International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-12 Issue-1, October 2022

Power Harvesting using Piezoelectric Materials from Aircraft Body

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Abstract: ***Using Piezoelectric Materials, Power Harvesting from Aircraft Body Power harvesting has been a key problem for many years, especially when taking into consideration cost and reducing system disturbances. The main objective of this research is to investigate the possibility of developing such a system using piezoelectric components. One notable characteristic of this material is its capacity to generate electricity from applied pressure. Power harvesting has long been a significant issue, particularly when costs and reducing system disruptions are taken into account. The primary goal of this study is to determine whether such a system may be created utilizing piezoelectric components. One noteworthy quality of this material is its ability to produce electricity when pressure is applied.***

Keywords: Aircraft, Piezoelectric, Vibration, Electrical Energy

I. INTRODUCTION

Major mechanical energy sources including oil, gas, water, and air are getting harder to get or less reliable every day. We need to find unique yet workable answers to this problem. An efficient and accessible alternative to traditional power generation is the use of piezoelectric materials. The goal of this study is to put up a design idea for a system that would employ piezoelectric materials to produce electricity from an airplane's body. The process of absorbing ambient energy and turning it into usable electrical energy is known as power harvesting.

Over the past few years, research into power harvesting has grown significantly. In these studies, advanced piezoelectric materials are used to transform pressure changes or vibrations into usable electrical energy. Despite the extremely little quantity of energy created, this issue may be effectively solved by utilizing all of the aircraft's surfaces. The main hurdles are incorporating a robust insulating system and ensuring flight stability. If these issues are resolved, this concept might lead to a revolution in the aviation power system or at the very least serve as a backup power source.

Manuscript received on 05 September 2022 | Revised Manuscript received on 10 September 2022 | Manuscript Accepted on 15 October 2022 | Manuscript published on 30 October 2022.

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II. LITERATURE REVIEW

Due to the growing number of uses for piezoelectric materials in industries like transportation, aerospace, and other fields, there is now a lot of research being done on them. Piezoelectric power harvesting has been the subject of several studies because of its adaptability and simplicity [5]. In transport vehicles, mechanical vibration is an inevitable occurrence.

In passenger aircraft, mechanical vibration results in considerable energy loss. Prior studies have been conducted on power harvesting using this phenomena and piezoelectric materials [8]; [6] One of these investigations suggested two potential locations for piezoelectric material to be placed on the airplane in order to collect more vibration. First, an engine cowl above the compressor stages, where the aircraft vibrates the most, can have a strip of piezoelectric material sandwiched between them. To generate power, a piezoelectric strip can be attached to the engine cowl, or it can be installed in the pressure bulk head, where it will be subjected to high operational stress and produce desired voltages. An example of such a configuration is an L-shaped energy harvester arrangement that was suggested for use as unmanned aerial vehicle landing gears.

It uses the amount of vibration it captures to refuel the apparatus [3];[1]. Structural Health Monitoring (SHM), where structural health monitoring is carried out by examining an aircraft's structure, is one common application for such materials in airplanes. One of the major factors behind numerous accidents in the aviation industry is metal fatigue and corrosion of aircraft structures. To address this issue, a technique called SHM has been developed as a cutting-edge and successful approach to figuratively monitor any flaws in an aircraft construction.

Amplified Piezoelectric Actuators (APA), which are intended to get beyond the drawbacks of conventional mechanical actuators, have been suggested for use in a research. These studies suggest that polarization loss, temperature effects, and brittleness are potential limits. The distinctive elliptical form of a single APA cell makes it possible for it to generate more power through vibration. Multiple cell APAs, which can have four cells or more, are also employed.

Additionally, it guarantees that APA can tolerate high frequency vibration, which is quite common in structural aviation components [7]. This is because employing a new energy-efficient material may be used to harness the inevitable pressure and vibration generated in the aircraft construction.

III. METHODOLOGY

A. Piezoelectric Material

When mechanical stress is applied, piezoelectric material has the ability to accumulate charges on the surface (the substance is squeezed or stretched). On the other hand, an electrical intervention results in mechanical deformation (fig-1).

Ferroelectrics are a class of materials that includes piezoelectric materials. One of the characteristics that distinguishes ferroelectric materials is the orientation of the molecular structure, which causes the material to show a local charge separation known as an electric dipole. Electric dipoles realign themselves in relation to the electric field when a material is heated over the Curie temperature and a very strong electric field is applied. The dipoles maintain their orientation after cooling, at which point they are referred to as being poled. The material will display the piezoelectric effect following the poling procedure (fig-2).

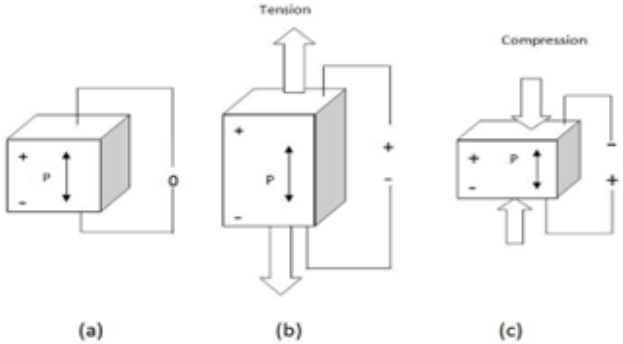

Fig. 1. Piezoelectric Phenomenon-Based Electromechanical Conversion

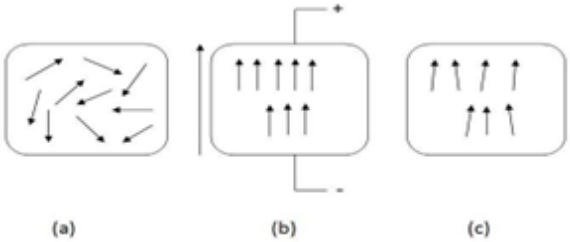

Fig. 2. Piezoelectric material before, during, and afterpoling with electric dipoles

B. Piezoelectric Material Types

A list of the several types of piezoelectric materials is provided below [2].

Table1: Piezoelectric Material Types

Serial No	Type	Materials
1.	Individual	Quartz Lead Magnesium Niobate crystals
2.	Ceramics	Lead Meta niobate (LMN), Lead Titanate, and Lead Zirconate Titanate (PZT) (LT)
3.	Polymers	Polyvinylidene Difluoride (PVDF)
4.	Composite	Glass Ceramic Polymer Composite

Lead Zirconate Titanate (PZT) seems to be the material that can be applied most easily for power generation in different parts of an aircraft's body. It was chosen because it can harness the pressure and vibration that the aircraft's surfaces experience to extract energy. Small strips are highly helpful for producing power efficiently.

A unit piezo-power generating cell is made by fusing several arrays. These charges are gathered, processed, and then dispersed or kept. These components will be under stress when the airplane is in the air, which will result in electric voltage across their ends. The lower side of the airplane is then covered with such unit cells.

IV. AREAS OF POTENTIAL APPLICATION

Any surface of the aircraft can experience vibration, but in order to get a greater output voltage, a PZT cell must be installed in the location with the strongest vibration. The regions are depicted in figure 3. Efficiency is the main factor in determining if a gadget will be helpful. Since the lower surfaces of the wings and fuselage have higher air pressure (around 230000 Pa) than the top surfaces, more electrical activity is needed to create an electric current there. When a cell is positioned in such a location, it is subjected to extreme stress, making the production of excessive voltage absolutely required [2]. A PZT cell can be placed between the metal skin and honeycomb of the lower surfaces of the wings and fuselage to provide additional output (fig-4). Due to the sophistication of these surfaces, insulation of these compact surfaces should be considered in order to prevent any kind of harm. From here, PZT may be directly linked to the bus bar, where the voltage can be used to recharge the batteries or for other purposes.

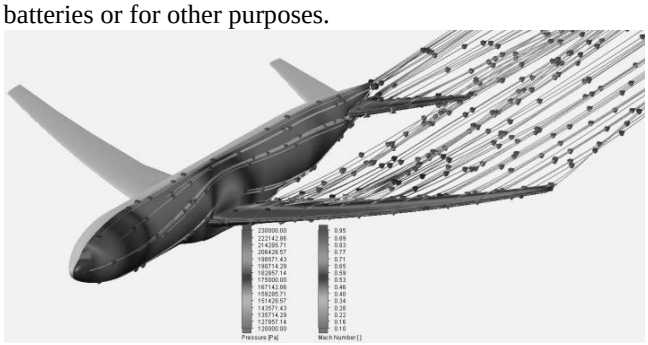

Fig. 3. Shows an air pressure simulation above an aircraft (dark areas represent areas where air pressure may be higher).

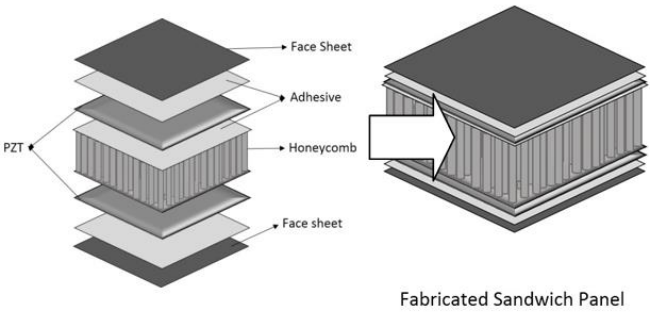

Fig. 4. Sandwich Structure

V. ANALYTICAL MATHEMATICS

Two linearized constitutive equations with two mechanical and two electrical variables can be used to simulate the behavior of a piezoelectric material. The following matrix equations can be used to simulate the direct effect and opposite impact [4].

Retrieval Number: 100.1/ijeat.A38171012122
DOI: 10.35940/ijeat.A3817.1012122
Journal Website: www.ijeat.org

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Piezoelectric action directly: D = [e]T {S} + [αS] {E} (1)

Piezoelectric effect in reverse: T = [c E] {S} - [e] {E} (2)

Here, "D" stands for "electric displacement," "T" for "stress," "e" for "dielectric permittivity,""cE" for "matrix of elastic coefficients at constant electric field strength," "S" for "strain vector," "S" for "dielectric matrix at constant mechanical strain," and "E" for "electric field" are all used.

By applying a force of one newton to various piezoelectric materials, we may produce different amounts of charge. For instance, the output for quartz, BaTiO3, PbTiO3, PZT, and PZN-9PT is 2.3, 90, 120, 560, and 2500 C/N, respectively. This shows that, when compared to the other materials, PZN-9PT provides the highest o/p on load application. However, PZT has already been selected for the suggested proposal because of its benefits in other fields. There are also further PZT variations. PZT (iii) BM 800 is the chosen type because to its mechanical Q factor and high Curie temperature. Despite having a rather low charge constant, it is adequate for recharging batteries during flight [2].

Table2: PZT Types and Their Properties [2]

SL No.	Materia Parameter	PZT (i) BM 400	PZT (ii) BM 500	PZT (iii) BM 800	PZT (vi) BM 532
1	Dielectric Constants	1350	1750	1000	3250
2	Voltage constant (g31 10-3Vm/N)	-10.5	-11.5	-10.5	-7.5
3	Charge constant (d31 10-12 C/N)	-115	-165	-80	-250
4	Curie Temperature (oC)	350	360	325	210
5	Mechanical Q factor	500	80	1000	70

VI. HOW TO GATHER AND USE ELECTRICITY

A unit piezo generating cell's output doesn't offer unipolar voltage or peaks that oscillate on a regular basis. In order to drive a useful voltage, certain care must be taken. Bridge rectifiers are used to provide unipolar output, which addresses the duality issue and creates unipolar flow (Fig-5).

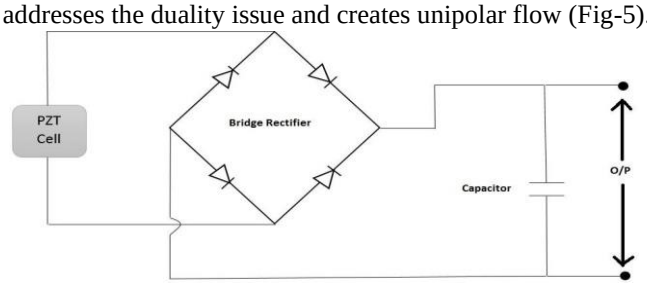

Fig. 5. Using a bridge rectifier, removing dual polarity and gaining unipolar flow

The output of the rectifier is linked in parallel with a capacitor with a high Farad value. This makes it easier to create the ideal regular and constant current flow. The values are equivalent since all the other unit cells are treated the same way.

Imaginary Piezo Power System:

Different power levels are produced by each piezo power production cell. Therefore, a system that adds up those various fluxes and generates a consistent and desirable amount of voltage and current must be designed. The suggested system is depicted in the figure-6 below; for further information, see the figure-6.

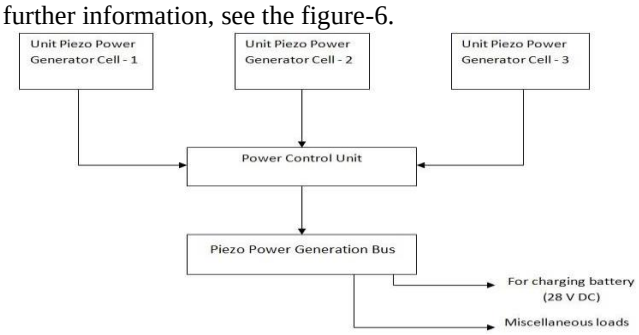

Fig. 6. Shows the electrical system for piezo power generation (I)

When using a DC supply, the majority of contemporary aircraft need either 14 V DC or 24 V DC for various loads. It is necessary to create a power control system that will maintain the required level of power. This power control device will combine the necessary power after processing the outputs of several cells. Where the regulated power will come from and from which the necessary power will be fed, a bus bar can be put. And to charge the battery, 28 V DC is needed. In figure 6, this bus bar is referred to as the "Piezo power generating bus." The DC Buses that may be found and utilized in contemporary aircraft are: Hot battery bus, Main battery bus, Left main and right main DC buses, Left secondary and right secondary DC buses, and finally Right secondary and hot battery bus Bus with a DC generator (if DC generator available) The generated power from the Piezo Power Generation Bus may be delivered to various loads and used to recharge batteries. Another suggestion is to directly feed the Main DC Bus power from the Main DC Bus and the output voltage of the Power Control Unit to the Main DC Bus (Fig. 7).

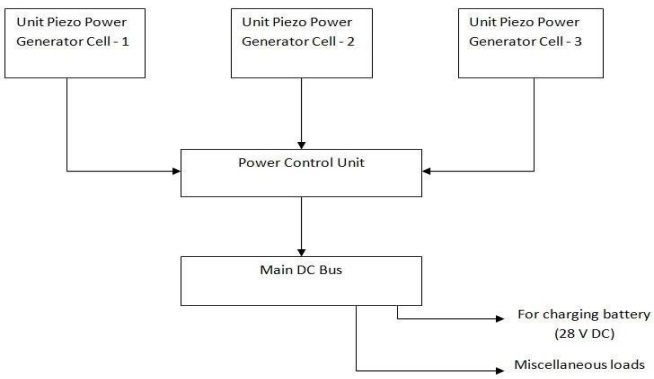

Fig. 7. The Electrical System of Piezo Power Generation (ii)

The Total system is depicted in the following-.

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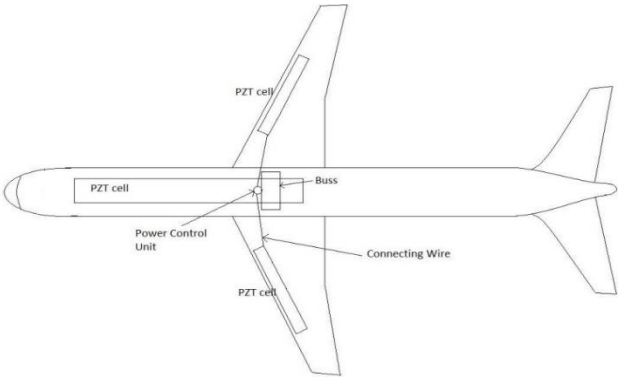

Fig. 8. The Piezo Power Generation System as a Whole with the Aid of an Aircraft's Bottom View.

Ideally, The Power Control Unit and Bus should be installed so that the minimal distances between each unit cell are achieved. As a result, less wire will be used, thus saving money. The most efficient technique that can be accomplished is to use affordable cables without sacrificing safety measures.

VII. FINDINGS

Utilizing piezoelectric materials effectively can offer solutions to several issues with power generation and storage, as well as act as an emergency backup source of electricity. However, employing piezoelectric material will be seen as beneficial when it is both affordable and effective. PZT (Lead Zirconate Titanate) is more effective in generating electricity than typical piezoelectric materials, according to a research. PZt is far superior than regular material for generating energy since it can create 560 c/N compared to normal material's 90–120 c/N. To increase its effectiveness, PZT strips are employed in place of a hard plate. The setting is also managed in a sophisticated way to get the greatest output. Using stiff PZT plate would prevent it from efficiently absorbing the dispersed pressure and vibration. To appropriately use the dispersed pressure and vibration in any region covered by these strips, a PZT cell is constructed using an array of PZT strips. These strips may be utilized effectively to distribute pressure and vibration throughout whatever region they cover. Since a larger area has been covered, more electricity is produced per square centimeter. The stability of the building is also carefully taken into account. The system is set up in a way that prevents it from affecting how the airframe and wings are aerodynamically shaped. Because of this, no danger has arisen when the air passes through the body. The weight of the entire system is insufficient to change the aircraft's CG (Centre of Gravity). Thus, the system has a very minor effect on an aero plane's stability and so has little bearing on whether it can take off and land vertically or horizontally.

VIII. CONCLUSION

With the development of contemporary aircraft technology, the need for electricity has been rising quickly. The extremely competitive aircraft industry has created new areas of rivalry in areas like IFE (In Flight Entertainment), comfort during flight, numerous business class amenities, etc., all of which need for additional power sources. Today's airplanes are less dependent on mechanical systems and more on electrical technologies. The need for electric power is rising as a result. Piezo may be a fantastic source for economically satisfying demand. To address several issues with insulation, polarization loss, handling, etc., more in-depth studies are required. Therefore, more research and in-depth investigations should be conducted to support the viability of employing this material for power generation.

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AUTHORS PROFILE

Kumara Yaleti Devendra Babu, was born on 03rd October 2001. He passed Matriculation and Higher Secondary in Andhra Pradesh. For his Bachelor's Degree he chosed Aerospace as his career path because of his interests in Air breathing propulsions systems and Flight Dynamics. During his early years of B. Tech, he developed his skills by learning some of the important design software like CATIA, SOLIDWORKS and simulation software called Ansys which is integrated into most of the Research laboratories and Well-developed industries. He has online Internship experience from some of the Prominent Aerospace companies like Ziegler and Bramhastra and an Offline internship experience from DRDO.

Magunta Vignesh, was born in 22nd July 2001. He passed Matriculation in Andhra Pradesh and Higher Secondary in Chennai. At a young age he is very fascinated by Aircrafts, drones, fighter jets etc. So, he chose Aerospace as his career path in his Bachelors. During his early years of Bachelors, he developed his skills by learning some of the important design software like CATIA, AUTOCAD, SOLIDWORKS andsimulation software like ANSYS and Fusion 360. Currently he is doing an Internship in Omspace (6months duration) and a Minor Project on Structures domain i.e., Generating Electricity from Aircraft vibrations using Piezoelectric sensors and actuators.

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Sripranesh V, was born on 08th April 2001. He passed matriculation and higher secondary in Tamil Nadu. At an young age he is interested in automation and aircraft design.so he chose aerospace department as his career path. He did an internship in IITM RESEARCH CENTRE and collected the certificate he is leaning his skills in the early days of his college life like software CATIA ANSYS AND a minor project in structures domain i.e Generating Electricity from Aircraft Vibration using piezoelectric material and he is there in saeindia ADC COMPETITION 2022.

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