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Energy Harvesting from Vibration on Aircraft Structures using Piezoelectric Materials

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***Abstract*—Energy Harvesting is the process of harnessing electricity from unconventional sources such as sunlight, wind, tides and natural elements from the surroundings such as vibrations, which are perennially available, thus a continuous supply of energy with nil adverse impact on the environment. An aircraft structure is subjected to vibrations due to the engine, flexing of various surfaces under aerodynamic loads, gusts, turbulence and manoeuvers in air. These vibrations are present throughout the aircraft mission from the point of start-up right up to cut off. It has been found feasible to utilize such vibrations and convert it to electrical energy. Ongoing research on piezoelectric materials and their output as well as their application on aircraft has shown the feasibility of such concepts. With the advent of modern piezoelectric materials, it is possible that energy from vibrations can have a major contribution on power and weight savings on an aircraft. Piezoelectric energy harvesting is the process of converting energy from mechanical vibrations/distortion of dimensions to electrical energy. This concept can be applied to aircraft structures to power On-board payload and systems thus relieving certain amount of load from the primary sources of power, i.e. the power plant or battery. This would result in increments in efficiency and performance. The present work demonstrates the aspects of a Remote Controlled (RC) aircraft design and fabrication and development of a Piezoelectric Energy Harvesting system that is integrated on to the aircraft to power LED lights. In addition, the novel concept of energy harvesting with the help of piezoelectric materials has been introduced and practically demonstrated.**

***Index Terms*— Vibrations, Energy Harvesting, Piezoelectric Material, Aircraft Structure, Energy Harvesting.**

I. Introduction

With the advancements in aviation technologies all over the world at a fast pace and a wide range of equipment being procured, modern techniques such as energy harvesting, could prove to be beneficial in the long run. Energy Harvesting is the process of harnessing power from unconventional sources such as sunlight, wind, tides and elements of the surroundings such as vibrations, which are perennially available, thus a continuous supply of energy with nil adverse impact on the environment. The Piezoelectric Energy Harvesting (PEH) technology has been researched for many years. Shashank Priya et al. invented a pocket piezoelectric windmill which was attached to a rotating cam. The prototype piezoelectric windmill consisting of ten piezoelectric bimorph transducers was operated in the wind speed of 1-12 mph. A power of 7.5 mW with the wind speed of 10 mph was

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measured across a matching load of 6.7 kΩ [1]. Yoshiyasu et al. developed a piezoelectric carpet, which was tested at the entrance of the subway and at shopping malls. The results showed that the 252 Nos. of these developed carpet produced 1400 kW of electricity per day [2]. Alexander et al. (2010) developed a system to collect vibration energy generated by pedestrians walking on the roads [3]. Innowattech (2010) developed a pavement energy harvesting systems: Innowattech Piezo Electric Generator (IPEG) is based on a piezoelectric transducer. When traffic volume of vehicles is more than 500 in the single lane per hour, up to 250 kW of electrical energy can be collected per kilometer per lane [4]. Guan et al. (2010) studied the cement-based piezoelectric materials for road power generation, where the cement-based piezoelectric composites are manufactured by preembedding piezoelectric ceramics [5]. Xiang et al. (2013) designed the piezoelectric materials using the finite element analysis, they demonstrated that the pavement deformation by vehicle processing and the vibration caused by moving vehicles on the road can be used for the collection of electric energy. [6]. Yuan et al. (2014) studied the use of piezoelectric transducers in the collection of track vibration energy for railway safety driving and found that the piezoelectric energy harvester could generate 30 mW power [7]. Zhang et al. (2014) studied the performance of a concrete-piezoelectric cantilever beam transducer in a single vehicle using ANSYS simulation. Results show that the natural frequencies of the two kinds of piezoelectric cantilever beam are 9.77 Hz and 10.02 Hz, respectively. Laboratory experiments of the two piezoelectric cantilever beam show that with the natural frequencies are 8.79 Hz and 8.83 Hz respectively, obtaining the peak voltage of 42.6 V and 57.0 V, and the average power of 1.04 mW and 1.97 mW [8]. Joo et al. (2015) proposed ways of generating power from piezoelectric modules by hitting and vibrating. By hitting, such material will undergo a load directly on piezoelectric modules. On the other hand, in the vibration method, where loads are merely superficial, the latter has a wider application because of its increased durability [9]. Diaz et al. (2017) carried out a study on power generation from ocean wave using piezoelectric devices which can obtain a great amount of electricity. He proposed to install piezoelectric devices on buoys or floats offshore and can be used as sensors for navigation [10].

Piezoelectric Energy Harvesting (PEH) on Aircraft and Unmanned Aerial Vehicle (UAV). A piezoelectric device can convert small vibrations or strain differences into electrical energy. The electrical energy produced can be converted by an energy harvesting circuit and modified into a usable form to power downstream circuits. These downstream electronics usually consist of some kind of sensor, an analog-to-digital converter and an ultralow power microcontroller. These components can take the harvested energy, in the form of an electric current, and wake up a sensor to take a reading or a measurement and then make this data available for transmission via an ultralow power wireless transceiver. Steven et al. performed a research for proof of concept on piezoelectric energy harvesting in UAV applications through flight testing of an RC aircraft, and also to compare the performance of piezoelectric harvesting to photovoltaic harvesting in UAVs. Based on the two flight tests that have been performed, it can be concluded that both the piezoelectric and solar energy harvesting devices have the capability of charging energy storage devices. Preliminary tests show that during a 13- minute flight, the solar panels could charge a 170 mAh battery to 14% capacity and the piezoelectric patches could charge the EH300 4.6 mJ internal capacitor to 70% capacity. These results show promise for the ability to use energy harvesting in UAV applications to supply energy to low-power subsystems. [11]. Researchers from Cedrat Technologies in France discussed about an energy harvesting system based on an electromechanical device mounted in proof mass configuration able to produce electrical power from vibration injected to its base. The efficiency of the device with an AC-DC converter reached up to 48% with only 45µm vibration. This result showed the possibility of harnessing high energy in the form of electrical output. [12]. In the report "Energy Harvesting Technologies for Structural Health Monitoring of Airplane Components—A Review" it was shown that due to abundance of dynamical excitations on airplanes, kinetic EH devices, usually based on piezoelectric or electromagnetic transduction, are a very attractive and broadly investigated solution provided that the devices are mounted in the vicinity (enclosure or mounting fixture) of the airplane engine, i.e., in locations with stable and predictable dynamical excitation conditions [13]. Magnetostrictive and electrostatic devices have, in turn, their inherent limitations and their technology readiness is not yet at the level required by the aeronautical industry. [14]. Based on previous research around the world, it was found out that to maximize output power; energy harvesters should be excited in resonance with external vibration sources. In the other words, the natural frequency of the energy harvester should be matched to those of external vibration sources. The typical linear energy harvester has only one dominant natural frequency which should be carefully selected in accordance with the external vibration frequency. However, when the excitation frequency is unknown or varies with time, the energy harvester with fixed natural frequency cannot achieve an optimal output power. Therefore, in practice, the resonance frequency tuning scheme is essential to increase its power output [15-18].

An aircraft structure is subjected to vibrations due to the engine, flexing of various surfaces, gusts, turbulence and manoeuvers in air and on the ground. These vibrations are present throughout the aircraft mission from the point of start-up right up to cut off. It has been found possible to utilize such vibrations and convert it to electrical energy. Ongoing research on piezoelectric materials and their output as well as their application on aircraft has shown the feasibility of such a concept. the advent of modern piezoelectric materials, it is possible that energy from vibrations can have a major contribution on power and weight savings on an aircraft **[19-21]**. Piezoelectric energy harvesting is the process of converting energy from vibrations to electrical energy. This concept can be applied to aircraft structures to power on board payload and systems thus relieving certain amount of load from the primary sources of power, i.e. the power plant or battery. This would result in increments in efficiency and performance. The present work encompasses the aspects of RC aircraft design and fabrication and development of a Piezoelectric Energy Harvesting system that is integrated on to the aircraft to power LED lights thus demonstrating the proof of concept. During the course of the project, the trainees were exposed to practical and hands on experience of designing and building RC aircraft thus reinforcing their classroom knowledge in aerodynamics and aircraft structures. In addition, the novel concept of energy harvesting with the help of piezoelectric materials has been introduced and practically demonstrated.

Advancement in Piezoelectric The available results adequately demonstrated that piezoelectric energy harnessing has potential to provide power to various devices and supplement the primary source of power in aviation industry. It has gained popularity during the early part of 21stcentury due to its clean and low weight characteristics.

II. Methodology

A. Experimental Set Up

The experimental work was carried out on an RC Model aircraft onto which the piezoelectric circuit could be incorporated and successfully demonstrated. The previous results showed that piezoelectric energy harnessing has potential to provide power to various devices and supplement the primary source of power in aviation industry. The experiment was divided into the following domains:

Structure

The structure was built using Commercially Off the Shelf (COTS) materials such as foam boards, balsa wood, aluminium frame, plastic wheels, etc. while keeping in mind the requirements of maintaining a low weight for the model as far as possible.

Control

The aircraft is controlled using a 6-channel hobby transmitter and receiver, which can provide a maximum range of 02 km. The control surfaces were interfaced with the signals received at the receiver via servomotors.

Energy Harvesting Circuit

The electrical output was generated from the piezoelectric devices is convert this into usable using a full wave rectifier circuit and the energy thus generated is stored in the capacitor.

Propulsion System

A motor had to be selected to propel the aircraft model keeping in mind its weight and speed requirements so that enough airflow takes place over the wings to generate lift. A 10 x 4.5 propeller was chosen and a battery with 2200 mAh would give sufficient power and endurance while maintaining the weight within tolerable limit.

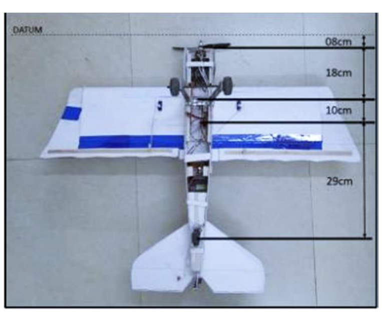


Figure 1: Structure of RC aircraft

B. Description of the Process and Data Collection

The work, as depicted in Figure 2, was undertaken sequentially dividing the work into two parts – Selection and Positioning of appropriate type of piezoelectric material. Ceramic discs piezoelectric to mount near the landing gear and cantilever type piezo to mount under the wing were selected. Accessibility Features. Since the project requires constant alteration in the circuit, the base of the fuselage was cut into four sections which made it possible to access the inner circuitry for frequent troubleshooting. This feature proved to be helpful.

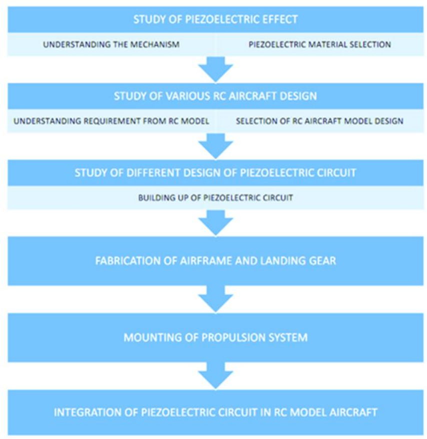
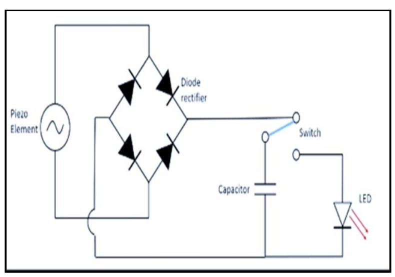


Figure 2: Description of Process

C. Piezoelectric Circuit Design

The list of electronic components and circuit design has been described. For ease of demonstration, a switch was incorporated onto the aircraft platform that could be utilized to show the output of the energy harvesting circuit as depicted in Figure 3 and Figure 4.



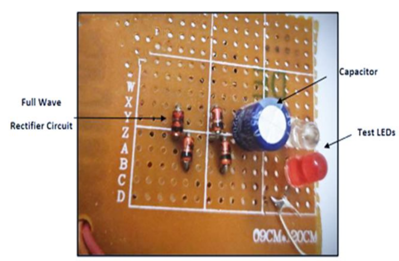


Figure 3: Circuit Design

Figure 4: Assembly

III. APPLICATIONS

A. Aircraft Structural Health Monitoring

Structural Health monitoring is the process of damage detection in a structure. Real time structural health monitoring for unmanned aerial vehicles becomes crucial which enables the user to assess the condition of the structure while it is in flight. This is done via on board units that sense a change in the structure, convert this into digital data, process this data and transmit it to the user.

Vibrations offer a continuous source of energy during flight. A piezoelectric device can convert the mechanical energy from vibrations to electrical energy that can be stored and used as per system requirements. The power densities achieved by this method is the highest after solar cells.

C. Wireless Sensor Nodes

A Wireless Sensor Node (WSN) to be used for the SHM system consists of the following units:

a) Piezoelectric Energy Harvesting Unit
b) Energy Storage Unit

c) Sensing Unit
d) Processor and Memory Unit
e) Transmitter/Receiver

The power from the piezoelectric device is used to power the sensing unit as well as the processing/memory and communication unit. Stored data is wirelessly transmitted to the central control unit on board the aircraft. The main advantages offered by this approach are:

a) Unlimited lifetime
b) Modularity. Sensors can be interchanged, replaced and used on multiple platforms.
c) Less weight. The total weight would be less than a wired system.
d) Cost. Advances in System on Chip technology and MEMS as well as Moore's law indicate a drop in cost in the future.

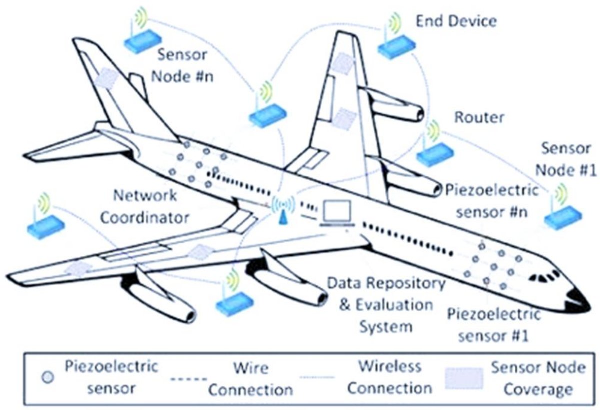


Figure 5: Aircraft Piezo-Electric System

TABLE I: DIFFERENT METHODS

S No.	METHOD	POWER DENSITY	TRL
1	SOLAR	$1.5\mu J/m^3$	8
2	PEIZO	$29.2\mu W/mm^3$	4
3	ELECTRO MAGNETIC	$0.162\mu W/cm^3$	2
4	THERMAL	$27 \mu W/cm^2$	2
5	MAGNETIC	$0.27 \mu W/cm^3$	2

The area of concern is mainly the Low Technological Readiness Level (TRL) due to the fact that this is a relatively new area of research and hence the technology may take time to mature and become commercial.

IV. CONCLUSION

Since vibrations are perpetual source of energy as long as there is motion in an aircraft, the project demonstrates such potential, which can be clean as well as cost effective at the same time, being light in weight. The concept of piezoelectric energy harvesting offers an attractive method to power low powered onboard systems. This would be the first step in the direction of integrating such systems on actual aircraft under development in present day.

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REFERENCES

[1] S. Priya Modeling of electric energy harvesting using piezoelectric windmill Appl. Phys. Lett. 8718 2005, 184101-184101-3.

[2] Yoshiyasu Takefuji, Known and unknown phenomena of nonlinear behaviors in the power harvesting mat and the transverse wave speaker, in: Proceedings of Inter-national Symposium on Nonlinear Theory and Its Applications. Budapest, Republic of Hungary, 2008.

[3] D. Alexander, M. Perille, Energy harvesting from a piezoelectric sidewalk [EB/OL], 2010, 2008.

[4] INNOWATTECH, Innowattech's solution-The innowat-tech piezoelectric generator (IPEGTM) [EB/OL], 2010.

[5] Xinchun Guan, Yanchang Liu, Hui Li, Jinping Ou Study on Preparation and properties of 1–3 cement based piezoelectric composites J. Disaster Prevent. Mitigat. Eng., 30 (S1) (2010), pp. 345-347.

[6] H. J. Xiang, J. J. Wang, Z. F. Shi, and Z. W. Zhang, “Corrigendum: Theoretical analysis of piezoelectric energy harvesting from traffic induced deformation of pavements (2013),” vol. 095024.

[7] Yuan Tianchen, Yang Jian, Song Ruigang, Liu Xiaowei Vibration energy harvesting system for railroad safety based on running vehicles Smart Mater. Struct. 23 (12) (2014).

[8] H.J. Xiang, J.J. Wang, Z.F. Shi, Z.W. Zhang Theoretical analysis of piezoelectric energy harvesting from traffic induced deformation of pavements Smart Mater. Struct., 22 (9) (2013) 95024–95032(9).

[9] S. Joo et al., “Designing and manufacturing a piezoelectric tile for harvesting energy from footsteps,” Curr. Appl. Phys., vol. 15, no. 6, pp. 669–674, 2015.

[10] M. González Díaz, “Facultad Ciencias Obtención de energía de las olas empleando materiales piezoeléctricos (Ocean wave power generation using piezoelectric devices),” 2017.

[11] Steven R. Anton “Energy Harvesting for Unmanned Aerial Vehicles”, Center for Intelligent Material Systems and Structures, Virginia Polytechnic Institute and State University, Blacksburg, VA 24060.

[12] “Compact and Low-Frequency Vibration Energy Scavenger using the longitudinal excitation of a piezoelectric bar”, Journal of Physics Conference Series 476(1):2135, DOI:10.1088/1742-6596/476/1/012135, December 2013.

[13] Energy Harvesting Technologies for Structural Health Monitoring of Airplane Components—A Review, DOI:10.3390/s20226685, November 2020.

[14] Haocheng Xiong, Linbing Wang, Dong Wang, Druta Cristian Piezoelectric energy harvesting from traffic induced deformation of pavements Int. J. Pavement Res. Technol., 5 (5) (2012), p. 333-338.

[15] “Israel: A road that generates electricity!!” [Online].Available: https://www.natura- medioambiental.com/israel-una-carretera-que-genera-electricidad/. [Accessed: 04-April- 2019].

[16] Zhao Hong-duo, Liang Ying-hui, Ling Jian-ming. Study on harvesting energy from pavement based on piezoelectric effects. J. Shanghai Jiaotong Univ, 45 (S) (2011), p. 62-69.

[17] M. Akbar, A. Riyad Firdaus, S. Wibowo and N. Wirawan, "Piezoelectric Energy Harvesting from A Fixed-wing Unmanned Aerial Vehicle," 2019 2nd International Conference on Applied Engineering (ICAE), Batam, Indonesia, 2019, pp. 1-4, doi: 10.1109/ICAE47758.2019.9221651.

[18] S Boisseau et al., Synchronous Electric Charge Extraction for Multiple Piezoelectric Energy Harvesters, Proc. NEWCAS, 2015.

[19] Pearson Luhanga, Albert Chawanda , Piezoelectric Energy Harvesting Using Synchronized Switching Techniques, International Journal of Engineering and Technology Volume 2 No. 6, June, 2012.

[20] Umais Tayyab, Hussain A. Alzaher, "A Self-Biased Active Voltage Doubler for Energy Harvesting Systems", Active and Passive Electronic Components, vol. 2017.

[21] Zohreh Alaei, Power Enhancement in Piezoelectric Energy Harvesting, Degree Project In Electronics And Computer Engineering, Stockholm, Sweden 2016.