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MINIATURIZED MODEL OF A MACRO FIBER COMPOSITE PIEZOELECTRIC TRANSDUCER BASED WIND TUNNEL AND ITS OPTIMIZATION FOR ENERGY HARVESTING

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Abstract

In this study, wind energy has been used to investigate the voltage produced from macro fiber composite (MFC) piezoelectric transducers at different conditions. Miniaturized model of a wind tunnel has been designed and produced to measure and optimize its performance practically in the lab environment. The geometrical shape of this wind tunnel is a rectangular prism with fiber glass side walls one of which includes small fan motors as the source of wind. The wind speed reaching the piezoelectric cantilevers has been adjusted by the applied voltage on these fans. MFC transducers are placed into this tunnel with different axes. The voltages produced by these active materials in different positions have been compared and the proper placement of the material for the maximum electrical signal output has been determined. In addition, it has been aimed to increase the produced voltage by attaching differently shaped polyurethane materials on the MFC piezoelectric transducer. After establishing the optimum conditions, the total produced voltage is brought to maximum voltage level. But the storage operation could not be performed because the obtained current level was insufficient.

Key words: *MFC, Piezoelectric, Wind tunnel, Energy harvesting*

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1. Introduction

Energy need and energy generation studies have always been popular subjects in the past and today. Regarding the wind flow energy and wind turbines, there are small sized energy production studies at mW levels [1-4] as well as kW-sized power plants [5-8].

Piezoelectric materials which produce electricity in response to a mechanical effect are mostly preferred in small size energy production applications. In this work, wind flow energy is applied to move the piezoelectric material and produce electricity.

Priya et al. are the first to study energy harvesting using wind energy and piezoelectric transducers [9, 10]. They designed a windmill with several piezoelectric bimorph structures circled around a shaft. They obtained 5 mW power output at 4.5 m/s wind speed. Taylor et al. conducted a piezoelectric eel study in which they used a polyvinylidene fluoride (PVDF) based piezoelectric material [11, 12]. Li and Lipson followed this work by a “piezo-leaf” study which is a reference study in this area [13]. In their study, 1.8 μW power output is obtained at 3.5 m/s wind speed. Bryant et al. used aeroelastic flutter vibrations based piezoelectric benders, which can generate voltage even below 2 m/s wind speed thanks to the low expansion coefficient of PVDF material [14]. However, benders longer than 25 cm were concluded to be not suitable for use in microelectronic systems. These studies are the reference studies for piezoelectric energy generation using wind energy. There is a plenty of academic research on different sizes and material types of piezoelectric materials used in different designs and conditions [15-22]. In this study, macro fiber composite (MFC) piezoelectric transducer is used in a miniature wind tunnel application. Electrical output is obtained from transducers installed inside the tunnel and suitable conditions for the maximum energy production are determined.

2. Material and Methods

A miniaturized wind turbine, isolated from the outer environment, is designed to observe the electrical response of MFC material at different wind flow energies. This tunnel is made of fiberglass material with 31cm x 31cm x 60cm sizes. 9 fans are placed inside the tunnel which can provide constant wind energy to the MFC material at 2- 40 m/s speed range. Wind speed is measured by an anemometer placed in the tunnel. Fig. 1 shows the produced wind tunnel setup.

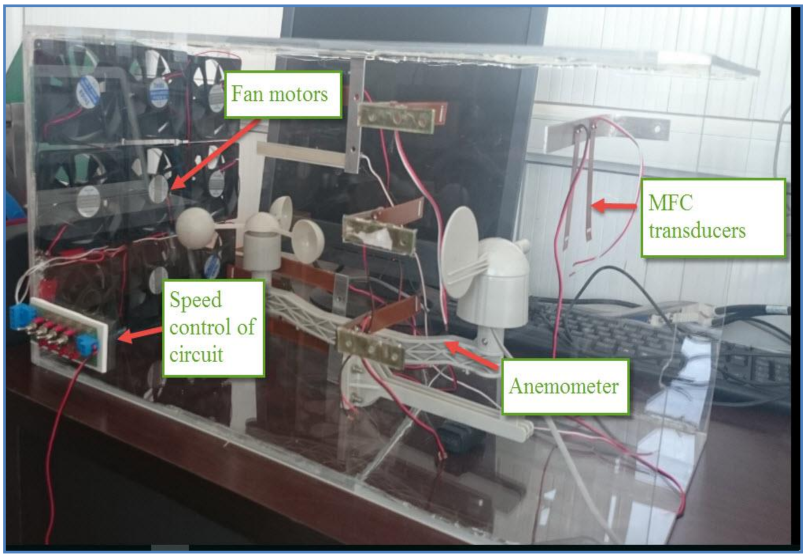

Fig. 1. The miniaturized wind tunnel designed to perform wind energy harvesting experiments using piezoelectric transducers at the lab conditions.

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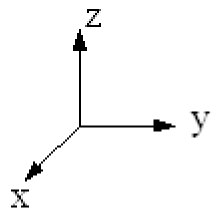
Table 1. Maximum voltage values obtained from transducers placed in x, y ve z directions (Constant wind 5 m/s, load 1MΩ).

Direction	V_{rms} (mV)
X	720
Y	830
Z	404



In order to increase the flexion and deflection of the MFC transducer and amplify the oscillation amplitude, additional masses are attached to the end of the material. The weight, shape and size of this additional part is changed for trial and error in order to find optimum material type and size. Table 2 gives the parts, sizes and material type that gave the maximum voltage values.

Each part in Table 2 is attached to the MFC transducer at x, y and z locations at constant wind speed (5 m/s) and produced voltage values are measured. Table 3 shows the voltage levels of MFC transducers with increased deflection angle. If the MFC transducer is to be placed on x or y direction in the tunnel, the part to be attached is “B” in Table 2, and “A” should be used for z direction. The effect of this additional part on the produced voltage is clearly seen in Table 1 and Table 3.

Table 2. Shape, size and type of the parts attached to the end of MFC material.

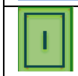
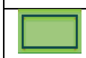
Added piece of MFC	Dimensions of the pieces	Type of the material
 A	3cm x 3 cm x 0,7 mm	rigid plastic
 B	4 cm x 2 cm x 0,7 mm	rigid plastic
 C	8cm x 12cm x 2cm	polyurethane
 D	12 cm x 8 cm x 2cm	polyurethane

Table 3. Variation of VPP obtained from MFC material according to the placement of the material of the material and the parts attached (wind speed 5 m/s, load 1 MΩ).

	Maximum produced voltage V_{PP} (5 m/s)			
	A	**B**	**C**	**D**
Position x	2100	2288	1280	485
Position y	3202	3420	2317	538
Position z	7793	6970	6227	2883

Measurement results show that the maximum voltage is obtained by placing the MFC transducer in z direction and attaching the triangular part A in Table 2. Fig. 2 shows the installation of MFC in the tunnel for the maximum voltage production. Fig. 3 gives the wave pattern produced by this installation state.

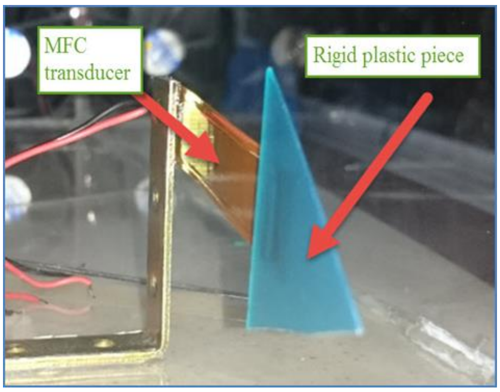


Fig. 2. Installation of MFC transducer in the tunnel for the maximum voltage production.

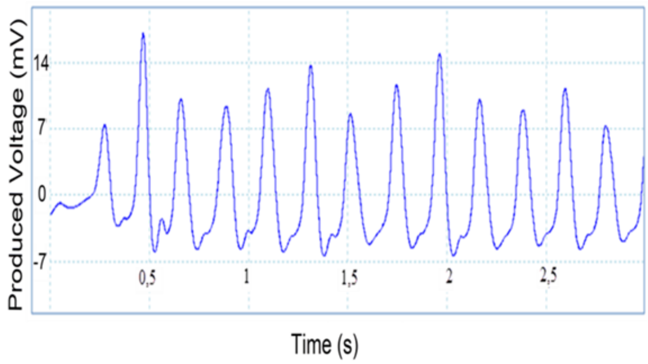


Fig. 3. Maximum *Vpp* wave pattern produced when MFC material is in its proper placement.

3. Power Calculation of the Produced Energy

After determining the proper direction in the tunnel in which the MFC piezoelectric transducer is to be installed, and the ideal part to be attached on the MFC transducer to amplify the produced voltage, it comes to monitor the voltage produced by the material according to the wind speed and associated variation of the produced power. Results are taken for the wind speed range of 2-8 m/s and given in Fig. 4 as the voltage and power produced by the MFC transducers installed in x, y and z directions. Power values in the graph are calculated using equation (1):

$$P_0 = \frac{(V_{rms})2}{R0} \qquad (1)$$

Fig. 4 shows that the voltage obtained from MFC transducer increases by the wind speed. Voltage level reaches its maximum at 6.5 m/s wind speed and decreases sharply beyond this speed. Another key point when calculating the maximum power is to choose the load, attached parallel to the piezoelectric energy harvester, according to the dielectric loss and damping coefficient of the material (R0) [23]. Therefore, R0 value is calculated using equation (2):

$$R_0 = \frac{1}{2\pi f C} \qquad (2)$$

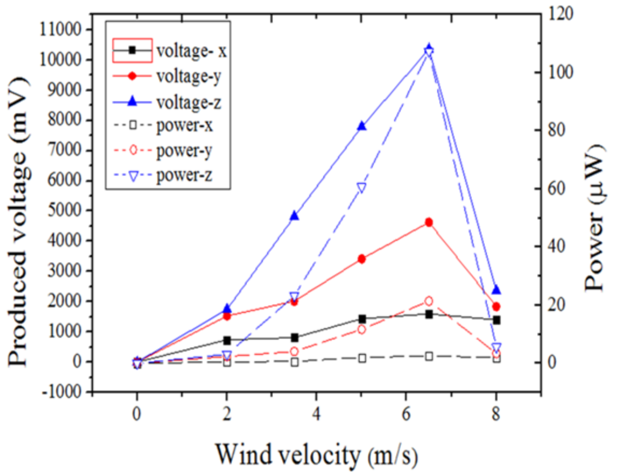


Fig. 4. Voltage and power produced by MFC transducer according to the wind speed.

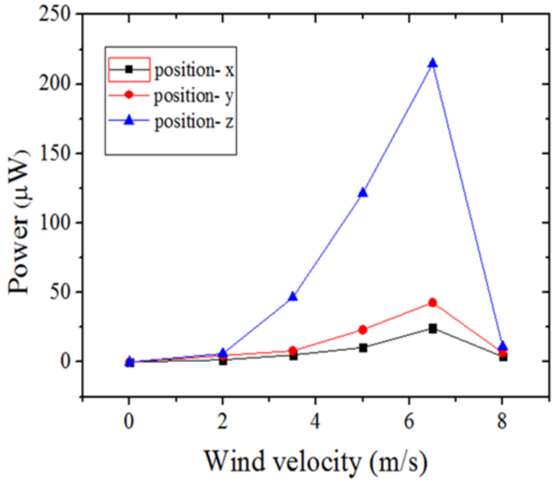


Fig. 5. Produced voltage level (R0=2 MΩ).

Load is calculated as 2 MΩ according to the calculated frequency of 10 Hz and 7.8 nF capacitance of MFC transducer used in the study. With these data, Fig. 5 shows that produced voltage is observed to increase up to 215 µW level at a wind speed of 6.5 m/s.

4. Results and Discussion

In this study, energy production capability of MFC piezoelectric material by using wind energy is investigated. In order to enable the MFC transducers to operate independent of the outer environment, a miniaturized wind tunnel is designed. Fan motors installed into the tunnel are adjusted by a control circuit and the maximum voltage produced by MFC transducer is found as 830 mV. Then, this voltage value is increased up to 7790 mV level at 6.5 m/s wind speed by attaching an additional part to the end of the material. Power calculated for this condition is 110 µW and is increased to 215 µW levels by attaching a parallel load to the transducer output. Low MFC current from 915 nA to 10.36 mA is not suitable for storage because the produced current should be greater than or equal to one-tenth of the current value required for charging a rechargeable battery [24]. Since the obtained values belong to only one MFC piezoelectric transducer, the number of transducers can be increased and materials can be connected in parallel, to achieve a storable level of electric current.

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