Estimation of the power of a MFC type piezoelectric used for electric energy recovery from vibrations

M Placzek and M Brzezny
Silesian University of Technology, Faculty of Mechanical Engineering,
Institute of Engineering Processes Automation and Integrated Manufacturing Systems,
Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: marek.placzek@polsl.pl

Abstract. One of the possibilities of piezoelectric transducers applications are systems for electric energy recovering from mechanical vibrations. The obtained amount of electric energy is not big but sometimes it is enough for power supply some elements such us microcontrollers or other electronic devices with low energy consumptions. The main advantage of piezoelectric transducers used as power supply elements is that there is no necessary to replace batteries or use wires. In this paper results of laboratory tests of Macro Fiber Composite piezoelectric transducer that is used for electric energy recovering from mechanical vibrations are presented.

The aim of the presented work was to estimate the maximum power of the MFC transducer that can be used as power supply for some electronic device. To do that a series of laboratory tests was done. The MFC transducer was glued on the cantilever beam surface. The beam’s vibrations were excited using the second one MFC transducer. The tested MFC transducer was electrically loaded with a voltage divider of various resistances. The generated electric voltage was measured and electric current was calculated to estimate the maximum power of the piezoelectric MFC transducer.

1. Introduction
In the world of ubiquitous electronics and miniaturization, the way of powering electronic circuits is becoming a more and more frequent problem. The limitations that are generated by wires or batteries are impossible to solve at some point. Cables become not handy and sometimes impossible to implement, while batteries, despite their great popularity, sometimes do not fulfil their role. This is mainly due to the short operation time, which translates into frequent replacement or low-efficiency of cell loading system. Another problem is the size of the battery, which with increasing capacity increases their size and weight. Opposite these problems, piezoelectric materials can be used which, by means of mechanical vibrations, can generate electric voltage and power low-current electronic circuits.

All technical means are developed all the time to obtain better efficiency, exploitation, lower noise and vibrations etc. [1,2]. Development of mechatronic systems is a big step in this process [3-6]. Piezoelectric materials are getting more and more popular in many modern technical devices [7-12]. This is because of their very good properties that allow them to work as sensors as well as actuators in various applications. There is a possibility to apply them for example in systems for vibration control, displacement control and so on in order to develop them and to obtain better efficiency [13-15, 21, 22]. One of the possibilities of piezoelectric transducers applications are systems for electric energy
rerecovering from mechanical vibrations [16-20]. The obtained amount of electric energy is not big but sometimes it is enough for power supply some elements such as microcontrollers or other electronic devices with low energy consumptions. The main advantage of piezoelectric transducers used as power supply elements is that there is no necessary to replace batteries or use wires. Piezoelectric materials are also developed all the time to get new, more effective transducers that can offer better piezoelectric properties and so get better efficiency of transforming mechanical energy into electric energy in energy harvesting applications. Such kind of non-classical piezoelectric transducers are Macro Fiber Composite (MFC) transducers that were invented by NASA in 1996. They are produced as thin, elastic foils so they can be glued on almost every surface or can be laminated in intelligent structures used in variety of applications, such as vibration and noise damping, excitation of vibration and so on [8].

In this paper results of laboratory tests of Macro Fiber Composite piezoelectric transducer that is used for electric energy recovering from mechanical vibrations are presented. So, it is a task of the direct piezoelectric effect application. The aim of the presented work was to estimate the maximum power of the MFC transducer that can be used as power supply for some electronic device. To do that a series of laboratory tests was done. The MFC transducer was glued on the cantilever beam surface. The beam’s vibrations were excited using the second one MFC transducer. The tested MFC transducer was electrically loaded with a voltage divider of various resistances. The generated electric voltage was measured and electric current was calculated to estimate the maximum power of the piezoelectric MFC transducer that was used as a source of electric power.

2. An overview of the state of art

With the development of electronic systems, over time they have become smaller and more energy-efficient. Therefore, other methods of obtaining electricity to power these systems, other than traditional ones, have been started. It soon turned out that acquiring energy to supply such systems is limited only by the imagination of the designer himself. There are phenomena in each place that can be used to harvest energy. Research on energy harvesting from other, alternative sources has quickly become a new area that will avoid problems with powering systems with very low power, placed in places where the traditional power sources cannot be used. Such an innovative way sometimes even allows you to give up the battery.

In the work [12], a group of scientists has undertaken to investigate the possibility of acquiring electricity from the movement of muscles inside the body to power the heart pacemaker. The PZT material was placed on a polyamide tape, which after previous bio-neutrality tests with smooth muscle cells of mice showed no negative effect on cell reproduction and metabolism. In laboratory conditions, the ready-made PZT MEH (Mechanical Energy Harvester) tape was able to produce from 1V to even 4V and 0.04A - 0.14A depending on the material deflection from 1.5mm to 10mm. Tests carried out on beef and sheep heart showed that the efficiency of the piezoelectric material differs depending on the place of its attachment (right ventricle, left ventricle, free wall), as well as the angle of its attachment in a given area of the heart. Studies have shown that the best results are obtained by placing the piezoelectric tape on the right chamber at an angle of 45°. Although the left ventricle is more muscular, the effects are much better on the right ventricle. Depending on the organism, the tapes in the most optimal place were able to generate up to 4V on beef and 2V on sheep's heart. The heart rate also affects the measurement results. The tests were performed on beef heart and the values were 4.06V for the heart rate of 80 contractions per minute to 4.32V for 120 contractions per minute. The diaphragm was the next muscle on which the PZT MEH tape was placed. Despite the differences in the structure and action of the heart muscles and the diaphragm, there are no significant differences in the performance of the system. In addition, the PZT placed on the polyamide is sufficiently flexible and durable to attach it to different muscles. Such systems can produce up to 0.18 μW/cm² by placing them on the right ventricle. Unfortunately, a single such system would not be able to power a heart pacemaker yet. The most energy-efficient versions take about 0.3 μW, therefore more layers of PZT have been laid on the one polyamide patch. A polyamide patch with three and five PZT layers was constructed for testing, which can generate
for three layers of 5.8V and for five layers of 8.1V. Five layers of PZT on the polyamide patch already generate 1.2 μW which is sufficient for the correct operation of the heart pacemaker.

Another example is the generation of electric energy from walking [13]. For the construction of footwear with piezoelectric strips, tapes developed by NASA and produced by Face International Corp. were used. The properly bent system was placed in a sports footwear between the sole and the insole exactly under the heel. In addition, an additional PVDF piezoelectric tape was placed under the toes. Such shoes, when moving at a speed of one step per second, could generate about 100 mW of electric energy. By loading each strip with a 250.000 ohms piezo resistor, the PZT belt generated up to 150V, and the PVDF belt was able to generate about 60V.

Another way is to receive energy from falling drops of water. In the work [14] it was shown that the energy of a drop of water falling on the dry surface of the system is not fully absorbed, but a part of it is used to spray drops of water, decompose and partially recoil. With the increase in the amount of water on the surface of the piezoelectric system, it was noted that with each next drop, more and more energy is absorbed, which translates into the efficiency of the entire system. Therefore, the energy recovered from one drop falling on a dry surface is much smaller than the energy of a drop of water falling on a previously formed water lens on the surface of the piezoelectric system. This situation persists until the water lens in the system is thin enough to transfer all the energy of the falling drop to the surface of the piezoelectric system. When the water layer in the system becomes thicker, some of the energy will not be delivered to the surface of the piezoelectric, and the next part will be dispersed over the entire surface, which will reduce the efficiency of the system.

Another example is the use of air flow for generating electric energy. Harvesting energy from Von Karman whirls can be very effective, as shown in [15].

As it was shown, a lot of phenomenon can be used to generate electric energy using piezoelectric transducers that generates it from mechanical vibrations.

3. Estimation of the MFC type piezoelectric transducer power in laboratory conditions

In the laboratory tests two MFC piezoelectric foils, which were placed on opposite sides of an aluminium beam mounted in a vice were used. The first piezoelectric film, which used the reverse piezoelectric effect, was used to generate vibrations of the beam. The beam was excited using harmonic electric voltage generated by the wave generator and amplified by the high voltage amplifier. A scheme of the laboratory stand is presented in figure 1. During the tests a MFC M8514-P1 piezoelectric transducers were used. Dimensions of the active area of the MFC transducer are 85 mm length (l_p), 14 mm width (w_p) and thickness (h_p) about 0.3 mm. Dimensions of the beam are 400 mm length (l_b), 20 mm width (w_b) and thickness (h_b) 2 mm.

![Figure 1](image_url)  
**Figure 1.** A scheme of the laboratory stand.

The second piezoelectric foil, using a simple piezoelectric effect, was deformed under the influence of the vibration of the aluminium beam and connected to the rectifier system. This piezoelectric foil was loaded with a voltage divider with different resistance values from 1MOhm to 800MOhm. The divider was used to test the maximum power of the piezoelectric film and to lower the tested voltage to safe values in the case of the analog-digital card used for measurements, which operates in the range from -
10V to +10V. The electrical diagram of the circuit used to load the piezoelectric film electrically and estimate its power is shown in figure 2.

![Figure 2. The electrical diagram of the circuit used to load the piezoelectric transducer.](image)

Tests were carried out with several different load and frequency values of the beam's vibrations. All measurements and calculations were performed bypassing the bridge rectifier. The resistor R2 had a constant, unchanging value of 100 kOhm, and the resistance of the R1 resistor was changed during measurements. Values of the generated electric voltage were measured and using equations of the electric circuits the power of the MFC piezoelectric foil was calculated.

In figure 3 values of the electric voltage measured on the resistor R1 depending on the frequency of the beam’s vibrations and value of the applied resistance is presented.

![Figure 3. Values of the electric voltage measured on the resistor R1 depending on the frequency of the beam’s vibrations and value of the applied resistance.](image)

Figure 4 presents the results of calculated electric current on the divider in relation to the source load in the case of the beam vibrations frequencies. Figure 5 presents the results of the calculated power of the MFC piezoelectric transducer in relation to the load for selected vibration frequencies of the beam.

![Figure 4. The electric current on the divider in relation to the source load in the case of the beam vibrations frequencies.](image)
Figure 5. The calculated power of the MFC piezoelectric transducer in relation to the load for selected vibration frequencies of the beam.

4. Conclusions

Analysing the obtained results, it can be noticed that while the resistance of the load of the source increases the value of the generated voltage increases regardless of the frequency of beam vibrations. This is characteristic for an electric current source. With the assumption of an ideal electric current source, the value of the generated voltage increases theoretically indefinitely. The real current source behaves similarly to the ideal one, with the difference that by increasing the value of the load, the value at which the voltage stops growing is obtained. This is related to the alignment of the load resistance with the value of the internal resistance of the source.

Figure 4 shows behaviour of the electric current at selected frequencies under different electric load values of the piezoelectric transducer. The characteristic feature of electric current sources is visible, which try to maintain a constant current value, regardless of the electric load value. Then, while the limit of the efficiency of the source is obtained by increasing the load, the current decreases.

In figure 5 a characteristic extreme is noticeable, which determines the maximum power of the electric current source. This means that the divider resistance equals the internal resistance of the piezoelectric tape. It is also visible that as the vibration frequency of the beam increases, the power value is higher but after exceeding the internal resistance value by the electric load value, the power drop is much larger and more visible than in the case of lower beam vibrations frequency, where the drop is smoother.

The analysed MFC piezoelectric transducer generates a different power depending on the frequency of deformation of the film and the applied load. On the characteristics of the source power in relation to the load in the case of selected frequencies, it is possible to read that in the tested range, with increasing beam vibrations frequency, the piezoelectric tape can generate more power and requires less load to obtain maximum electric power. The analysed MFC piezoelectric tape obtained the highest performance loaded with a 200 MOhm resistor at a beam vibration frequency equal to 20 Hz. In the case of given excitation and load parameters, the MFC piezoelectric transducer generated a power of about 128.81μW.

5. References

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