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Power Harvesting from Aircraft Body using Piezoelectric Material

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Power harvesting to a satisfactory level at the same time considering cost and avoiding any disturbances in the system has been a big challenge throughout years. The main purpose of this paper is to focus on the possibility of developing that kind of system using piezoelectric materials. There is a prominent characteristic of this material that it can generate power from applied pressure. Here is ample chance to use this material on aircraft by developing a suitable system. Huge amount of pressure is generated on various parts (i.e. engines, wing surfaces, fuselage etc.) when the aircraft is on air. Using this pressure we can generate power which will steer to remove the extra burden of the power that need to be fed to the aircraft.

Keywords- Aircraft, Piezoelectric, Vibration, Electrical energy

Introduction

The common sources of electricity, such as oil, gas, water, air or any other mechanical sources of energy are getting scarcer or unavailable day by day. To face this problem we have to look for alternative but effective ways. A useful and available alternative option for producing electricity is piezoelectric materials. The objective of this paper is to develop an idea of a system through which electrical power will be generated from aircraft body using piezoelectric materials. The process of acquiring energy surrounding the system and converting it into usable electrical energy is termed as power harvesting. In the last few years, there has been a surge of research in the area of power harvesting. These researches include sophisticated use of piezoelectric materials in converting vibrations or change of pressure into useable electrical energy. Though the amount of energy produced is very low, using the maximum possible surfaces of the aircraft can give a practical solution to this problem. Incorporating a strong insulating system and taking care of the stability of flight are the big challenges. If these are taken care of, this idea can give a revolutionary thrust in the aircraft power system or at least can provide a backup source of power.

Literature Review

Piezoelectric materials are now the object of great interest in the field of research because of their newly increasing applications in transportation, aeronautics and others. Many researches have been carried out on power harvesting using piezoelectric materials due to its flexibility and simplicity (Kim et al, 2011).

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Mechanical vibration in transport vehicle is an unavoidable phenomenon. Research on power harvesting using this phenomenon through piezoelectric material has been done earlier (Zuo and Tang, 2013; Sodano et al, 2004). In case of passenger aircraft, a significant amount of energy is lost due to mechanical vibration. Some research also have been done in this field. One of these studies proposed two possible places to locate piezoelectric material on the aircraft to capture higher amount of vibration. Firstly, a strip of piezoelectric material can be sandwiched in between engine cowl above compressor stages in where the aircraft experiences maximum vibration. Besides placing the piezoelectric strip on the engine cowl, it can be alternatively placed in the pressure bulk head where it will experience large amount of operational strain to get desirable amount of output voltage (Arora et al, 2013). One research proposed L-shaped piezoelectric energy harvester configuration for using as landing gears in unmanned aerial vehicle. The amount of vibration it catches is used to recharge the system (Erturk et al, 2009).One popular proposed application of piezoelectric materials in aircraft is Structural Health Monitoring (SHM). Various researches have been carried out to show the effective methods and mechanisms of using piezoelectric materials for SHM in aircraft (Giurgiutiu et al, 2002; Armstrong, 2010). Metal fatigue and corrosion of aircraft structure is one of the crucial causes behind many accidental occurrences in aviation sector. To take care of this problem SHM is a process that is introduced as a modern and effective way to literally watch over any defects in the structure.The possible limitations according to these study are loss of polarization, temperature effects and brittleness.Another research proposed using devices called Amplified Piezoelectric Actuators (APA). APAs are basically designed to overcome the limitations of classical piezoelectric actuators. A single cell APA has a unique elliptical shape which allows it to produce more electricity from vibration. Multiple cell APAs are also used which can be of four cells or more. This study also ensures that APA is capable of withstanding high frequency vibration which is very natural in aircraft structural components (Sosnicki et al, 2006). Power generation from ambient sources has immense possibility to make aircrafts more economical. Due to the unavoidable pressure and vibration generation in the aircraft structure, applying piezoelectric materials has got immense opportunity.

Methodology

Piezoelectric Material

Piezoelectric material is capable of accumulating charges on the surface when mechanical stress is applied (the substance is squeezed or stretched). On the converse, a mechanical deformation is produced in term of electrical intervention (fig-1). Piezoelectric materials belong to a larger class of materials called ferroelectrics. One of the defining traits of ferroelectric material is that the molecular structure is oriented such that the material exhibits a local charge separation, known as electric dipole. Throughout the material composition the electric dipoles are oriented randomly, but when the material is heated above a certain point, the Curie temperature, and a very strong electric field is applied, the electric dipoles reorient themselves relative to the electric field; this process is termed poling. Once the material is cooled the dipoles maintain their orientation and the material is then said to be poled. After the poling process is completed the material will exhibit the piezoelectric effect (fig-2).

Figure1: Electromechanical Conversion via Piezoelectric Phenomenon

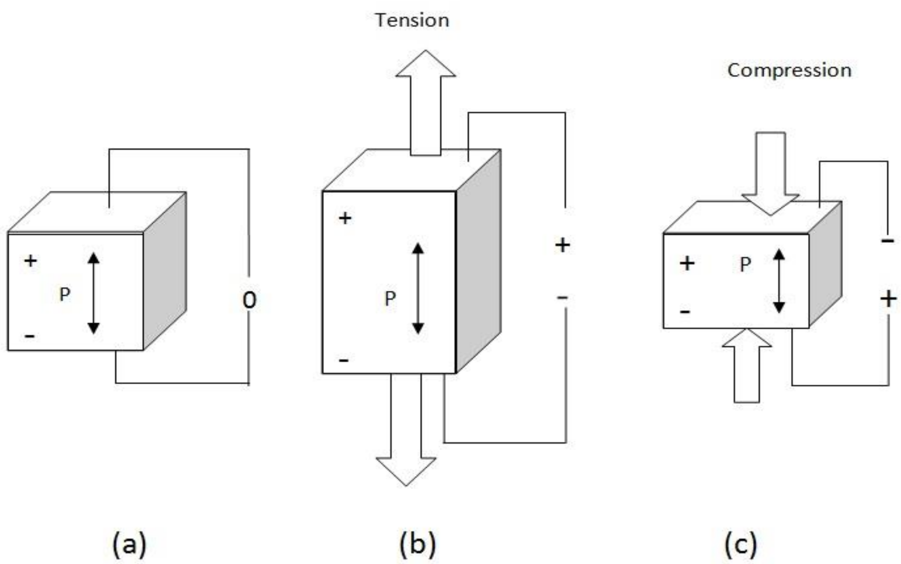
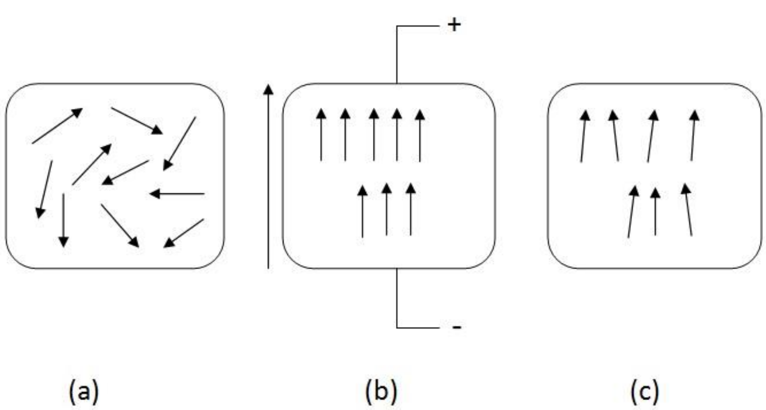


Figure 2: Electric Dipoles in Piezoelectric Material Before, During and After Poling



Types of Piezoelectric Material

There are various types of piezoelectric materials, a list of these materials(Arora et al, 2013)is given below–

Table1: Types of Piezoelectric Materials

Serial No.	Type	Materials
1.	Single Crystals	Quartz Lead Magnesium Niobate
2.	Ceramics	Lead Zirconate Titanate (PZT) Lead Metaniobate (LMN) Lead Titanate (LT)
3.	Polymers	Polyvinylenedifluoride (PVDF)
4.	Composite	Ceramic polymer Ceramic glass

After analyzing all the properties of available materials, Lead ZirconateTitanate (PZT) appears to be the most convenient for power generation applying in various positions of an aircraft's body. It has been chosen because of its capability to extract energy using the pressure and vibration exerted on the surfaces of the aircraft. For efficient power generation small strips are very useful. Combining small strips of PZT an array of PZT is formed. Combining many arrays a unit piezo-power generation cell is created. Those unit cells are then applied on the high stress locations like lower side of wings and fuselage of the aircraft. When the aircraft is on air, those units will experience stress which will cause electric voltage across its ends. Charges are then collected and after some processing it is distributed or stored.

Potential Areas of Application

Efficiency is the prime criterion for useful application of any device. Vibration can be obtained at any surface of the aircraft but for getting higher output voltage it is required to place PZT cell in the area where intense vibration is found. The areas are shown in figure-3. When the cell is placed such area it experiences excessive stress on it and it is very necessary to produce excessive amount of voltage(Arora et al, 2013). From one of the studies we observe that air pressure is higher on the lower surfaces of the wings and fuselage (around 230000 Pa)(Trebunskikh and Ivanov, 2013). To get extra amount of output, a PZT cell can be sandwiched in between the skin of metal and honeycomb of the lower surfaces of wings and fuselage (fig-4). As this surfaces are much sophisticated, insulation of this compact surfaces should be kept in mind and to avoid any type of danger PZT can be directly wired from this location to the bus bar where the voltage can be harnessed for recharging the batteries or for other uses.

Figure 3: Simulation of Air Pressure over the Aircraft (Dark Areas Represent the Potential Areas Where Air Pressure Is Higher)

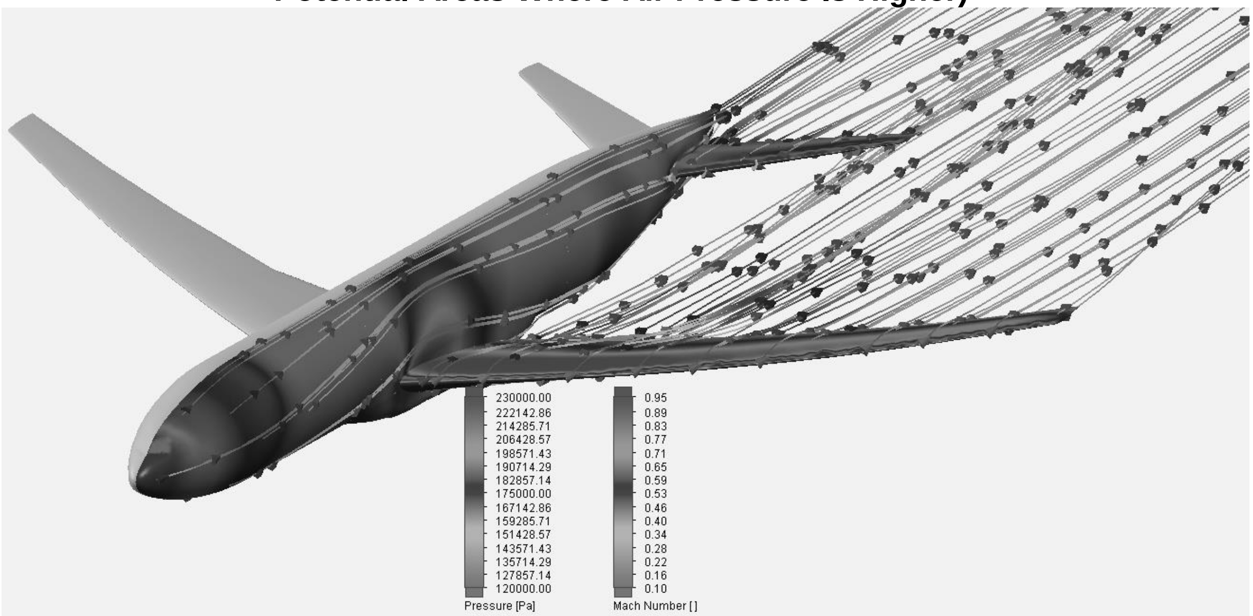
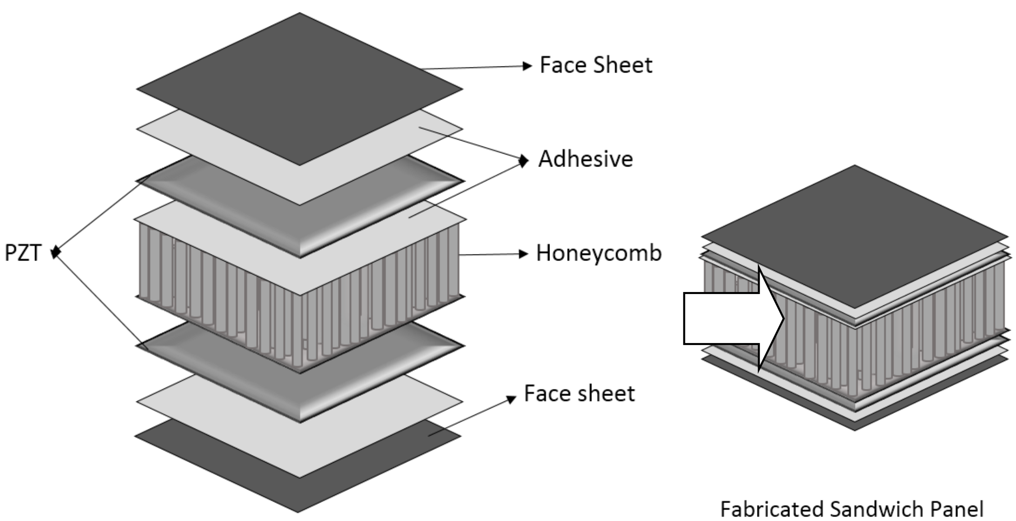


Figure 4: Sandwich Structure



Mathematical Analysis

The mechanical and electrical behavior of a piezoelectric material can be modeled by two linearized constitutive equations. These equations contain two mechanical and two electrical variables. The direct effect and converse effect may be modeled by the following matrix equations(Sodano et al, 2004),

Direct piezoelectric effect: $\{D\} = [e]^T \{S\} + [\alpha^S] \{E\}$ (1)

Converse piezoelectric effect: $\{T\} = [c^E]\{S\} - [e]\{E\}$ (2)

Here, {D} is the electric displacement vector, {T} is the stress vector, [e] is the dielectric permittivity matrix, $[c^E]$ is the matrix of elastic coefficients at constant electric field strength, {S} is the strain vector, $[\alpha^S]$ is the dielectric matrix at constant mechanical strain, and {E} is the electric field vector.

From various piezoelectric materials we get various charge output by applying per newton force. For instance, quartz, $BaTiO_3$, $PbTiO_3$, PZT, PZN-9PT gives output as 2.3, 90, 120, 560, 2500 C/N respectively. From this, we can see that PZN-9PT gives the maximum o/p on load application compared to the other materials. But PZT has already been chosen for the proposed idea due to its advantages in other domains. There are some other variants of PZT. Among all variants, PZT(iii) BM 800 is preferred due to mechanical Q factor and high Curie temperature. Though it has comparatively low charge constant, but it is sufficient to charge batteries during flight(Arora et al, 2013).

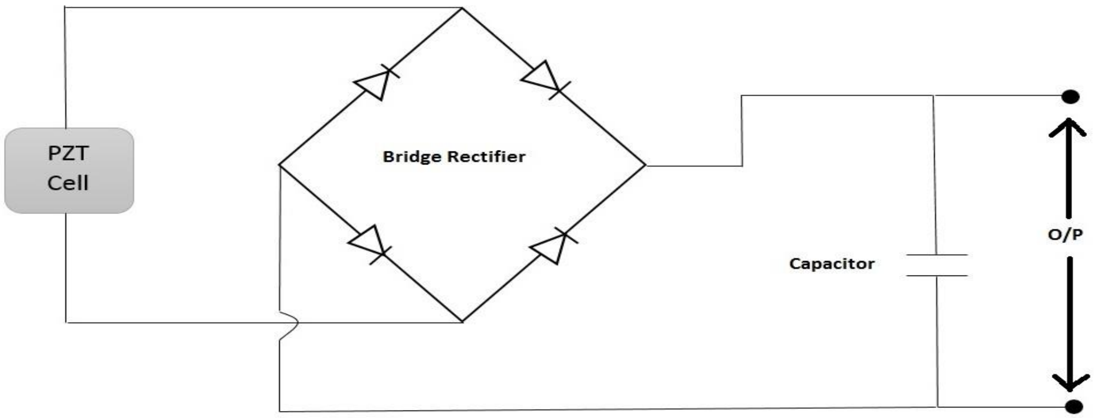
Table2: Properties of Different types of PZT(Arora et al, 2013)

SL No.	Material 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^{-3}Vm/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

How to Collect Electric Energy and Use

The output of a unit piezo generation cell provides neither unipolar voltage nor regularly oscillated peaks. Some random and irregular oscillated peaks are generated with dual polarity. Hence some treatment has to be taken to drive a purposeful voltage. For obtaining unipolar output bridge rectifier is used which resolves the duality problem and provides unipolar flow(Fig-5).

Figure 5: Removing Dual Polarity and Gaining Unipolar Flow Using Bridge Rectifier

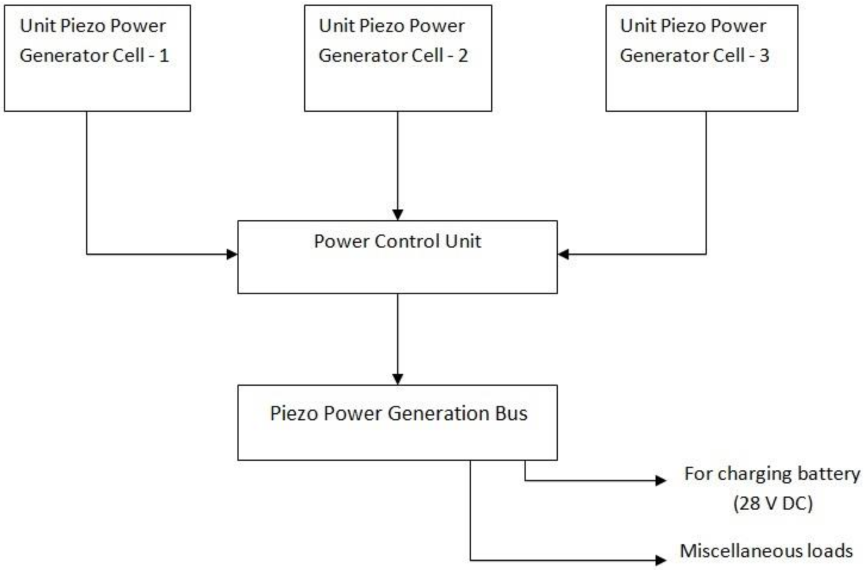


A capacitor with a high Farad value is connected in parallel to the output of the rectifier in order to accumulate charges in the plate of the capacitor. This helps to provide a regular and steady current flow which is desired to be achieved. All the other unit cells are treated as the same.

Proposed Piezo Power System:

Each piezo power generation cell produces different power level. But power has to be distributed according to the requirement of the loads. So a system has to be developed which adds up those different flows and produces a regular and desired level of voltage and current. A proposed system is illustrated below (fig-6).

Figure 6: PiezoPower Generation's Electrical System (I)

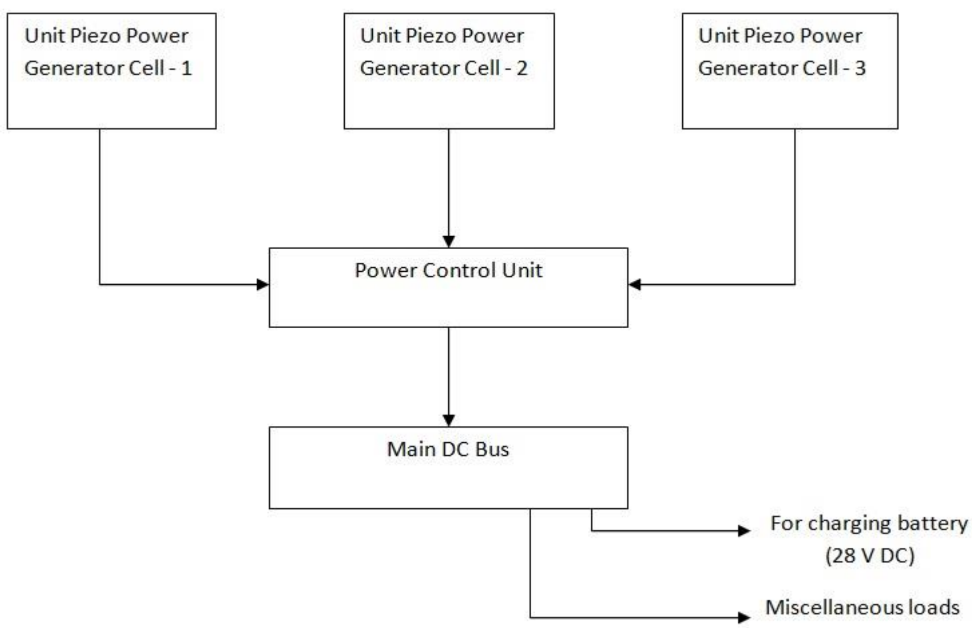


A power control unit has to be developed which will regulate a steady and desired power. For most modern aircrafts (in case of DC supply) 14 V DC or 24 V DC is required for different loads. And 28 V DC is required for charging battery. This power control unit will process the outputs of different cells and combine the required power. A bus bar can be installed where the regulated power will come and from where the required power will be fed. This Bus Bar is named as “Piezo power generation Bus” in the figure-6. The available DC Buses that are used in modern aircraft are:

i. Left Main DC Bus
ii. Right Main DC Bus
iii. Left Secondary DC Bus
iv. Right Secondary DC Bus
v. Hot battery Bus
vi. Main battery Bus
vii. DC generator Bus(if DC generator available)

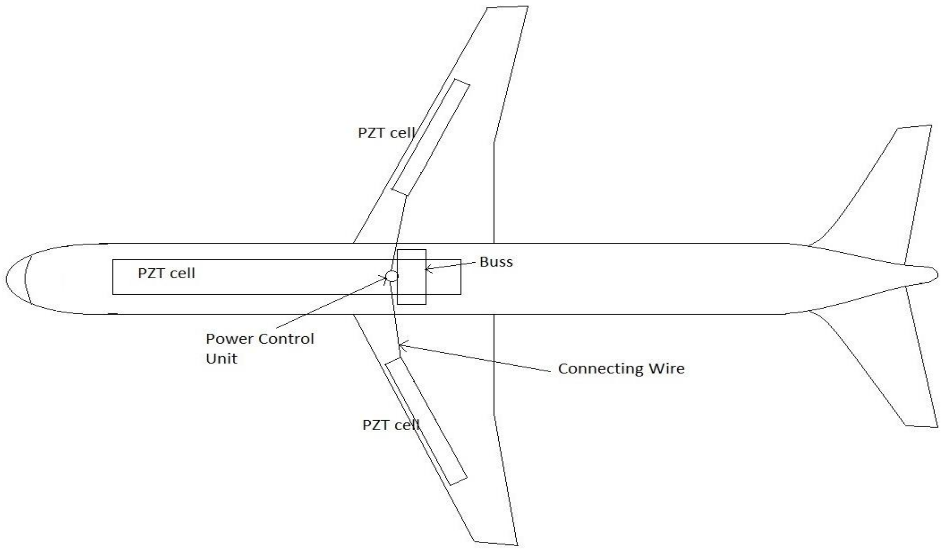
From the Piezo Power Generation Bus the obtained power can be distributed to miscellaneous loads along with charging battery. Another proposal is that to directly feed the output voltage of the power control unit to the main DC Bus (Fig-7) and from the Main DC Bus power can be supplied as convention.

Figure7: PiezoPower Generation’s Electrical System (Ii)



The Total system is illustrated below-.

Figure 8: The Total Piezo Power Generation System withthe Help of Bottom View ofan Aircraft.



To make the system more economical the use of connecting wire is very remarkable. Using economical wires at the same time not compromising the safety factors is the effective process which is likely to be achieved. Another point is that the installation of the Power Control Unit and Bus should be in a position that the distances from all the unit cell are minimum. This will reduce the use of wire and eventually the cost.

Findings

Effective use of piezoelectric material can give solution to many problems regarding power generation and storage and it also can provideemergency backup source for electricity. But using piezoelectric material will be regarded as effective when it will be economical as well as efficient. Efficiency depends on the electricity generation against the given input. In this study we have chosen PZT (Lead Zirconate Titanate) among various piezoelectric materials. PZT is more efficient in producing electricity. Normal piezoelectric material can produce 90-120 C/N whereas PZT can produce 560 C/N which proves that PZT is fur better than normal piezoelectric materials. To get the highest output the configuration is also controlled in a sophisticated manner. PZT strips are used instead of a rigid plate to make it more effective. If rigid PZT plate was used the PZT plate would not be able to absorb the distributed pressure as well as vibration effectively. An array of PZT strips is used to make PZT cell so that the distributed pressure and vibration in any area covering by these strips can be used properly. Large area has been covered which results in more power generation.The issue of stability of the structure is also considered very precisely. The system is installed in such a fashion that it cannotaffect the aerodynamic shape of the airframe and wings. That’s why no hazard has been occurred while the air flows through the body. Again the weight of total system is not enough to affect the CG (Centre of Gravity) of the aircraft. So the system has a very smallimpact on the stability of the aircraft.

Conclusion

The demand of electric power has been increasing rapidly with the advancement of modern aviation technology. The highly competitive aviation market has opened some new field of competition such as IFE (In Flight Entertainment), comfort during flight, various services for business class etc. which necessitates more sources of power. The modern aircrafts are now getting dependent more and more on electrical systems than mechanical systems. As a result the demand of electric power is increasing. Piezo power generation can be a great source to meet the demand in an economical way. Though it is still in an initial stage, recent interest indicates its competence. Specific researches are needed to troubleshoot some limitations regarding insulation, loss of polarization, handling etc. So, more researches and intensive studies should be carried out to substantiate the possibility of using this material for power generation in the near future.

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