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A SURVEY ON EFFICIENT PIEZOELECTRIC ENERGY HARVESTING TECHNIQUES AND THEIR APPLICATIONS

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Abstract— Energy harvesting is the process of foraging electrical energy from energy sources available in the environment. This paper reviews energy harvesting technology using PZT as the specific piezoceramic material with its modules to determine the capacitance for optimal energy-storage in piezoelectric vibration energy harvesting (VEH) systems . It reviews various applications of piezoelectric energy harvesting from different sources . The PSPICE software can be used to determine the optimal energy-storage capacitance in a VEH system with one or more piezoelectric modules. By the simulation, the optimal capacitance of the storage capacitor can be determined to obtain a maximum energy storage power. Keywords- piezoelectric, PSPICE, vibration energy harvesting (VEH).

I. INTRODUCTION

Energy harvesting by piezoelectric devices has gained great attention for its potential applications in self-powered sensor networks, portable electronic devices, widespread computing systems, and other areas. It uses piezoelectric effect to convert mechanical vibration or strain variation with time into electric energy and devices like super-capacitors and rechargeable batteries are used for energy storage.

Numerical analysis of a vibration energy harvester system is extremely helpful to the optimization of the system. But the research on this topic is very little. Guan and Liao [1] used the PSPICE software to analyze the energy storage power of a vibration energy harvester with one piezoelectric component.

Yang and Tang proposed an equivalent circuit for the simulation of vibration energy harvesters by the SPICE software [2].

A. Piezoelectric energy harvesting

In the Piezoelectric energy harvesting, we use certain materials that have the ability to produce charges when stress/strain is applied to them. Such materials are called Piezoelectric materials. Jacque and Pierre Curie discovered the phenomenon of piezoelectricity in 1880. They found that in case of certain materials, when mechanical strain is applied, an electrical polarization occurs and that degree of polarization is proportional to the applied strain. Such materials get deformed on the application of electric field across them. So the piezoelectricity is defined by a relation between a mechanical deformation and electricity. This property is used for the conversion of mechanical energy (due to the motion) to electrical energy. This effect is described as direct piezoelectric effect when an electric field is created upon mechanical deformation and indirect piezoelectric effect when an applied electric field causes a mechanical deformation. In energy harvesting, the direct piezoelectric effect can be brought into play to transduce mechanical energy into electricity. These piezoelectric materials occur in many sorts such as thin film(e.g. sputtered zinc oxide) , single crystals (e.g. quartz), screen printable thick-films based upon piezoceramic powders piezoceramic (e.g. lead zirconate titanate or PZT), and polymeric materials such as polyvinylidenefluoride (PVDF) [3].

Many piezoelectric energy harvesting circuits were designed and studied to enhance the electric energy-storage efficiency [4]–[6]. Many of them derive from a classical one-step energy harvesting circuit consisting of a full-bridge rectifier and an energystorage capacitor, which is still being widely used. In the design of the energy-storage circuit consisting of a capacitor and full-bridge rectifier [1], [7] for a piezoelectric energy harvester operating in a finite time, one of the major tasks is to decide the optimal capacitance of the energy-storage capacitor. However, research on the method to efficiently decide the optimal capacitance and to clarify the effect of the equivalent circuit parameters of piezoelectric components on the optimal energy-storage capacitor is still very scarce. The optimal capacitance of energy storage capacitor of a vibration energy harvester can be simulated with multiple piezoelectric components to obtain a maximum energy storage power, and to investigate the effect of the equivalent circuit parameters of piezoelectric components on the stored energy.

B. VEH used in simulation

Xiaobin Cui has proposed , as shown in Fig. 1, the VEH used in the simulation consists of three parts, i.e., the top and bottom frames, and the cantilever beam [17]. The frames are made of stainless steel, and phosphor bronze is used as a material to make cantilever beam. Four piezoelectric modules (PZT-T-EX, PZT-T-IN, PZT-B-EX, and PZT-B-IN), each with five identical piezoelectric plates connected in parallel electrically, are bonded to the top and bottom frames. At the top of the cantilever beam there is a proof mass. Two piezoelectric plates (PZT-T-IMP and PZT-B-IMP) are bonded onto the end of the frames to receive the impact energy of the proof mass. The VEH could be mounted on a vibrating source. In our experiments, it is bolted on an electric shaker. The piezoelectric material adopted here is Lead Zirconate Titanate (PZT) ceramics (HAIYING P-51).[8]

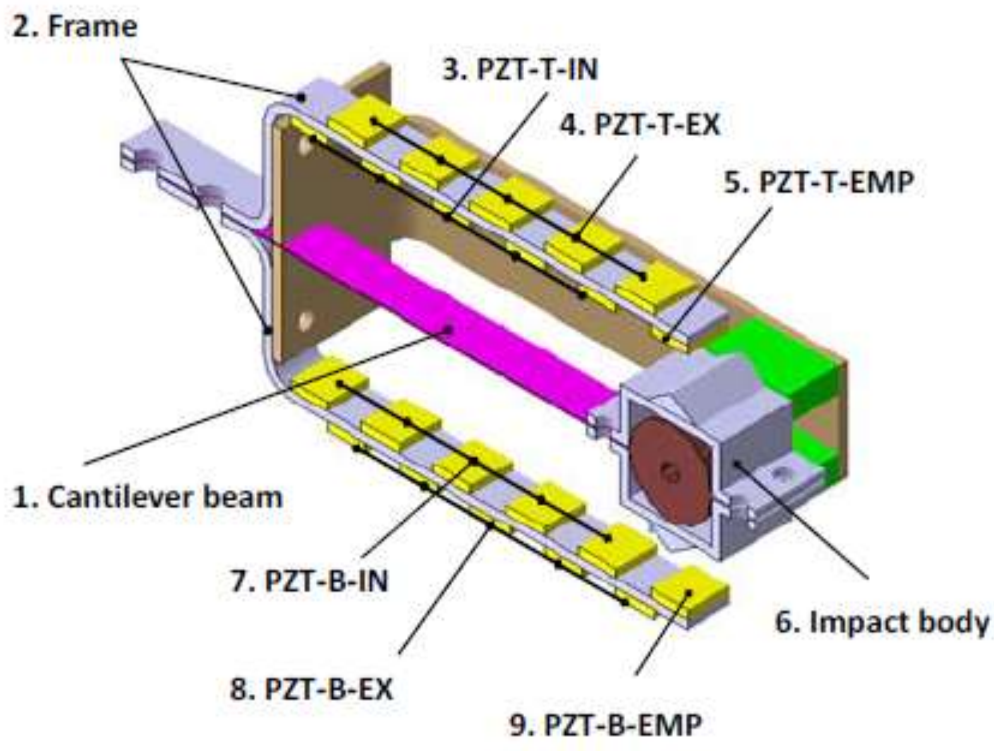

Figure 1: Structure of VEH[18]

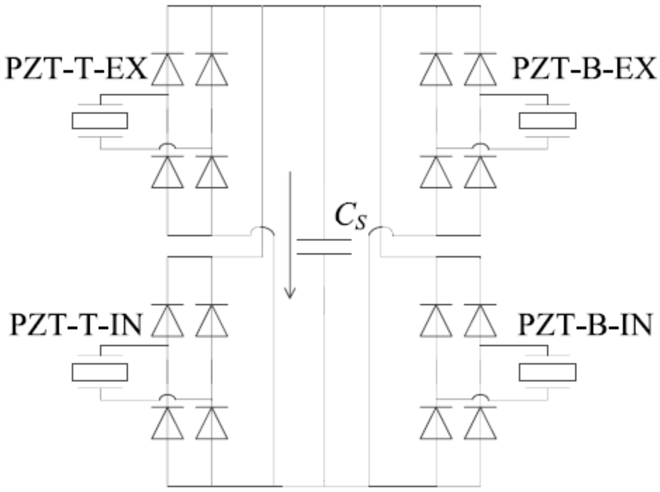

Figure2: Schematic of the VEH device for simulation.[17]

While simulating any of the technology that are discussed above either in sources or in applications we will need a circuit, that will be consisting of a capacitor which helps in the storage of optimal energy, after the production of energy . This optimal energy storage capacitance can be calculated using the PSPICE software working with multiple piezoceramic units in various combinations. This capacitance can be used in any circuit for the storage of maximum energy. The equivalent circuit of the piezoelectric module for simulation is shown in Fig 3.

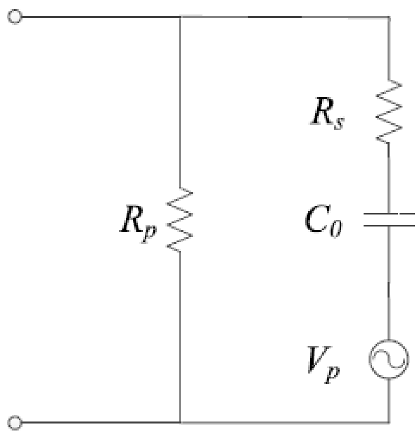

Figure3: Equivalent circuit of piezoelectric module[17]

II. SOURCES OF AMBIENT ENERGY

A. Mechanical Vibrations

Mechanical vibrations are one of the most common sources of ambient energy that are converted into electrical energy. Typically, the electrical energy is generated by applying strain energy from the vibrations to a piezoelectric material, which becomes polarized electrically when subjected to strain, or to displace an electromagnetic coil. The method and results of this study involves the development and demonstration of a wireless measurement system for use in diagnosis of the state of a rotating machinery system were presented by Clark, Romeiko, Charnegie, Kusic, and Mo [8] . Fig.4 shows the driving motor attached with the energy harvesting devices . The energy harvesting devices are excited by the vibration of the motor itself.

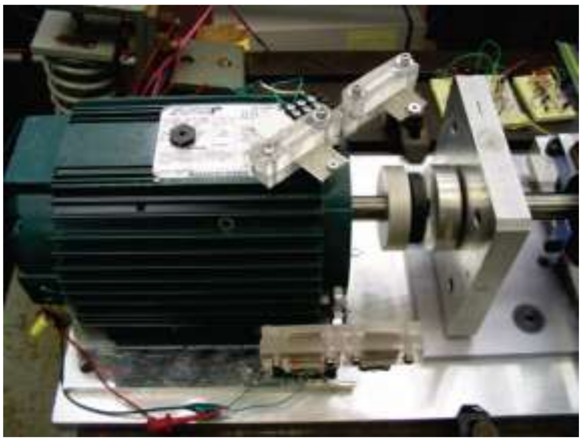

Figure 4: Photograph of Motor Test Rig with the Beam Harvesters Attached[8]

B. Wind

It is known that many bridges are located in windy areas, wind power generation has received much attention. Park, Jung, Jo, and Spencer [9] investigated the feasibility of using small scale wind generators, referred to as micro-wind turbines, to power wireless sensors on a cable-stayed bridge. Recognizing that conventional, geared rotating airfoils, like micro-wind turbines, that pull energy from the wind may be too expensive or inefficient for some locations, some researchers [10, 11] have focused on harvesting energy from aerodynamic instability phenomena such as galloping, flutter, and vortex induced vibration. Sirohi and Mahadik [12] present an analytical model for a piezoelectric wind energy harvester design that harvests energy from a prismatic body oscillating due to aerodynamic galloping (Fig. 5).

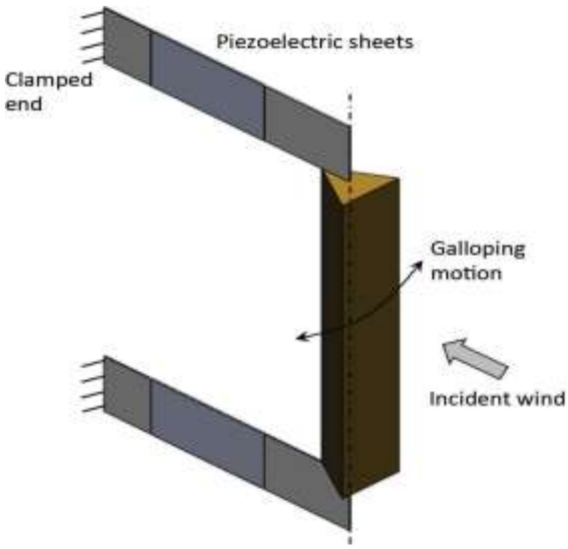

Figure 5: Galloping Energy Harvester with Tip Body Having Equilateral Triangle Cross Section[12]

C. Kinetic Energy of Rotation

Another method for Harvesting is the kinetic energy of rotation. A rotating energy harvester is based on magnetostatic coupling between a stationary circular-arc hard magnet array and rotating magnetic solenoids. When installed on a wheel rotating at 60 mph, the prototype device produced a maximum output voltage of 9.2 V and power density of 4.5 W/cm3 and was demonstrated to be a viable method for powering a real time tire pressure monitoring system (TPMS). For all rotating machines and structures, like turbines, for example, real-time condition monitoring is highly desirable in order to achieve improved safety and equipment performance. Khameneifar, Arzanpour, and Moallem [13] investigated a energy harvester based on vibration for rotary motion health applications (e.g. strain gauges and accelerometers). The novel design consists of a piezoelectric cantilever with tip mass mounted on a rotating hub (Fig. 6) . Continuous oscillations are generated during the rotation of the cantilever beam due to gravitational force on the tip mass. An analytical model developed with the energy method is presented for predicting the maximum output power and optimal resistive load. The 6.4 mW of power obtained from the PZT harvester beam with a tip mass of 105 g is enough for supplying a typical wireless sensor.

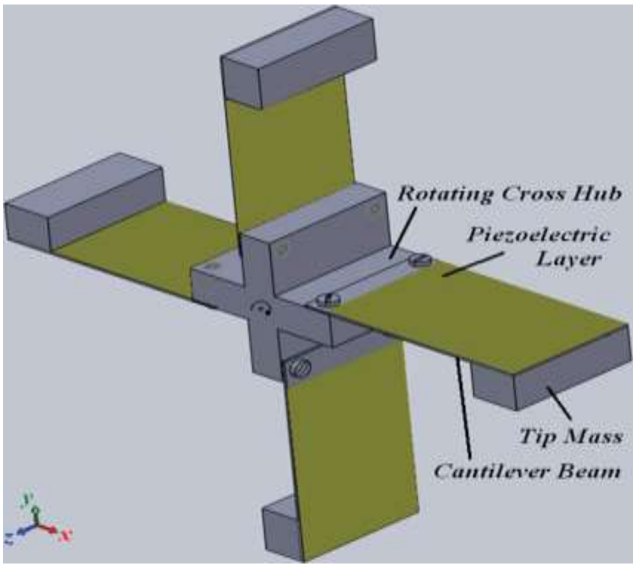

Figure 6: Schematic View of the Energy Harves ter Mounted on a Rotating Hub[13]

D. Thermal Energy

Another method of acquiring energy from ambient sources is with the use of thermoelectric generators (TEGs) operating on the Seebeck effect, which expounds the generation of an electric current at the junction of dissimilar metals at different temperatures. The TEG is a fully fledged technology that has been extensively studied over the past three decades. An advantage of a TEG over a vibration-based energy harvester is that it has no moving parts. A disadvantage is that TEGs are relatively inefficacious when low thermal gradients are present. Because aircraft flying at high altitudes are subject to large thermal gradients, the use of TEGs to power wireless sensors for aerospace applications is a field of interest. Pearson, Eaton, Pullin, Featherston, and Holford [14] investigated using piezoelectric materials and TEGs to harvest ambient vibration and thermal gradients, respectively, present on aircraft. Utilizing temperature data simulation results, taken from thermocouples placed at various positions on an aircraft (Fig. 7) yield peak power levels ranging from 5.46–34.15 mW depending on the location of the thermocouple.

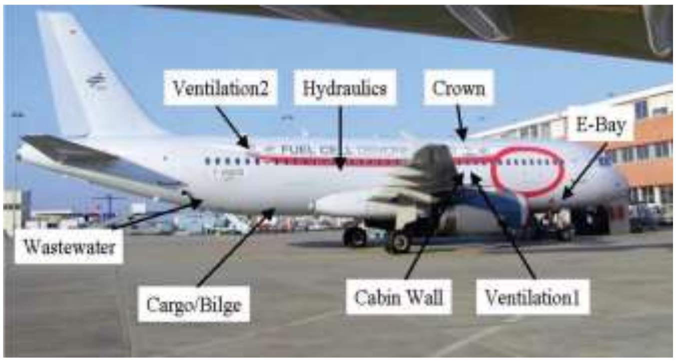

Figure 7: Locations of Thermocouples Used for the TEG Power Output Simulation[14]

III. APPLICATIONS

A. Piezoelectric vibration energy harvesting system can be used as Implants devices that are surgically inserted into the human body for medical reasons. Implantable medical devices are gravely required for the survival of patients suffering from certain serious diseases. Some of these devices work in the body to help or replace the function of certain organs. This specifies their urgent necessity. The implants can be classified into two types: One that require power supply for their functioning and others that do not need power supply. Some of the active implant devices include cardiac pacemaker, cochlear implants and drug pump etc. These implantable medical devices need continuous supply of electric power and thus there is a need to develop methods for their long term powering. These methods need to be easy, convenient and safe for the patient too. The conventional technology that has been used over the years for powering of the implant devices is batteries. But batteries suffer from the drawback that they have a limited lifespan. They have fixed energy density and may have chemical side effects. This necessitates the replacement of the batteries after a time period defined by their lifetime. The continuous cycle of replacement of batteries can be extremely inconvenient for the patients [15]. The procedure might include several surgeries and costly medical procedures to be followed. Hence using a rechargeable battery may address the need for battery replacement. So the concept of Energy harvesting from human or environmental sources appears as an effective solution to this problem.

B. Nowadays, wireless sensor networks are alluring much attention in monitoring and controlling plants, resources and infrastructures. An essential component of the wireless sensor network is the power supply. If power is supplied through cables, the wireless network will not be precisely wireless. Therefore, traditional batteries are usually used in wireless sensor networks. But in numerous applications, replacing batteries, due to their limited lifetime, is very inappropriate. The labour and cost associated with changing hundreds or thousands of batteries would be exasperating and expensive in maintaining the network. Piezoelectric materials can be used to form transducers, which are capable of interchanging electrical energy and mechanical motion or force. This coupling nature reveal that the application of an electrical potential to a piezoelectric element produces a strain or mechanical deformation. Reversely, if the piezoelectric element is strained, it will produce an electrical charge. Therefore, piezoelectric materials can be used as contraptions to transform ambient motion (usually vibration) into electrical energy, which may be stored and used to power other devices. By implementing power harvesting devices, one can prosper wireless sensor networks that do not depend on traditional batteries for supplying power. However, the major constraint faced in the piezoelectric power harvesting is that the average harvested power is overly little. Therefore, usually, some storage means are used to store and gather the harvested energy for intermittent use. Many of the early researches into power harvesting considered the use of capacitors as a way to store energy [16]. One recent advance is the use of rechargeable batteries as a means of accumulating the energy generated.

IV. CONCLUSION

This paper also reviews relatively recent energy harvesting technologies for various applications. Most common ambient energy sources used are briefly overviewed, which include mechanical vibrations, wind, rotational kinetic energy, and thermal energy. Energy stored in the energy storage capacitor *Cs* with a voltage of V_{rms} is calculated by the measuring time for the energy stored in the capacitor *Cs* in 10 minutes[17]. The output energy from PZT-T-EX versus capacitance *Cs* of the energy storage capacitor is shown in Fig. 8.

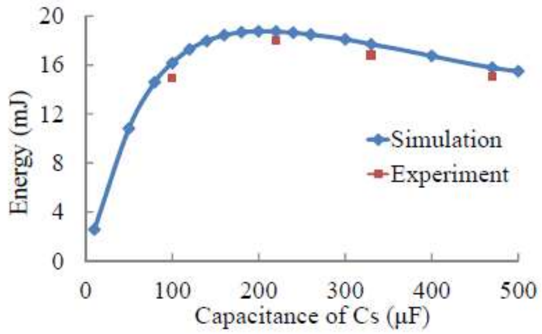

Figure8: Calculated and measured output energy from PZT-T-EX versus capacitance [17]

It is seen that there exists an optimal capacitance for obtaining the maximum stored energy. The optimal capacitance to realize the maximum energy storage during a limited operating time can be determined by the PSPICE calculation and that capacitance can be used for the production of utmost energy or power with any type of sources in any field.

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