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POWER GENERATION PIEZOELECTRIC VIBRATION FOR SENSOR

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ABSTRACT

Proper Power generation piezoelectric vibrations have been proven to be an attractive technology for harvesting small magnitudes of energy from ambient vibrations. In recent years, energy harvesting to obtain electrical energy from the energy that exists around the body (energy harvesting) technology is attracting attention. This work investigates the optimization of a micro piezoelectric cantilever system using a genetic algorithm based approach with numerical simulations. The genetic algorithm globally considers the effects of each parameter to produce an optimal frequency response to scavenge more energy from the real vibrations while the conventional sinusoidal based method can only optimize the resistive load for a given resonant frequency. Focus on the method of using the electrostatic induction which gives high conversion efficiency. Step by step manufacturing process slider chip discussed. Research toward an independence operation of the fabrication mechanical sensor network terminal and introduces the micro vibration power generation technology has been developed. Experimental acceleration data from the vibrations cover demonstrates that the optimized harvester automatically selects the right frequency and also synchronously optimizes the damper and the resistive load beneficial in contributing a performance wise for output energy. This method shows great potential for optimizing the energy harvesting systems with real vibration data.

Keywords: piezoelectric vibrations, ambient, genetic algorithm, fabrication sensor, power.

INTRODUCTION

Natural world around of us, are full of energy that is not being used without having to pay much attention usually vibration and heat, and light. Energy harvesting technology refers to the technology to harvest the energy of these present thinly widely in the environment, effective use as electrical energy (Hui and Ho, 2005). In recent years, with the development of low power consumption of the semiconductor device, and a weak energy we are committed to the study of low power consumption technology of the circuit and ubiquitous sensor nodes and devices circuit that can be driven from energy are being developed, the utilization of the energy of the above has become realistic.

Miniaturization battery-less wireless terminal as one of the fundamental technologies, micro-electro-mechanical system: working on research and development of vibration energy harvesting technology by Micro-Electro-Mechanical Systems (MEMS) technology. In this research, introduce principles and electrostatic induction generator devices using electrets that convert electrical energy to vibration energy, the basic characteristic structure, and manufacturing process. Thus process depends on the environment contribution on supply renewable energy for increase yield for energy harvested over time, where genetic algorithm (GA) contribution vital.

In the field of artificial intelligence, a genetic algorithm (GA) is a search heuristic that mimics the process of natural selection. This heuristic (also sometimes called a metaheuristic) is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. Employ genetic algorithm (GA) is important in our research to enhance output power.

GENETIC ALGORITHM TECHNIQUE

This research describes the optimal design of a piezoelectric energy harvester using genetic algorithm (GA) based approach using real vibration data. The genetic algorithm allows a numerical evaluation of the output power, instead of restricting in an analytical solution which is difficult to derive from tonal vibrations. This research also describes the experiment of acquiring acceleration data from an engine cover and demonstrates that the harvested power is improved by comparing to the conventional system designed by assuming a purely sinusoidal excitation.

The piezoelectric energy harvester is considered as a cantilever structure with a purely resistive load. Figure-1 shows a generic system and it can be modeled by the following ordinary differential equations (Roundy, Wright and Rabaey, 2003), (Shu and Lien, 2006), (Lien and Shu, 2012). In kinetic energy harvesting, a piezoelectric transduction mechanism is used to extract electrical energy from motion. The generator also requires a mechanical system to couple environmental displacements to the transduction mechanism. The mechanical system has to be designed to maximize the coupling between the mechanical energy source and the transduction mechanism.

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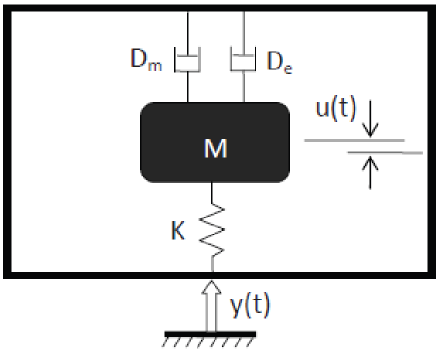

Figure-1. Generic system model for piezoelectric energy harvester.

$$M\ddot{u}(t) + D\dot{u}(t) + Ku(t) + Av(t) = -M\ddot{y}(t)$$

$$v(t) = RA\dot{u}(t) - RC\dot{v}(t) \qquad (1)$$

The symbol$'.'$ denotes differentiation. The parameters and variables are denoted as follow. M is the proof mass; K is the stiffness of spring (cantilever); Dm is the mechanical damper (or equally D in Equation 1) and De is the electrically induced damper expressed in Equation 2 A is the piezoelectric coefficient; C is the capacitance of the piezoelectric material and R is the resistive load. t is time; (t) is the displacement of the mass; $y(t)$ is the external excitation displacement and $v(t)$ is the outgoing voltage.

The electrically induced damper shown in Figure 1 can be expressed by:

$$D_e = A^2R - ARC\frac{\dot{v}(t)}{\dot{u}(t)} \qquad (2)$$

If the external excitation (t) is purely sinusoidal at the natural frequency of the system, Equation 1 can be solved analytically and hence the output power of the system is expressed by (Minazara, Vasic and Costa 2008),

$$p = \frac{RM^2A^2w^4}{2\left[\left(A^2R + D\right)^2 + \left(RCDw\right)^2\right]}y^2 \qquad (3)$$

Where w = $\sqrt{K/M}$ is the natural frequency of the system. If the system is weakly electromechanically coupled ($A^2R \ll D$ in Equation 3), the maximum power of the system can be attained from the optimal R expressed by,

$$R_{op} = \frac{1}{Cw} \qquad (4)$$

In the context of real vibration sources, it is difficult to select an optimal natural frequency of the piezoelectric energy harvester system as real vibrations usually have a broad bandwidth with multiple frequency peaks. Create robust platform deep exploitation is essential.

GENETIC ALGORITHM EFFICIENT CONSERVATION

Due to the difficulty of deriving an analytic solution to the output power of a piezoelectric energy harvester with real tonal vibrations, this paper utilizes numerical optimization methods in which the evaluation of output power can be computed numerically. The simplest approach is to simply populate the parameter space and calculate all possible values of all of parameters, also termed as enumeration. However this technique is very inefficient, especially in high dimensionality. An advanced method is to estimate the local gradient of a previously selected point, and then select a new point in the direction of the steepest positive gradient (for maximization) or largest negative gradient (for minimization). This is called the gradient-based method and is widely used in engineering. However the gradient-based methods are susceptible to trapping in local minima. This paper selects a genetic algorithm which is a stochastic method including random elements to avoid the drawbacks of local gradient search. However, global optimization is not always guaranteed. Many other global minimization methods are suitable for that purpose, although they are used rather rarely in this context.

The genetic algorithm initially starts by selecting a random trial point for each parameter, and then iteratively runs to survive good points which can harvest more energy, and eliminates poor points, until the parameters converge to maximize the harvested energy. The genetic algorithm used in this work follows the procedure described in (Chipperfield *et al.*, 2013) and the related MATLAB toolbox is used. In this work, binary Cartesian coding, a frequently used method is used to map the discrete space of the parameters to a genetic string (often referred to as chromosomes). Roulette wheel selection is used to reproduce a new population (new trial points), based on a linear ranking of the fitness values. Then we develop and fabricate it in electrostatic induction method that will be future discussed in the next section.

An evaluation function is devised to measure how well the trial solution performs. Typical acceleration data acquired from a car engine cover will be used to evaluate the trial points. Since the continual output power of the harvester also depends on the vehicles start engine coz it stick on the engine cover, the work here defines a new power metric to evaluate the harvester. It is defined by the harvested energy (Joule) per mili-second. The time of noise and vibration created is usually less than two seconds, but the vibration of the harvester's mass can last much longer especially in the case of a low frequency piezoelectric system. This means that energy would be stored in the harvester and output to the associated interface circuit even after the efficient vibration or noise stop. In this work the output evaluation is simulated for 250 mili-seconds to let the harvester output most of the energy.

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THE POWER GENERATION PRINCIPLE BY ELECTROSTATIC INDUCTION

The method of converting electrical energy to the vibration energy, there is electrostatic induction method, an electromagnetic induction method, and a piezoelectric system. Considering the power supply to the various kinds of integrated circuit ultra-small mechanical sensor networks, such as (Xue Gonzalez-Argueta and Sundararajan, 2007), (Sari Balkan and Kulah, 2008) (Yang *et al*., 2014), (Cahill *et al*., 2014) described above case, the conversion efficiency is high, because the affinity of the semiconductor process is high, were we focused on the method of using the electrostatic induction.

The electrostatic induction, and close the (charged body) object that static electricity is charged conductor such as a metal, it refers to the phenomenon of opposite charge (induced charge) occurs charge of the charged body and the (fixed charge). As a familiar phenomenon surrounding static electricity such a phenomenon that is attracted hair was rubbed with clothing as underlay of plastic, it is brought close to human hair has been known well.

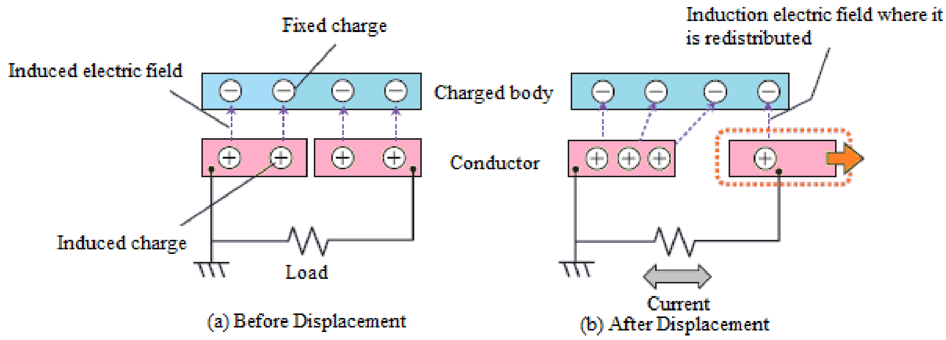

Figure-2. The power generation principle by electrostatic induction.

The principle of power generation by electrostatic induction is shown in Figure-2. Move closer the conductor such as a metal of two charged body. Then by electrostatic induction as described above, the surface of the conductor of the charged body near the induced charge with opposite polarity is generated in the charge of the charged body, the electric field is formed between the induced charge and fixed charge.

For example, a similar relationship is and may be charged to the body, was close to two conductors R_i stands (Figure-2 (a)). From this state, one of the two conductors, and is relatively displaced one, are redistributed (field) induced charge in response to the displacement, The idea to connect the load between the two conductors, in accordance with the charge transfer, the load current is generated (Figure-2 (b)). It will be necessary in order to produce continuously induced charge from the charging member, to always keep the static electricity charged in the body. It will be necessary in order to produce continuously induced charge from the conductor, is always held in the electrostatic charging member. It is preferable to use a material called electrets capable of holding a charge permanently for that is typical.

As a familiar example, the electrets have been used, for example, microphone and mobile phone filter dust collector. Further, for efficient generation of electrostatic induction, it is necessary to be controlled to a few 10 μm about the distance of the conductor and two charging member in Figure-2.

THE POWER GENERATION PRINCIPLE BY ELECTROSTATIC INDUCTION

As a structure for converting electromagnetic energy into vibration energy, we devised the slit and the slider structure as shown in Figure 3. This structure is made up of slit chip having a (slit) structure fixed electrode held electrets, the electrets, from slider chip having a movable electrode (slider) structure (size Figure-3 (a), of the movable portion is 1 mm angle) (Suzuki. *et al*., 2014), (Bischur and Schwesinger 2014).

Each chip is connected through a spacer. By varying the height of the spacer, it is possible to control the distance between the movable electrode and the fixed electrode (25 μm or so). Movable portion having a movable electrode has been suspended by a spring. When vibration is applied to the outside, relatively displaced in the direction of the arrow with respect to the substrate, a current is generated by the principle of electrostatic induction.

Detail the mechanism of the current generation in this structure. Figure-3 (a) and Figure-3 (b) show the basic elements of the movable electrode and the fixed electrode. If the positional relationship of the movable electrode and the fixed electrode is as shown in the figure, the induced charge corresponding to the fixed charge of the electrets will appear in the fixed electrode. Next, as shown in Figure-3 (c), when the movable electrode is moved horizontally with respect to the fixed electrode, a portion of the induced charge that has been localized to the fixed electrode appears to the movable electrode. As described above, the fact that with respect to the fixed electrode, the slider is relatively displacement, (current) is generated charge transfer the load between the two electrodes changes in the induced charge occurs.

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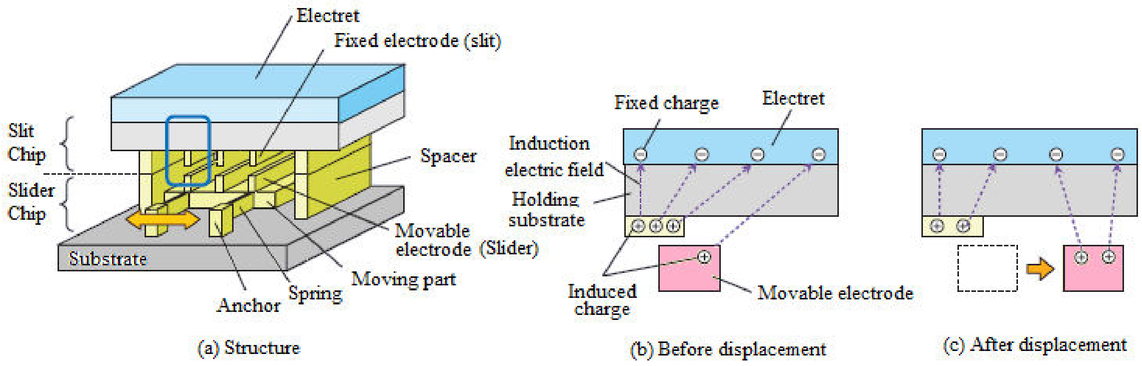

Figure-3. Slit and slider structure.

THE FABRICATION PROCESS

MEMS process (De Los Santos *et al.*, 2004) prepare a slit structure and slider. After producing independently the slider tip and slit chip as shown in Figure-3 (a), it will be bonding with flip-chip bonding, to produce a single chip.

This fabrication process is described with reference to Figure-4. First explain a method for manufacturing a slider chip. After the Si wafer on which a wiring layer is formed, thereby forming a resist pattern by photolithography, to form the lower structure such as a spacer with gold plating (Figure-4 (a)). After removal of the seed layer and the resist, by using a photosensitive organic resin, and flattens the lower structure (Figure-4 (b)). It is formed on a temporary basis in order to form a

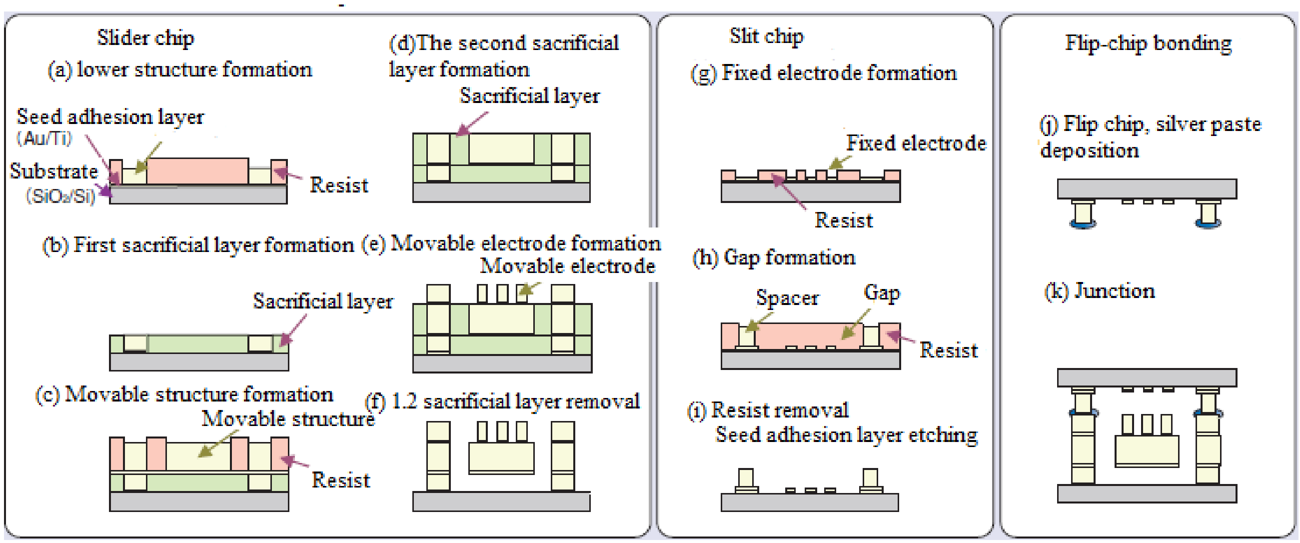

Figure-4. Fabrication slider chip.

movable element structure as a sacrificial layer. Onto a wafer is planarized, the organic resin is repeated a plurality of times similar process in Succoth, and stacked structure such as the movable electrode and the movable unit (Figure-4 (c) ~ (e)). Finally, after it was cut into chips and the wafer, and that it is removed by ashing the organic resin is a sacrificial layer, is the state in which the movable portion which is suspended by a spring moves (Figure-4 (f)). As for chip slit it fabricated by the same method. The first layer, forming a lower structure of the spacer and the fixed electrodes by gold plating (Figure-4(g)), the second layer forming an upper structure of the spacer (Figure-4 (h), and (i) will cut into chips). Structure is completed by bonding by flip chip bonding (Enami *et al.*, 2015), the upper and lower tip thereof (Figure 4 (j), (k)) complete.

The chip was actually manufactured by using the manufacturing process described above. Movable portion of 1 mm angle, the structure of the 10 μm class is fabricated in the periphery, as the element of the energy harvest of electrostatic induction method; we were able to produce a very small structure of the world's smallest level.

POWER GENERATION EXPERIMENT

Basic experiment of generating electric power using an evaluation system conducted, such as shown in Figure 5. Place the electret that is charged on top of the chip of Figure-4 (k). Place the shield plate on top of the electrets, and secure it to the chip electrets. It is vibrated in the horizontal direction by the vibrator and the tip, was measured by a lock-in amplifier current is synchronized

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with the vibration. If the vibration from the shaker, the movable portion is relatively displaced from the initial state, current is generated. As an external vibration caused by a vibrator, we have applied while sweeping the frequency, the vibration of the acceleration of 1 m/s^2.

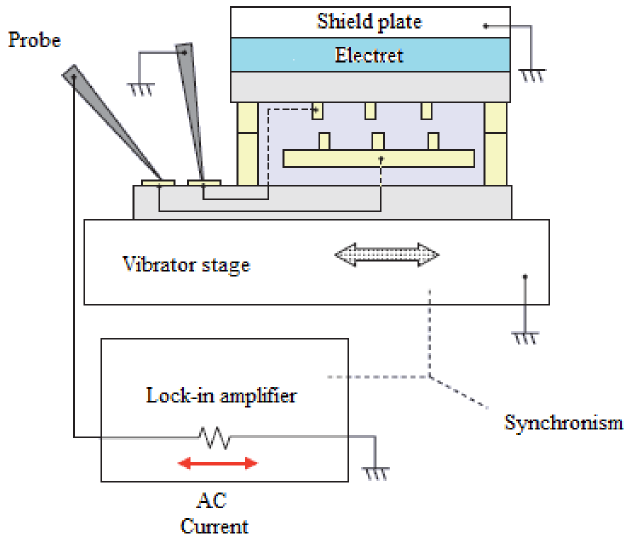

Figure-5. Power generation evaluation system.

In this evaluation, as an electret, we used a film of common materials that are used widely in the world which is ETFE (Ethylene-TetraFluoro Ethyrele copolymer). It is charged by corona discharge treatment (Eifert *et al.*, 2015), (a), a film of 100 µm thickness. The results of the charge ETFE film of corona discharge treatment. We find that on the surface of the film, there is a charged voltage of 450 V.

Figure-6 shows the results of the energy assessment. This indicates that the vibration from the outside, at the resonant frequency of the movable portion, current is generated. From these results, in the vibration from the outside, confirmed that the MEMS element having a slit and slider structure is power generation continues around 1.75 mW saturated compare to previous micro piezoelectric cantilever break down by time to 0.375 mW. Moreover, voltage generated by performance 9.37 V while previous model break down at 1.97 V. The result is sufficient for power up 3 sensors employed with microcontroller.

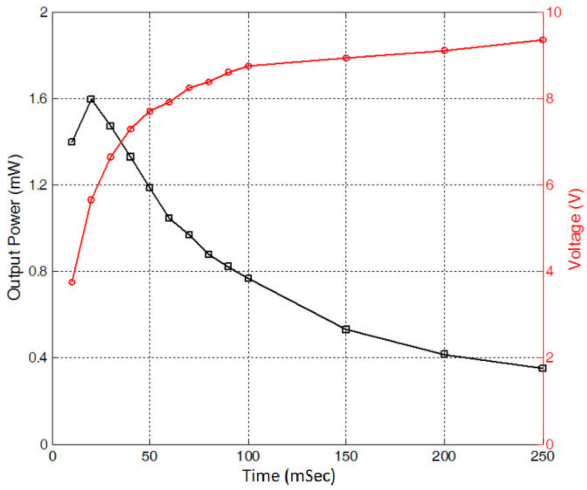

Figure-6. Energy assessment results.

FUTURE DEVELOPMENT

Develop a vibration energy harvesting technology based on MEMS was introduced. We aim to further performance of the power generation device, by working on the integration various mechanical sensors circuits for management power generation in medical application. In the future, research and development of energy harvesting technology intend to lead to the creation of ubiquitous service to support a safe, secure, and comfortable life.

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