Institut Clément Ader (ICA), Université de Toulouse, CNRS, IMT Mines Albi, INSA, ISAE-SUPAERO, UPS, Tarbes, France

Keywords : *Active Composites, Energy Harvesting, Piezoelectricity, Structural Health Monitoring, Smart Systems, Mechatronics Technology.*

1 Introduction

To gain a competitive advantage in the twenty-first century, the development of materials and structures with increasing levels of functionality and energy efficiency will be critical. This will be realized through continued efforts in engineering material advancements, which have influenced the emergence of smart systems such as mechatronic systems [1]. This has been greatly impacted by the development of "smart materials," which are defined as materials that can receive, transmit, or process stimuli in a manner that yields a beneficial effect. A suitable example of this is a piezoelectric material, a transducing element capable of generating an internal electric field when subjected to mechanical stress or strain, and conversely of producing mechanical deformation when an electric field is applied. These materials primarily find use in energy harvesting, sensing, and actuation. When these capabilities are combined with signal processing and control mechanisms, they form mechatronic systems. Moreover, recent advancements have made it possible for sensors, actuators, processing, and control mechanisms to be integrated at different points inside mechatronic systems or to be co-fabricated [1].

Currently, various industrial sectors, such as aerospace, are striving for a greener future to achieve high performance with optimal energy efficiency. As a result, promising solutions such as lightweight fiber-reinforced composite materials for aerospace structures have been adopted. Their application has resulted in reduced fuel consumption and environmental impact. Furthermore, the critical need for smart systems deployment in the aeronautical sector necessitates the development of active composite structures. Indeed, the development of these smart structures is made possible by the high-quality features of active piezoelectric materials and their ease of integration/co-fabrication with fiber-reinforced composite structures. Additionally, the technologies and processes for producing these active materials with integrated functionalities continue to gain interest from researchers and industrial players. Thanks to their potential application in sensing, energy harvesting, and dampening destructive vibrations. There is no doubt that the widespread use of composite materials for aircraft parts, including engine fan blades, fuselages, wings, and other critical underlying components, requires continuous monitoring of their mechanical integrity during operation since these components are vulnerable to failure due to overloads and fabrication flaws that occur throughout the manufacturing process in order to prevent their progression [2]. Therefore, a significant paradigm shift in the aircraft sector will result from the "structural health monitoring" (SHM) strategy referring to a new technology that utilizes embedded sensors inside the structure to continuously and autonomously monitor the physical status of a structure with as little manual intervention.

This strategy is realized based on the smart material mechatronic systems employing sensor technology with an integrated intelligent algorithm to assist in the collection and analysis of data on the health status of structures, thereby improving life-cycle management. Furthermore, embedded sensors allow for the monitoring of some critical and inaccessible structural parts, as well as the identification and monitoring of barely visible impact damages (BVID) in composite structures. Indeed, the SHM strategy is desirable in the aeronautics industry because vital information about the health of plane structures can be established before the development of critical damages leading to the avoidance of accidents [3]. Nonetheless, commercial full-scale SHM systems are still being investigated, with the researchers' main concern being the limited battery lifespan required to power these sensors, which impedes achieving monitoring autonomy. Additionally, since these sensors are primarily intended for use inside structures, replacing their batteries could be difficult. The energy harvesting (EH) approach, which refers to the process of capturing ambient energy and converting it into electric energy, allows these SHM systems to be supplied with electric energy, thus extending the life of their associated batteries.

In the context of aeronautics, EH can be realized using active composites with embedded strain piezoelectric harvesters that take advantage of the strain of a vibrating aeronautical component. Moro et al.[4] for example, in their investigation of vibration energy harvesting for use in aircraft, placed the piezoelectric patches on the wing slats of a plane, noting that the most exploitable vibrations come from turbulence and random engine vibrations. This is because they last the entire flight, both when the slat is deployed and when it is retracted. However, it is challenging to determine where the optimal patch position should be on the wing because aircraft parts can have several complex modes of vibration that can all be triggered simultaneously by broad-band excitation. Nonetheless, the energy obtained from this dynamic strain has one most important use in aeronautics, which is to power the structural health monitoring systems[3]. In our current work, we seek to design and fabricate active aeronautic composite structures to investigate the feasibility of harvesting energy from vibrations. We also aim to optimize the position and layout of the embedded active material to harvest maximum vibration energy to supply sensor nodes for continuous health monitoring of aerospace structures. It is anticipated that these factors will have a positive effect on the development of energy-efficient mechatronic systems.

2 Materials and Methods

The materials considered in this study are; FlaxPreg T-UD 110, a pre-impregnated material made of an epoxy resin and reinforced with unidirectional flax fibers developed by LINEO, Mu-copper tape with conductive adhesive, and FV30-MZ-000145 Polyvinylidene fluoride (PVDF) a polymer-based piezoelectric material developed by Kynar, Goodfellow. Following a vacuum-assisted consolidation molding process, active composite beams measuring 50mm by 250mm and composed of six layers of pre-impregnated flax fibers with an embedded patch of PVDF film were fabricated. Two samples were clamped together and subjected to vibration tests

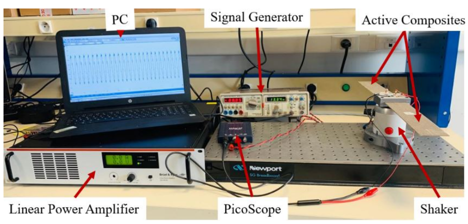
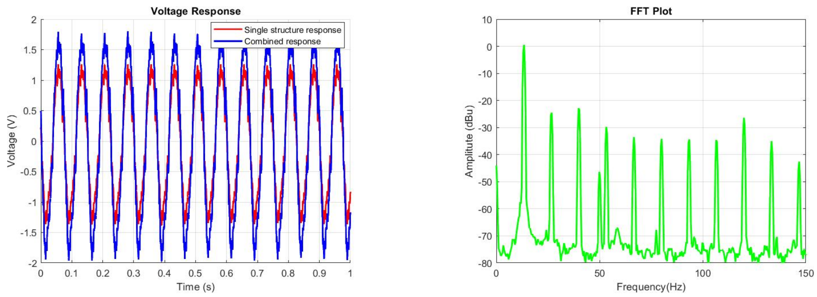


FIG. 1: Proposed vibrations test setup

using an LDS V201 shaker (see Figure 1). In one of the beams the piezo is located between the fifth and sixth ply and the other has the patch between the fourth and fifth layers.

3 Results and Discussions

Figure (2) depicts the results of the dynamic vibration test performed on the structures. Figure (2a) presents the response of the clamped beams with the peak-to-peak voltage at the resonance frequency for a single beam with embedded piezo at the 5th layer being 2.637V and a current of 2.415 μA was recorded across a 214kΩ load resistor. It was demonstrated that the accumulation of energy from stressed neighboring components is significant as the combination of the two beams resulted in 3.973VP-P. Finally, we plotted the response's FFT spectrum (see Figure 2b). The extracted natural frequencies of the structures reveal a promising potential to harvest energy from ambient vibrations.



(a) Voltage response signal

(b) Fast Fourier Transform analysis of the signal

FIG. 2: The vibration tests results at an excitation frequency of 13.33Hz.

4 Conclusions and Perspectives

To realize energy-efficient mechatronic systems and structures in the aerospace sector, preliminary results show that combining active and traditional fiber-reinforced materials results in functionalized structures with a significant potential to harvest energy from ambient vibrations. This also improves remote sensing and, as a result, enhances autonomous structural health monitoring. Additional research is being conducted to develop an analytical and numerical model to validate the experimental work. Furthermore, this work aims to show the optimal size and position of the active embed in terms of maximum energy recuperation at ambient frequencies. Verification of the energy generated to power health monitoring sensor nodes will be examined and reported at a later stage.

References

[1] Rrahim Maksuti. Applications of smart materials in mechatronics technology. *JAS-SUT Journal of Applied Sciences-SUT*, 5(9-10):9–13, 2019.

[2] K Dragan, M Dziendzikowski, A Kurnyta, A Leski, and J Bienias. Structural health monitoring of composite structures with use of embedded pzt piezoelectric sensors. In *Proceedings of the ECCM-16th European Conference on Composite Materials, Seville, Spain*, pages 22–26, 2014.

[3] Matthew Pearson, M. Eaton, Rhys Pullin, Carol Featherston, and Karen Holford. Energy harvesting for aerospace structural health monitoring systems. *Journal of Physics: Conference Series*, 382, 08 2012.

[4] Domenico Tommasino, Federico Moro, Bruno Bernay, Thibault De Lumley Woodyear, Enrique de Pablo Corona, and Alberto Doria. Vibration energy harvesting by means of piezoelectric patches: Application to aircrafts. *Sensors*, 22(1), 2022.