

Influence of the excitation parameters of the mechanical subsystem on effectiveness of energy harvesting system

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Abstract. Piezoelectric transducers are used more and more often in modern technical devices. The wide range of their possible applications is a result of the possibility to use both direct and reverse piezoelectric effect. Nowadays, application of piezoelectric transducers in energy harvesting systems is getting more and more popular. It is caused by the easy way to convert energy of mechanical vibration to the electric voltage using piezoelectric transducers. This paper presents results of influence analysis of the vibrating mechanical subsystem's excitation parameters on the effectiveness of the system designed for energy harvesting. The considered vibrating system is a composite plate with piezoelectric transducer bonded to its surface. Vibrations of the system are excited by means of an actuator with possibility to change the excitation amplitude and frequency. Recovering of electrical energy from mechanical vibrations is possible by using the direct piezoelectric effect – generation of the electric voltage while the transducer is mechanically deformed. In carried out test Macro Fiber Composite (MFC) piezoelectric transducers were used. It was proved that the time that is necessary for switch on the output voltage in analyzed system depends on the frequency of the excitation.

1. Introduction

The development of piezoelectric transducers allows new applications of such kind of materials and improves operation of existing devices. One of those applications is energy harvesting – recovering of the electrical energy from vibrations. Systems designed for such kind of operations cannot generate a huge power but their advantage is that the energy is recovered from phenomena that are unavoidable and normally it would be lost. What is more such kind of energy production allows design systems that work in difficult conditions, where other ways of supplying is difficult or impossible. For example it is impossible to use wires or replace discharged batteries. This is why nowadays a lot of research works are concerned with energy harvesting [1, 4, 12, 13].

In such kind of systems piezoelectric transducers can be easily use for recovering electric energy from mechanical vibrations. In presented work the application of Macro Fiber Composite (MFC) piezoelectric foils in energy harvesting system is presented. MFC transducer is consists of rectangular piezo ceramic rods sandwiched between layers of adhesive, electrodes and polyimide film. Main benefits of the MFC given by the manufacturer are: increased strain actuator efficiency, damage tolerance, environmentally sealed packages, available as elongators and contractors [1, 11].

In this work some results of measurements carried out on laboratory stand are presented. A series of tests with different types of MFC transducers (types P2 and P3) with different field of active area



were carried out. Also the influence of excitation parameters on the system's effectiveness was verified, as well as, the influence of the mechanical subsystem fixing. Influence of the system's fixing (boundary conditions) was also considered. Measured data were acquired using the real time computer CompactRIO produced by National Instruments and analysed using LabVIEW software. Obtained results were juxtaposed and analysed. This work was a first step of the research project that aim is an implementation of the energy harvesting system on real objects and use of the generated electrical energy to supply systems with low energy consumption.

Gliwice research centre has a great experience concerning with tasks of modern technical devices and modern technology [5,7,9,10,16] as well as analysis and synthesis of mechanical and mechatronic systems [2,3,6,8,14] also supported by computer methods [15].

2. Laboratory stand for testing of energy harvesting system

In order to carry out test and measurements the laboratory stand that allows generating of mechanical vibrations with required parameters of excitation was created. It is presented in figure 1. The laboratory stand consists of:

- the composite plate (the mechanical subsystem) with piezoelectric foil bounded to its surface,
- the vibration exciter (in the form of electric motor) with the connecting rod mounted on the eccentric shaft and connected to the laminate,
- the motor speed regulator,
- measuring system consisting of a real-time computer CompactRIO produced by National Instruments with required analogue input card.

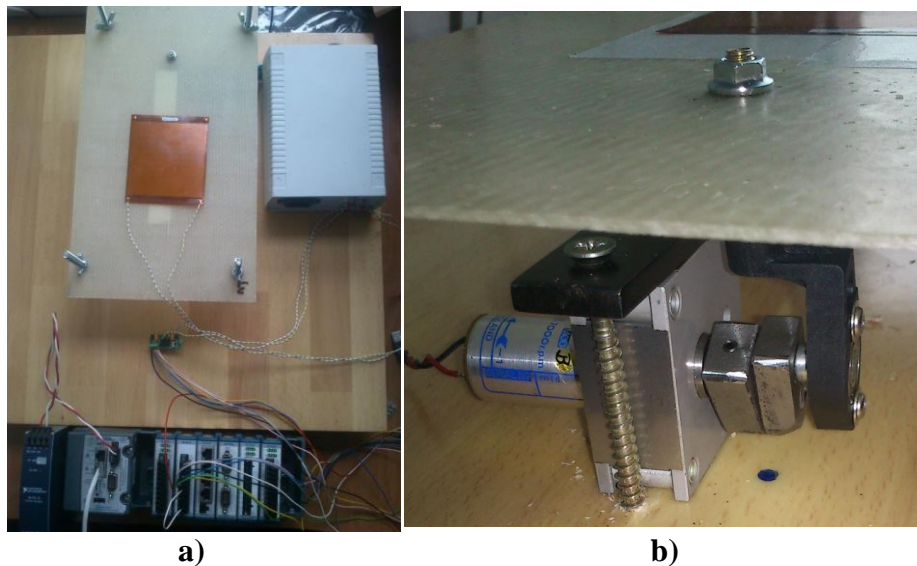


Figure 1. The laboratory stand with measurement equipment (a) and the system for vibration generation (b).

The system for vibration generation was designed in the way that allows adjusting values of vibration frequency of the mechanical subsystem with piezoelectric transducer as well as the amplitude of vibrations. In this paper results obtained in the case of the mechanical subsystem rigid fixing at four points at the corners of the plate are presented while parameters of excitation were changed. Because the CompactRIO real-time computer is a universal tool it was necessary to prepare the corresponding block diagram (computer software) in order to carry out required measurements and data acquisition. The dedicated software was created using LabVIEW.

In presented tests the Macro Fiber Composite transducer type M8585-P2 was used. It was glued on the surface of the mechanical subsystem and connected to the system for generated electric voltage processing and measuring system.

3. The system for generated electric voltage processing

Energy harvesting systems are usually used as power supply for systems with low power operating conditions, where the use or exchange for new ones standard batteries is difficult or impossible. The electric voltage generated by piezoelectric transducers as a result of vibrations of mechanical subsystems cannot be directly used as power supply. Especially when the vibrations of the system are random. This is why it is necessary to use the for generated electric voltage processing. In presented work the LTC3588 chip that can function as an alternative power source for systems with low power consumption was used. In figure 2 its application diagram and ready to use form are presented.

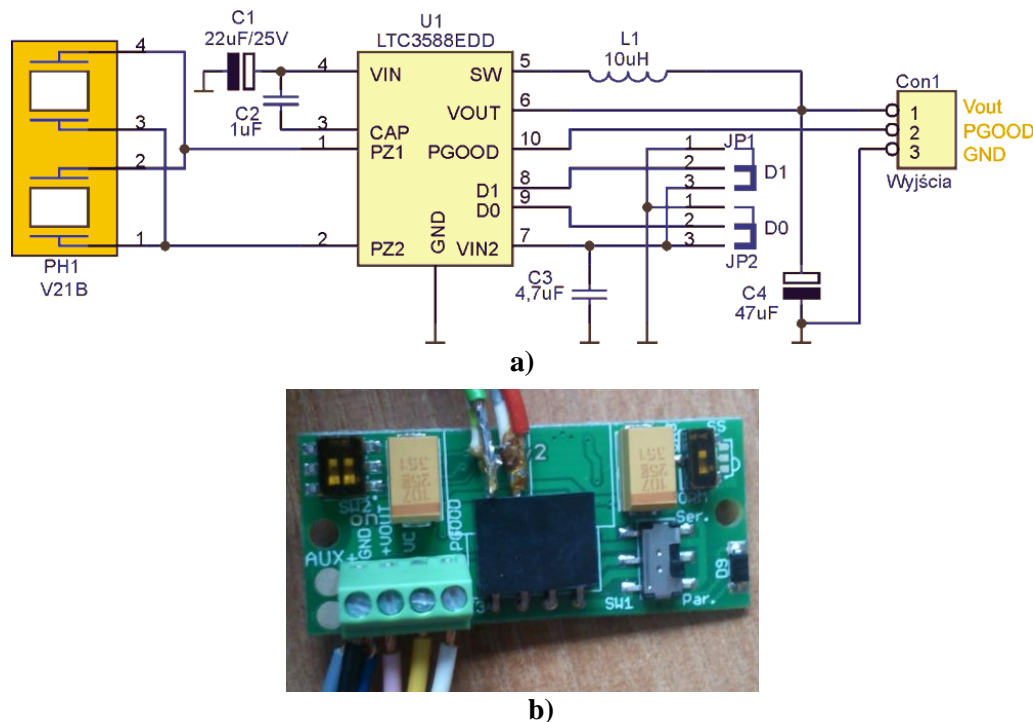


Figure 2. The application diagram of the inverter system (a) and ready to use form (b).

The converter LTC3588 produced by Linear Technology can be used to generate stabilized voltage of selected value: 1.8V/2.5V/3.3V/3.6V. It has the current capacity up to 100 mA. The system is structurally adapted to supply by the energy derived from unconventional sources, such as, for example, piezoelectric generators, photo- or thermocouples. It has the opportunity to work with a backup power source, for example battery is used when no power from piezoelectric transducer is available. A small number of additional components are needed for the operation of the inverter.

During carried out measurements values of the electric voltage generated directly by the piezoelectric transducer as well as the voltage on output of the inverter and status signal (denoted PGOOD in Figure 2a) were collected. In figure 3 values of the signal measured on the inverter system during loading and unloading of the system are presented. There can be noticed that if the value of the voltage on the system's capacitor reaches a certain value the state of the status signal as well as the output voltage is changed (output voltage is switched on or switched off). Those values are about 5.1 V on the capacitor during the system loading (switching on the output voltage) and 5.6 V during unloading (switching off the output voltage).

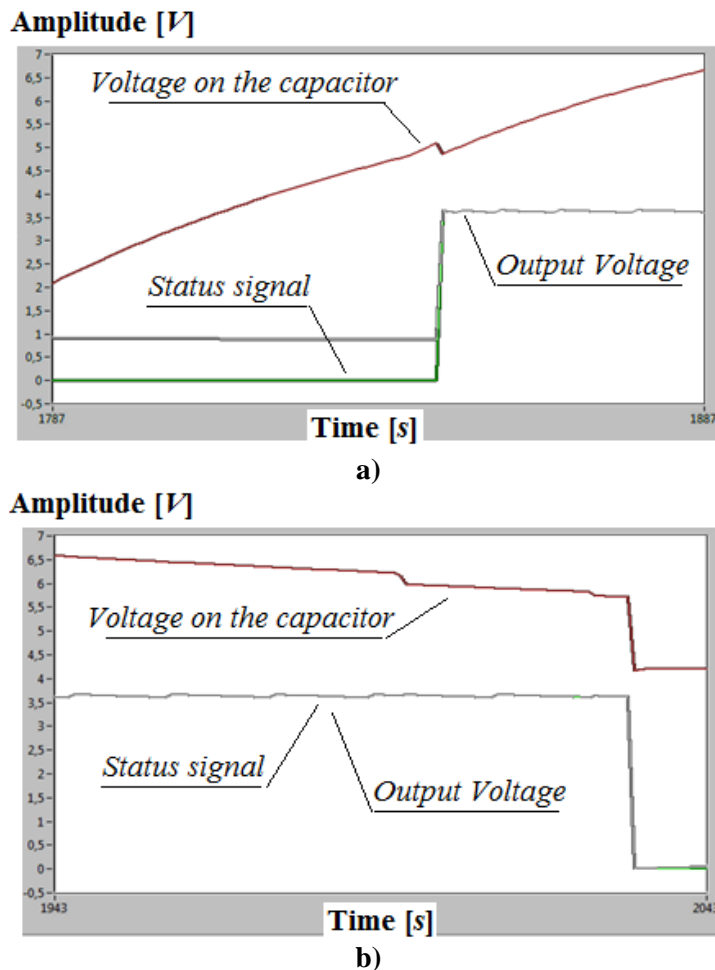


Figure 3. Values of the signals on the inverter system during loading (a) and its unloading (b).

4. Results of measurements

The main aim of the presented tests was to verify the influence of the parameters of vibrations of the mechanical subsystem on the time that is necessary to generate enough electric energy by the piezoelectric transducer in order to get stable output voltage on inverter system. In this paper the influence of the vibration frequency is verified. The amplitude of vibrations was the same during all measurements. The frequency was changed by adjusting the rotational speed of the engine that was used for vibration excitation. In Figure 4 results of tests carried out for vibration frequencies 30 Hz, 45 Hz and 180 Hz are presented. On presented graphs measured values of the electric voltage generated by the transducer, voltage on the capacitor of the inverter system, output voltage and status signal are presented. It can be noticed that increase of the voltage on the capacitor has a linear characteristic. Time that is necessary for switch on the output voltage depends on the frequency of the excitation. For the higher frequencies the external equipment can be power supplied by the system faster. For the excitation frequency 30 Hz the time necessary to load the system is about 2000 ms. For the excitation frequency 45 Hz it is about 1100 ms while for the 180 Hz it was only about 950 ms.

5. Conclusions

The aim of this work was to verify influence of the mechanical subsystem vibration parameters on the effectiveness of the system designed for energy harvesting with electric voltage processing based on LTC3588 chip. In this paper influence of the vibration frequency was presented.

The carried out test show that by increasing the frequency of vibration it is possible to reduce the time necessary to switch on the stabilized output voltage that can be used for power supply of any kind of systems with low power operating conditions. The proposed energy harvesting system can be applied in technical means that work in difficult conditions, where other ways of supplying is difficult or impossible. The influence of the other parameters of the mechanical subsystem vibrations will be presented in other publications.

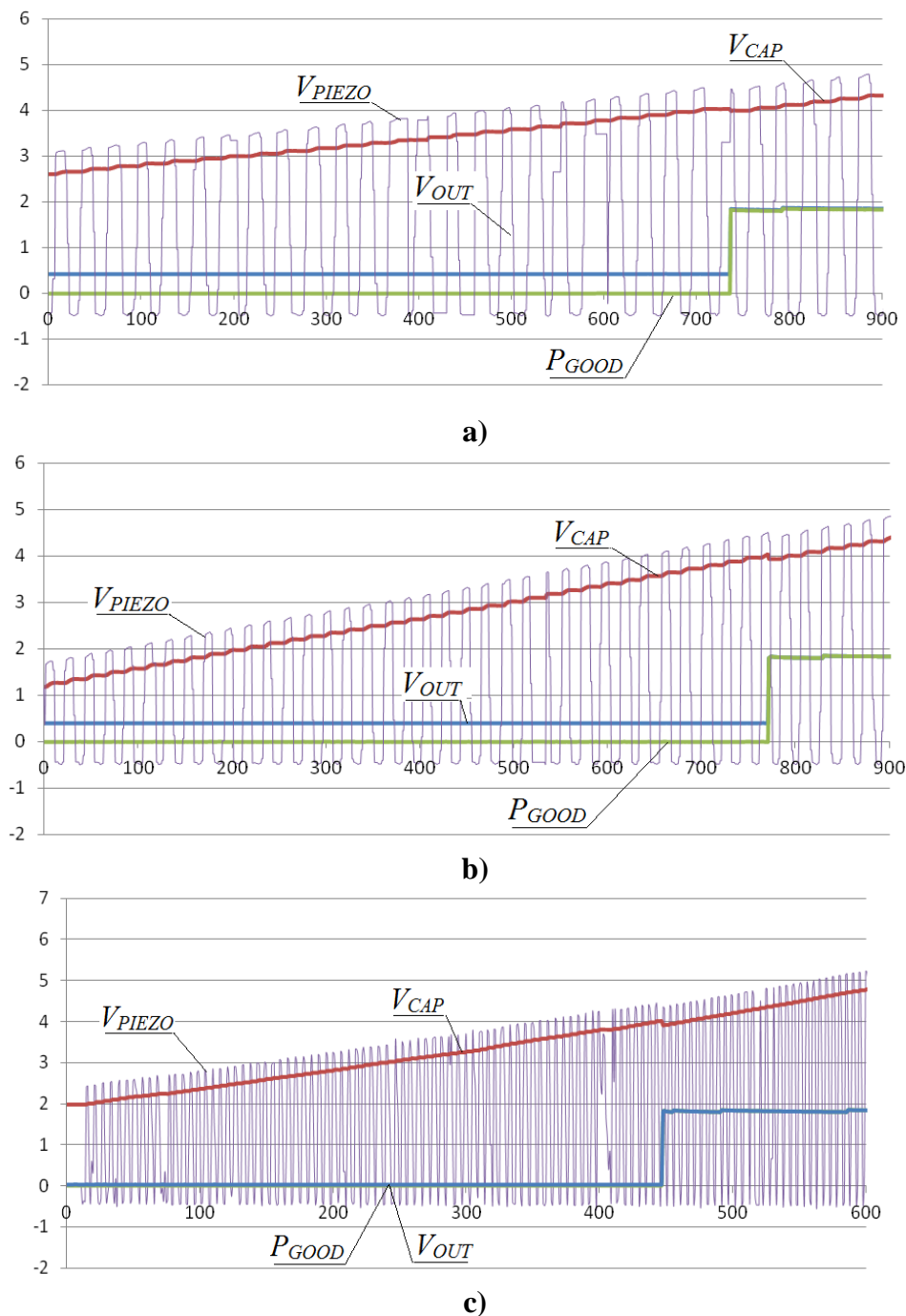


Figure 4. The results of the measurements for mechanical subsystem vibration frequency 30 Hz (a), 45 Hz (b) and 180 Hz (c).

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