

Piezoelectric Generator using Speed Breaker

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Abstract —The piezoelectric plates produces electric power which feeds a low power system. The piezoelectric effect is utilized to produce an electric power from Piezo-plates. The piezoelectric plates operates as a generator for the production of electricity. The piezoelectric plates converts mechanical energy in the form of deformation into an electrical energy. The deformation is applied to piezoelectric plates which deforms the piezoelectric material. The deformation in piezoelectric material changes an inherent resistance which in turn produces ac voltage. This paper proposes a mathematical analysis, design and hardware implementation of piezoelectric generator. The piezoelectric generator produces an electric power when a force exerted on speed breaker of road. The piezoelectric material is utilized in this paper to produce a voltage for street lights. The hardware implementation of piezoelectric generator is done and accurate results are found out experimentally.

Keywords —Electric power, Piezo-electric effect, Piezoelectricity

I. INTRODUCTION

The electric power is an important part in modern life. It is difficult to imagine lives without electric power. Using electric power, machines used in homes, parks, highways, streetlight etc. makes our tasks easier. The various technological developments are possible with the help of electric power. Electric power used in the field of automation, medicine, production makes our lives more pleasant. Electric power usage is indispensable in modern life.

In current scenario, the generation of electric power mainly depends on the burning of fossil fuels like coal, oil and natural gas or the usage of radioactive material. The high amount of dependence on these materials leads to severe pollution in our environment and society. The radioactive material can also put human life in risk in case of some leakage in nuclear power stations. The large amount of wastes and ash in coal power plants also creates problems in air. It can also be a source of many diseases.

The increase in demand of electric power and severe environmental problems propels to investigate the new alternatives to generate electric energy. A growing rise in the demand of electric power has shifted the attention of researchers towards newer opportunities. One very new form of generation of electricity is by usage of piezoelectric material. The piezoelectric material uses the concept of piezoelectric effect. The piezoelectric crystals subjected to a mechanical deformation when mechanical stress is applied over it. The mechanical deformation in piezoelectric crystals changes the dimension of crystal which causes a change in length and thickness of piezoelectric material. This change in dimension of piezoelectric material leads to change in resistance of piezoelectric material which in turn provides a change in potential difference across the piezoelectric material. This concept is further investigated to design piezoelectric generator which converts mechanical force of vehicle into AC electrical power. This electric power can be further fed to low power systems of street lighting.

II. PIEZOELECTRIC GENERATION

It is important to understand the concept of piezoelectric effect and at the same time, it becomes necessary to consider the microscopic structure of piezoelectric material. The piezoelectric effect is the effect of producing two opposite signs on faces of piezoelectric crystal. The opposite signs provides a difference in the potential across two opposite faces. This property is found in crystalline substances which are not conductive.

A piezoelectric material is considered as a material which can create a polarization across two opposite faces of its material. The polarization in piezoelectric material causes due to a dipolar moment which occurs because of the presence of two loaded particles in two different points. The dipole moment is also the product of the load by the distance that separates them.

The piezoelectric effect is the ability of piezoelectric materials to produce an electrical potential difference when mechanical force is applied over it. This effect takes place due to elastic deformation in solid which occurs because of an asymmetric distortion of the distribution of the positive and negative loads in the material. The piezoelectric effect can also be reversed when electric potential is applied across two opposite faces. The

distortion in distribution of loads created when electric field is applied. The geometric distortions are generated which creates mechanical stress in the piezoelectric material.

A. Piezoelectric Plates

Piezoelectric plates are made from quartz material. Piezoelectric plates generates an AC voltage when mechanical force is applied on it and it vibrates and when AC voltage is applied across the plates. Piezoelectric action is reversible as it creates AC voltage on application of force and produces stress when AC voltage is applied across it.

B. Piezoelectric Generator

Piezoelectric generators comprises of a series of piezoelectric plates installed in the speed breaker of road. They have the ability to generate an electrical power when mechanical deformation is subjected to a series of piezoelectric plates. The following factors of piezoelectric material needs to be considered for detailed analysis of the road speed breaker. In this case, road speed breaker is constructed from piezoelectric quartz materials. The following factors of piezoelectric quartz material are listed below:

- Type of piezoelectric material.
- Dimensions of the piezoelectric.
- Level of deformation.
- Loss of load.
- Static Piezoelectric constant.
- Capacitance of the piezoelectric.
- Force exerted on the material.
- Impedance of piezoelectric material

In order to obtain electric power from piezoelectric material, only the basic parameters of piezoelectric material is considered. The properties from the above list which are normally used in the production of electrical energy are diameter of piezoelectric material on which deformation is created, the force applied on piezoelectric material and the impedance of piezoelectric plates.

C. Electrical Voltage due to deformational force

The piezoelectric constants are important to understand for the calculation of electrical power obtained from piezoelectric plates when deformation is applied over piezoelectric plates. The piezoelectric constant is the ratio of dimensional variation of piezoelectric material to the potential difference applied. The force exerted produces a dimensional variation Δl in piezoelectric material in meters which is responsible for potential difference across the plates in volts. The electrical power is generated in coulombs and the force which is exerted in piezoelectric material is always in Newton.

The equation (1) indicates the electrical AC voltage produced after application of mechanical deformation on a dedicated area of piezoelectric plates.

$$V = (-g_{33} * h * f / A) \quad (1)$$

where, V is the desired electrical voltage obtained due to deformation of piezoelectric material.

g_{33} is the piezoelectric constant (Vm / N).

h is the length or thickness of the piezoelectric.

f is force that is applied on the piezoelectric crystal (N).

d is effective diameter of the piezoelectric crystal.

A is area of the piezoelectric crystal.

The force applied on this area is also called the stress level of the piezoelectric material. "In this case, for a disk (Lead Titanium Zircon ate) of 27mm diameter in its diaphragm and 20mm in diameter in the ceramic, the piezoelectric constants of the order of : $25 \times 10^{-3} \text{Vm/N}$ ".

The output voltage of piezoelectric generators will remain same when large number of piezoelectric elements are connected in parallel. The output voltage is independent of the piezoelectric elements connected in parallel. The current however varies depending on the number of piezoelectric materials connected. The output current of piezoelectric generator also depends on the impedance presented inside the piezoelectric material.

The piezoelectric materials used in the hardware have a very high impedance and it is approximately 400 Ω . The high resistance of piezoelectric material is due to inherent characteristics of material. Due to high resistance of piezoelectric material, the output current of piezoelectric material is very low. The values of output current

are normally in the range of milli-amperes. A base current of the order of 1mA is considered in this method for piezoelectric material.

The electrical power obtained from piezoelectric generator is the product of output voltage and output current. The electrical power from piezoelectric generator is evaluated using below equation.

$$P = V * I \quad (2)$$

where, P is the electrical power generated in watts.

V is the voltage obtained from piezoelectric generator.

I is the output current from piezoelectric generator in Amps.

To understand the operation of piezoelectric generator, mechanical properties related to piezoelectric materials are used. The mechanical properties forms the base for the calculation of force applied on the piezoelectric plates. Equation 3 is used for the evaluation of the force applied on piezoelectric crystals.

The force which is exerted on piezoelectric plates is the product of weight (mass) of an object and the strength of gravity. The exerted force in this method is nearly equal to hand weight which is normally 10 kilograms.

$$f = m * g \quad (3)$$

where, m is the mass of the object that is exerted on the piezoelectric, in this case a hand weight is used and g is the strength of gravity equivalent to 9.81 m/s^2 .

D. Electric Stress due to deformation

The area of piezoelectric crystal is calculated using equation (4) and it is evaluated according to the diameter of piezoelectric disk. The effective area is considered for calculation on which the force is exerted.

$$A = (\pi/4) * (\text{effective diameter of piezoelectric crystal})^2 \quad (4)$$

The calculations are done according to the stress created in the breaker plates after force exerted on it. It also takes characteristics of piezoelectric material into consideration for the calculation of an AC voltage. The alternating voltage is calculated for one plate of piezoelectric material taking all parameters of piezoelectric material and force exerted on effective area of piezoelectric crystal. The equation for voltage generated from piezoelectric crystal is obtained as follows:

$$V = (-g_{33} * h * (f/d^2 * \pi/4)) \quad (5)$$

Substituting the values in each of the variables

$$g_{33} = 25 \times 10^{-3} \text{ Vm/N}$$

$$h = 0.33 \text{ mm}$$

$$f = (10 \text{ Kg}) (9.8 \text{ m/s}^2) = 98 \text{ N}$$

$$d = 20 \text{ mm}$$

Replacement these values, we form the equation and get:

$$V = (25 \times 10^{-3} * 0.00033 \text{ m} * (98 \text{ N} / 0.02 \text{ m}^2 * \pi/4)) \\ = 2.57 \text{ V}$$

III. ELECTRONICS USED IN PIEZOELECTRIC GENERATORS

The electronics used in design provides help to piezoelectric plates to operate properly. The piezo-breaker plate's produces high amount of voltage but it generates a very low current. This is the greatest strength of piezoelectric element which produces ac voltage on application of force. The generation of low current allows piezoelectric technology to use electronics. The current demanded by load is an important criteria for the usage of piezoelectric materials as it produces high amount of voltage but low current. The piezoelectric breaker plates can produce high voltage but it generates only a small current due to high impedance of piezoelectric material. In order to overcome the drawback, the piezoelectric elements are connected in parallel. The connection of piezoelectric materials in parallel supports the drawback of piezoelectric element.

The different components of electronics in piezoelectric generators are used for transmission and storage of an AC voltage obtained from piezoelectric generators. The prototype of piezoelectric generator is made in speed breaker. The piezoelectric plates are installed beneath the speed breaker. The accurate results are obtained in loading and unloading time after completion of different experimentation on piezoelectric plates. The energy stored in capacitors can be further utilized by load and it also helps in calculation of time in which the energy gets utilized by load.

Various tests can be performed on piezoelectric material. One of the tests varies the force applied to plates which in turn generates electrical energy which can be stored in capacitors. After storing electrical energy in capacitors, the unloading time can be easily evaluated for which LED strips consume the energy from capacitors. A 10 kg is kept on speed breaker where generator is fixed. The weight concentrated on plates of generator using spring arrangement is about 10kg and the weight of 10kg is experienced in speed breaker when a vehicle passes

on speed breaker. It is observed that when vehicle exerts force on plates, the wheel of vehicle covers only a smaller part of the piezoelectric crystals leaving several plates unused.

The LED starts to glow when the discharge process starts and the voltage continues to drop across the multimeter. The multimeter is connected across the capacitor to provide an indication of discharge voltage. The capacitor charges to a voltage of 2.57V and it is indicated with the help of multimeter. Instead of capacitor, rechargeable battery can also be used which charges during day time and discharges during night time.

IV. HARDWARE IMPLEMENTATION

The hardware implementation of proposed piezoelectric generator is shown in Fig. 1. The piezoelectric plates in series are placed inside the breaker. Whenever vehicle passes over the breaker, it mounts pressures on the breaker which in turn produces stress or deformation in piezoelectric material. The street lights are powered from the energy obtained from the piezoelectric plates. The LEDs are connected across capacitors which continues to glow during discharging of capacitors.



Fig 1: Hardware implementation of piezoelectric generator

V. CONCLUSION

The energy obtained from piezoelectric material is stored in the batteries after converting ac into dc. The design and hardware implementation of piezoelectric generator is done with the help of electronic component. The rectifiers are used after piezoelectric generator which is used for the conversion of ac into dc. The piezoelectric generator produces a voltage of 2.75V when a deformation is applied on the plates of piezoelectric material. The analysis of output voltage of piezoelectric plates is done using the formula when 98N force is applied. The output energy of piezoelectric material is stored in batteries which is utilized in low power system. The illumination of street light is done with the help of proposed piezoelectric generator. These type of piezoelectric generators are suitable as they are more reliable and have long operating life. These piezoelectric generators do not require any external excitation as compared to other electric generators. Piezoelectric generators are clean and pollution free. The size and construction of piezoelectric generators are relatively low as compared to other big generators. The piezoelectric transducers has rugged in construction and small in size. The energy obtained from piezoelectric generators are available at free of cost. This technology could be further utilized unbelievable for open highway and passing vehicles. This type of energy can also be used in train routes and in train also for generation of electricity. It is also used in future signaling system.

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