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Research Article

Bond-Graph based simulation of sensors and piezoelectric beams' ranges in energy recovery circuit

Duong Quang Thien*, Nguyen Thi Hai Van

ABSTRACT

Currently, with the disappearance of fossil energy sources, finding new alternative energy sources is very necessary such as: solar energy, wind energy, tidal energy, flow energy, ... However, these energy sources require high investment capital, large capacity, and bulky size. In circuits requiring small power sources (below 12V), it is not applicable, or only used through intermediate devices such as transformers, current transformers; Therefore, the application of energy from mechanical vibration has been proposed as an optimal measure compared to the above methods..Energy recovery from mechanical vibration is the activity of reusing a part of the energy generated when there is a fluctuation with a constant frequency on solid surfaces. Mechanical vibrations occur mostly in production systems, and it also causes some damage. However, we can take advantage of these mechanical vibrations to cater for some basic life requirements if they have the right vibration frequency and amplitude, or we can adjust to have optimal vibration conditions. This article uses an intermediate control circuit to convert the energy generated by mechanical vibration into electrical energy (current and voltage), in which the piezoelectric sensors or piezoelectric beam are placed on the structures to be measured, we will receive oscillations at different frequencies, so that we can analyze the damage caused by vibration and evaluate the application range of piezoelectric sensors and piezoelectric beam on a case-by-case basis. The purpose of the paper is to study a constant frequency energy recovery circuit to create some initial parameters,the use a Bond-Graph to optimally simulate this energy recovery process. This is also a very good solution for generating energy for the SHM system from other mechanical energy sources.

Key words: Energy recovery, monitoring system, mechanical vibrations, piezoelectric, sensors, SHM system

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INTRODUCTION

Energy recovery is an area that provides the opportunity to develop science and technology applications that are currently struggling to obtain a reliable source of energy. This technology is suitable for Structural Health Monitoring (SHM) systems because it takes advantage of the different mechanical energy generated by the means of transport in moving process; The SHM system monitors the operation, detects and locates the damage occurring in vehicle structure (aircraft, space ship, etc.), thereby evaluating the nature and sseverity of the damage. "Structural Health Monitoring (SHM) systems have become a part of new avionics systems which will formfuture aircraft. Their objectives are to detect and locate damages occurring within the aircraft structure."[1], "SHM has become a part of new avionic systems which will form future aircrafts. To allow their deployment throughout the aircraft, they have to be autonomous. Vibration Energy Harvesting is a promising solution to provide energy to such systems"[2].

METHOS RESEARCH AND SURVEY RESULTS

This is a research paper. Based on the parameters measured from experiments on the control circuit model for piezoelectric sensors and piezoelectric beams (Figure 1), then simulate the energy conversion process, assessing the application ranges of each sensor type to apply in practice.

For this study, the author made a simple energy recovery circuit (Figure 2), based on the working principle of LTC 3588-1 IC; Using this circuit to obtain the measured parameters, the source of the experiment is the mechanical vibration source generated from a vibrator with a constant frequency. Based on the above parameters, we simulate on 20-sims software and comment on results.

Energy recovery circuit and experimental diagram

On the diagram, the piezoelectric sensors or piezoelectric beams will be placed on a thin tin sheet (2 -

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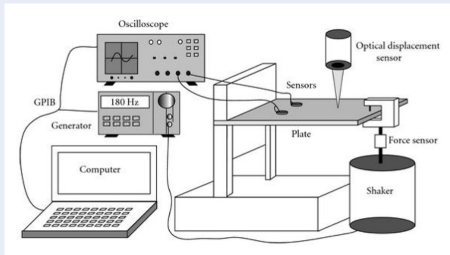

Figure 1: Energy recovery experiment [3]

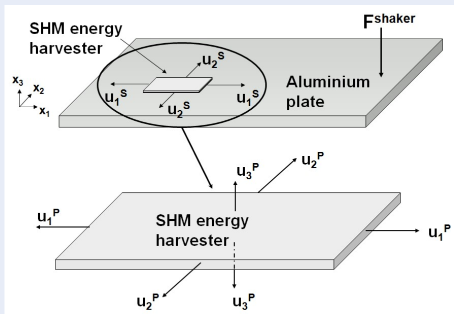

Figure 2: Energy recovery principal

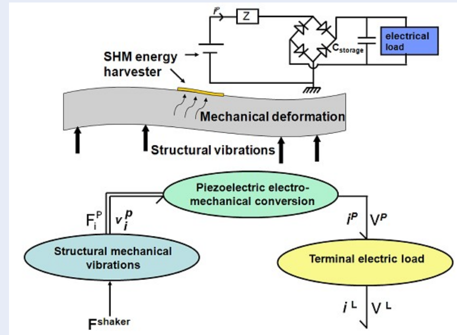

Figure 3: Experimental diagram and Bond-Graph [5]

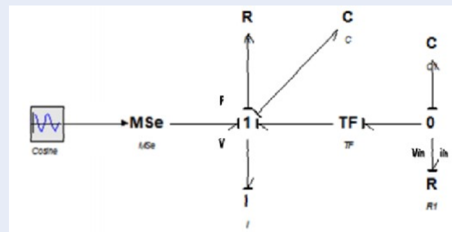

Figure 4: Bond-Graph diagramfor whole circuit

3 mm), the oscillating source will impact the tin plate with a variable frequency vibration, and the sensors will transfer mechanical energy into electrical energy, introduced into the recovery circuit and the resulting electrical signals to the subsequent processing.

The parameters taken from the experiments for piezoelectric sensors or beams are different, which clearly shows the difference in methodology and scope of use in this article.

Simulation

To simulate the above experiment, we uses the Bond-Graph [4] model. In the principle diagram (Figure 3), it is easy to see that energy exists in two forms: the input is mechanical energy (F, V) and the output is the electrical energy (U, I). When performing simulation with other tools (block diagram, signal diagram, ...), we have to convert to a unit. Bond-Graph, however, is in the "multi-energy" field, meaning it can incorporate many fields seamlessly. This is a powerful tool because of the ability to represent physical quantities in the form of bi-directional exchange [3]. The diagram below shows the transformation from the principle diagram to the Bond-Graph of the energy recovery circuit.

We create Bond-Graph and put the data that are measured and calculated by the software 20-Sims (Figure 4), this graph will show the change of quantities when the transition occurs. When testing the system with oscillations at different frequencies, we obtain a graph representing the dependence of the voltage as well as the power on the oscillation frequency.

Research results

After the experiment, based on the data sheet of the thin tin plate and the oscillation values generated on it, we have constructed the graphs that distinguish the function of the piezoelectric sensor and piezoelectric beam as follows (Table 1).

Table 1: Post-experimental data of the sensor.

L	0.025m	**L**	0.025m
H	0.01	P	$1.155x10^{13}$
V	$6.25x10^{-7}$	M_p	0.004813
S_{33}	$2.3x10^{-11}$	**TF**	$8.66x10^{-14}$
D_{33}	425	**C**	$3.68x10^{-11}$
ε_{33}	914	Pm	7700W
A	$6.25x10^{-4}$	**W**	2376242
K	27173913043	C_c	571.25

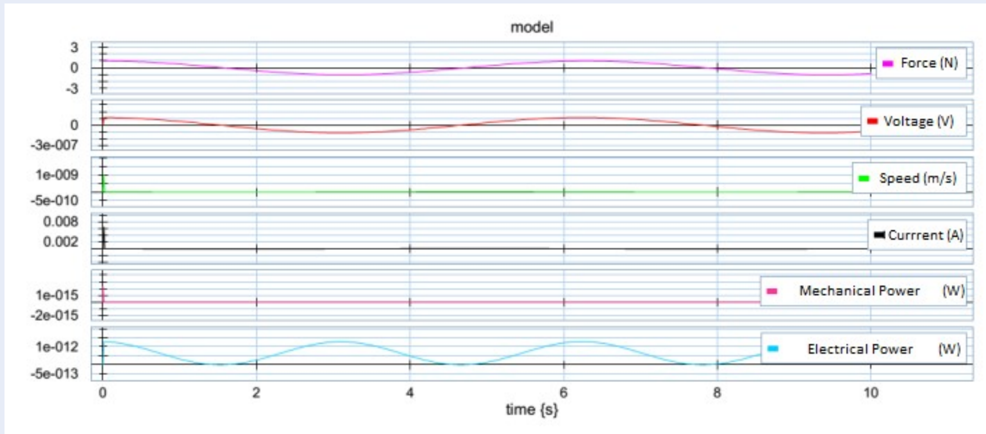

Figure 5: Graphical representation of the quantities when the sensor is working

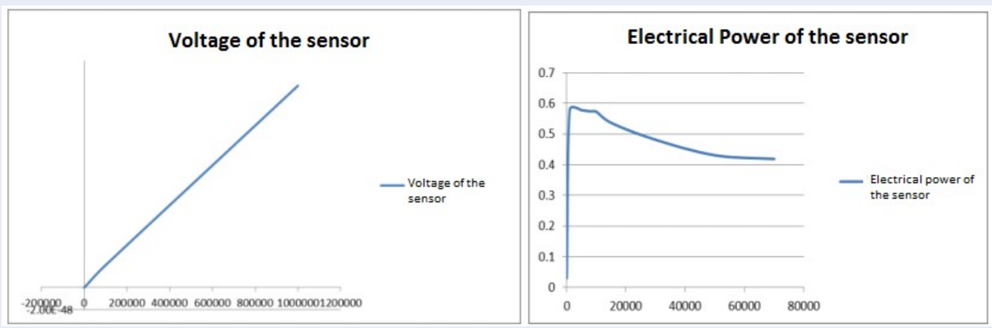

Figure 6: Voltage graph and power graph of the sensor interms of frequency

Throughout the Table 1, we find that there are some very large parameters compared with the rest (Figure 5 , Figure 6). This is understandable because during the simulation, these parameters are directly related to the operating range of the piezoelectric sensor when working in high frequency conditions.

Table 2: Post-experimental data of the piezoelectric beam.

L	0.025m	**L**	0.025m
A	0.000625	h_c	5x10^{-5}
Hp	5x10^{-4}	s_{11}	1.7x10^{-11}
d_{31}	-170	ε_{33}	914
K	0.1225	C_m	8.16
m_{eq}	0.0048125	**R**	0.01

In contrast to the piezoelectric beam (Table 2), the parameters are very small, the change in the parameters through simulation is often difficult to see and it only really changes when working at low frequencies (Figures 7 and 8).

DISCUSSION

Throughout the experiment, we noticed the fundamental differences in the use of piezoelectric sensors and piezoelectric beams. It is found that piezoelectric sensors only have resonance at high oscillation frequencies, so they are suitable for use in vehicles operating under harsh conditions (aircraft, spaceship,…). In contrast, piezoelectric beams only have resonance at low frequencies, so they are suitable for use in light industries with high reliability.

SHM is a widely used system in developed countries around the world. The purpose is to measure, retrieve information and to provide a reasonable analysis of the structural damage of large and modern buildings (bridges, tall buildings, works of politic and military, ...)[6]. In recent years, combined with a number of energy recovery devices, SHM has been used in many scientific and daily life applications, contributing to

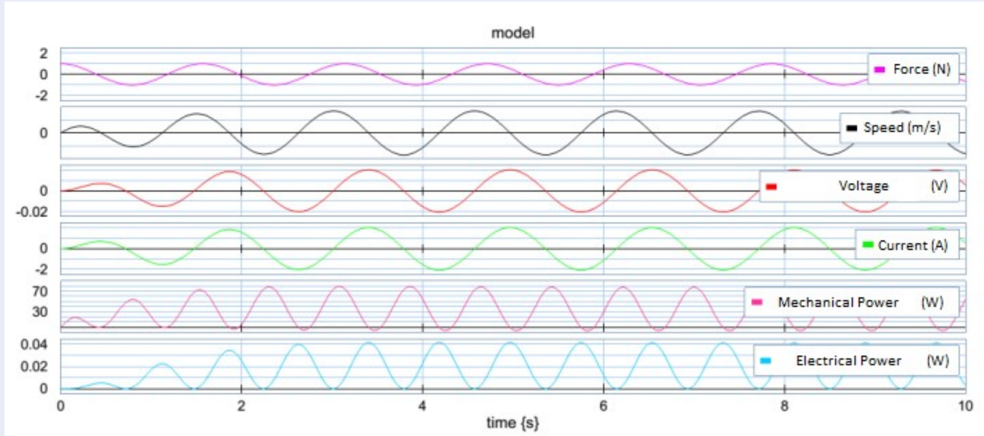

Figure 7: Graphical representation of the quantities when the piezoelectric beam is working

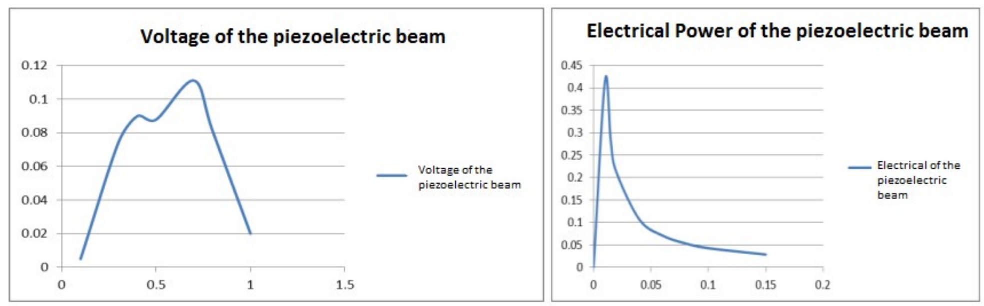

Figure 8: Voltage graph andpower graph of piezoelectric beam in terms of frequency

significant benefits. The transportation industry is not out of the law and it is particularly significant for the aerospace industry. The characteristics of the SHM system are well suited to this sector because of the fluctuations that occur when vehicles travel, and it further exerts its advantage for large and modern means of transport[7].

Currently in Vietnam, SHM system has not been widely applied. This system is only used to test the stability and safety of large, highly feasible bridges. However, it has not been widely used in other industries as well as in life. Due to limited reasons, this paper presents only very small aspects of the topic. Therefore, we can only apply this energy recovery circuit in the small power circuits, the output voltage is only provided to the amplifier as well as the source for the power circuits or the experimental set in the school.

CONCLUSION

Bond-Graph is a tool used in the field of mechatronics, especially in the field of integrated energy. In Vietnam, Bond-Graph has not been applied widely in simulation such as Matlab. Using Bond-Graph will open up a new direction for similar studies.

Through the voltage and frequency-power graph, it can be seen that the piezoelectric sensors only work (resonate) at high vibration frequencies and large oscillaton resistance, in contrast, piezoelectric beam works only where the frequency is low and the resistor is small or medium. We recognize the value of use of these devices when used in different working conditions; especially in harsh climates like in Vietnam. In the future, wireless technology will be studied to increase the usability and economy for large and high-space architectures, contributing to aesthetics. In the future, we will study for liquid media in highly complex scientific areas of social and industrial life.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

AUTHOR CONTRIBUTIONS

Duong Quang Thien: Building models and simulations, writing manuscripts of the paper.

Nguyen Thi Hai Van: Adjusting the parameters, simulation, paper format.

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Bài Nghiên cứu

Sử dụng Bond-Graph trong việc mô phỏng phạm vi ứng dụng của cảm biến áp điện và chùm áp điện trong mạch thu hồi năng lượng

Dương Quang Thiện*, Nguyễn Thị Hải Vân

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TÓM TẮT

Hiện nay, với sự biến mất của các nguồn năng lượng hóa thạch, việc tìm ra các nguồn năng lượng mới thay thế là hết sức cần thiết như: năng lượng mặt trời, năng lượng gió, năng lượng thủy triều, năng lượng dòng chảy,... Tuy nhiên các nguồn năng lượng này yêu cầu vốn đầu tư cao, công suất khá lớn, kích thước cồng kềnh. Trong các mạch điện yêu cầu nguồn năng lượng công suất nhỏ (dưới 25V) thì không thể ứng dụng được, hoặc chỉ được sử dụng thông qua các thiết bị trung gian như máy biến áp, máy biến dòng; nên việc ứng dụng nguồn năng lượng từ dao động cơ học đã được đặt ra như một biện pháp tối ưu so với các phương pháp trên.Thu hồi năng lượng từ rung động cơ học là hoạt động tái sử dụng một phần năng lượng tạo ra khi có sự dao động với tần số không đổi trên các bề mặt chất rắn. Rung động cơ học xuất hiện hầu hết trong các hệ thống sản xuất, và nó cũng gây ra những thiệt hại nhất định. Tuy nhiên trong một vài trường hợp, chúng ta có thể tận dụng các rung động cơ học này để phục vụ cho một số yêu cầu cơ bản trong đời sống, nếu chúng có tần số rung và biên độ dao động phù hợp, hoặc chúng ta điều chỉnh để có điều kiện dao động tối ưu. Trong bài báo này sử dụng một mạch điều khiển trung gian để biến đổi nguồn năng lượng do rung động cơ học gây ra thành năng lượng điện (dưới dạng dòng điện và điện áp), trong đó các cảm biến áp điện hoặc chùm áp điện được đặt trên các kết cấu cần đo, qua đó chúng ta sẽ nhận được các dao động với những tần số khác nhau, từ đó ta có thể phân tích được các thiệt hại do rung động gây ra, đồng thời đánh giá phạm vi ứng dụng của cảm biến áp điện và chùm áp điện trong từng trường hợp cụ thể. Mục đích của bài báo là nghiên cứu một mạch điện thu hồi năng lượng có tần số không đổi với quy mô nhỏ để tạo một số thông số ban đầu, sau đó sử dụng Bond-Graph để mô phỏng một cách tối ưu quá trình thu hồi năng lượng này. Đây cũng là một giải pháp rất tốt để tạo ra năng lượng cung cấp cho hệ thống SHM từ các nguồn năng lượng cơ học khác.

Từ khoá: Thu hồi năng lượng, hệ thống quan trắc, rung động cơ học, áp điện, cảm biến

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