

Piezoelectrics - A Potential Electric Source for Aircrafts

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Abstract-With the increase in energy consumption, charging of aircraft batteries with external electrical source has become ever demanding need. The concept of harvesting electrical energy onboard has aroused a renewed interest in humans. In this context, a piezoelectric generator is proposed that harvests mechanical vibrational energy available in huge amount from aircraft engine's vibrations. Embarked piezoelectric transducer, which is an electromechanical converter, when sandwiched between engine cowl, undergoes mechanical vibrations and thereby produce electricity. A static converter transforms the electrical energy in a suitable battery recharging voltage. Values of generated electrical power are discussed further in the paper.

Keywords – Aircraft, electrical energy, piezoelectric, vibrations.

I. INTRODUCTION

Electrical energy is one of the most vital forms of energy needed for various operations in aircraft. Majority of the subsystems in aircraft such as avionics system, cockpit control system, engine fire system runs on electrical energy. Presently, electrical energy is produced onboard by taking some proportion of power from the turbine. During this mechanical extraction, there is always loss of energy due to low efficiency of reduction gears. Moreover, due to this extraction it reduces output of turbine, as it not only gives energy to electrical systems but also drives compressor through shaft. In addition, the task of replacing the batteries is tedious and sometimes very expensive when the sensor is placed in a remote location [1]. Such problems can be alleviated through the use of power harvesting devices. The goal of a power harvesting device is to utilize the energy of a system, which is lost to the surroundings and convert it into feasible energy for the electrical device consumption. Electronics that do not depend on finite power supplies, such as batteries, can be supplied continuous power by utilizing this untapped energy. In the proposed paper, focus is on usage of piezoelectric material as

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potential energy harvester, which produces electrical energy from mechanical vibrations. A piezoelectric transducer is proposed, which extracts mechanical vibrations and provide electrical output in more efficient, clean and reliable manner. There are several types of piezoelectric materials available in abundance such as ceramic, polymeric and crystals. For the required operation, Lead Zirconate Titanate (PZT) has been employed, as it is having good comparable properties such as high mechanical Q factor and high Curie temperature.

II. WHAT ARE PIEZOELECTRIC MATERIALS?

Piezoelectric materials belong to a larger class of materials called ferroelectrics. One of the defining traits of a ferroelectric material is that the molecular structure is oriented such that the material exhibits a local charge separation, known as an electric dipole [2]. They exist in natural form but for our desired properties they are doped with metallic ions to increase its efficiency and sometimes artificial piezoelectric are used as they are manufactured according to the given requirement. The piezoelectric effect exists in two domains, the first is the direct piezoelectric effect that describes the material's ability to transform mechanical strain into electrical charge, the second form is the converse effect, which is the ability to convert an applied electrical potential into mechanical strain energy as shown in figure 1.

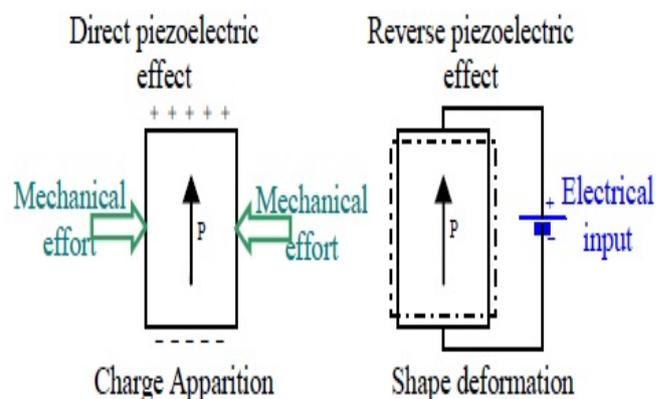


Fig. 1. Electromechanical conversion via piezoelectricity phenomenon

The direct piezoelectric effect is responsible for the material's ability to function as a sensor and the converse piezoelectric effect is accountable for its ability to function as an actuator. A material is deemed piezoelectric when it has this ability to transform electrical energy into mechanical strain energy, and the likewise transform mechanical strain energy into electrical charge [2]. Different types of piezoelectric materials under consideration are tabulated below [3],

Table I: Different types of Piezoelectric Material

S.No	Type	Material
1	Single Crystals	Quartz Lead Magnesium Niobate
2	Ceramics	Lead Zirconate Titanate (PZT) Lead Metaniobate (LMN) Lead Titanate (LT)
3	Polymers	Polyvinylendifluoride (PVDF)
4	Composite	Ceramic Polymer Ceramic Glass

III. PROPOSED IDEA

After going through all the properties of various available piezoelectric materials, PZT is found to stand on the outlined criterion. It is projected to extract energy lost to the surroundings during aircraft's flight with assistance of piezoelectric material. Piezoelectric material is placed on high stress locations in aircraft's engine cowl. It experiences cyclic stress and thus undergoes strain to produce electric voltage across its ends which can be directed to power the electrical subsystems by supplying continuous amperage to charge the batteries.

IV. PRINCIPLE OF OPERATION

The circuit diagram shown below consists of eight major components, namely PZT Ceramic strip, transformer, capacitor, load, DC filter, power unit, battery and Aircraft's Bus-bar system. Firstly, PZT Ceramic strip responses to mechanical vibrations and output voltage obtained are amplified using transformer. The amplified voltage is stored in capacitor to provide continuous voltage for certain time duration. After that, the output voltage is filtered using DC filter to avoid any noise or oscillations interferences in the transferred voltage. The system calculates the required amperage according to the load variations. The power unit used thereafter aids in charging of batteries and provides back-up as an auxiliary system. In addition, it also provides required electrical input to Aircraft Bus-bar system.

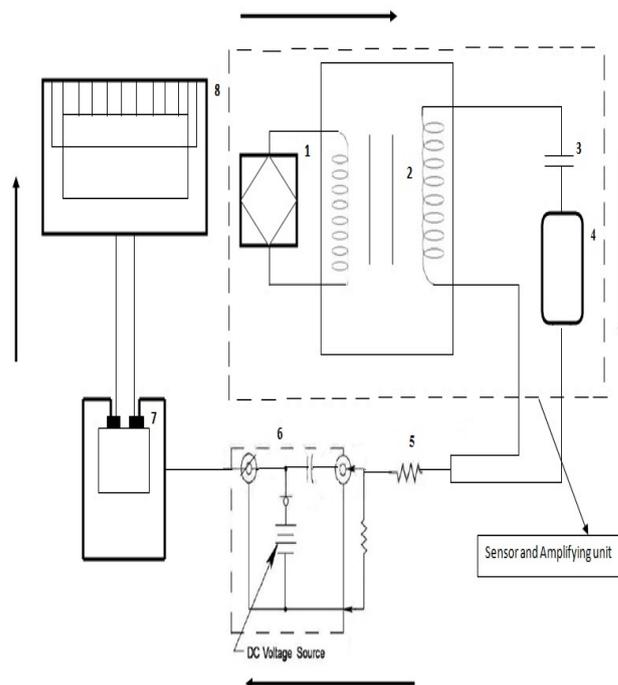


Fig 2: Circuit Diagram

Numbers marked are according to flow process,

1. PZT Ceramic
2. High end transformer
3. Capacitor
4. DC Filter
5. Load
6. Power Unit
7. Battery

The block diagram in figure 3 shows major components involved in the proposed mechanism.

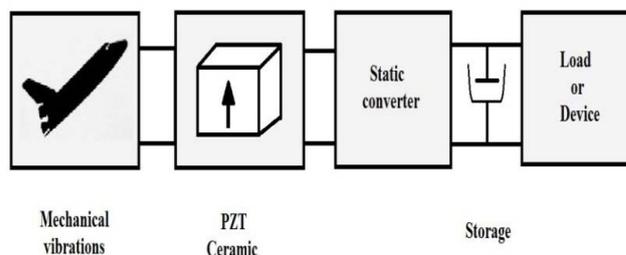


Fig 3: Block Diagram

V. MATHEMATICAL ANALYSIS

Piezoelectricity is the combined result of electrical and mechanical behavior of the material. The output power can be obtained by following linearized equation [4]:

$$D = d.T + e.E \quad (1)$$

Where D is the electric displacement vector, T is the stress vector; e is the dielectric permittivity matrix at constant mechanical stress, d is the piezoelectric constant matrix, and

E is the electric field vector. The subscript t stands for transposition of a matrix.[2]

Table II: Charge output per Newton force applied

Material	D ₃₃ (10 ⁻¹² C/N)
Quartz	2.3
BaTiO ₃	90
PbTiO ₃	120
PZT	560
PZN-9PT	2500

As table shows, PZN-9PT gives maximum electrical output on load application as compared to other piezomaterials, but PZT is preferred for proposed idea due to its advantages in other domains. There are further several variants of PZT, which is shown in tabular form along with their properties [3],

Among all variants, PZT (III) BM 800 is preferred due high mechanical Q factor and high Curie temperature. Though it has comparatively low charge constant, but it is sufficient to charge batteries during flight.

VI. POTENTIAL AREAS OF APPLICATION

Efficiency is the prime criterion for useful application of any device. Vibrations can be obtained at any given coordinate in the aircraft but for getting higher output voltage it is required that the PZT should be placed in areas of high intensity vibration. When piezoelectric material is placed in high intensity vibration localities, it experiences maximum cyclic stress and undergoes strain. Although there are several potential places, but in the paper two locations has been proposed. Firstly, a strip of piezoelectric material can be sandwiched in between the engine cowl above compressor stages, where the aircraft experiences maximum vibrations

due to high rpm of compressor stages. It can be directly wired from this location to the bus bar where the voltage can be harnessed for recharging the batteries.

Table III: Properties of Different types of PZT

S.No	Material Parameter	PZT (II) BM 500	PZT (VI) BM 532	PZT (I) BM 400	PZT (III) BM 800
1	Dielectric Constants	1750	3250	1350	1000
2	Dissipation factor %				
3	Voltage Constant (g ₃₁ 10 ⁻³ Vm/N)	-11.5	-7.5	-10.5	-10.5
4	Charge Constant (d ₃₁ 10 ⁻¹² C/N)	-165	-250	-115	-80
5	Curie Temperature (°C)	360	210	350	325
6	Mechanical Q Factor	80	70	500	1000

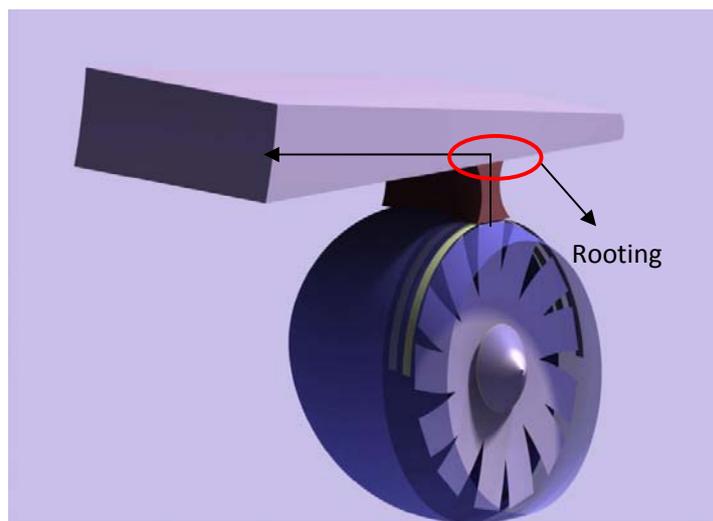


Fig 4: Rooting diagram towards Bus-Bar System

Besides placing the PZT strip on the engine cowl, it can be alternatively placed on the pressure bulk head where it will experience large amount of operational strain to get desirable amount of output voltage. Moreover one of the advantages of this location is that at this location we do not need any special wiring casing, the wiring can be clubbed with the running wire layout system.

VII. ADVANTAGES

- 1) Onboard continuous generation of electricity.
- 2) Continuous and Self-Charging of batteries
- 3) Highly durable, reliable and clean approach for harvesting energy.
- 4) Use of piezoelectric ceramics in engine cowl will aid vibration dampers as PZT will use vibrations to produce electricity.

VIII. LIMITATIONS

- 1) Stability issues,
 - Loss of polarization of piezoelectric material
 - Aging might reduce the material performance.
- 2) Strong temperature dependence of electromechanical properties [5].
- 3) Brittleness- Since the PZT is brittle, careful handling of material is required.

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