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Increasing the durability of piezoelectric impact-based micro wind generator in real application

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Abstract

The purpose of this study is to increase the durability of piezoelectric impact-based micro wind generator (PIMWG) in real application. Using new PIMWG design, numerical simulation, and experimental comparison analysis, we improved the durability of PIMWGs in real application. The experimental results show that the optimized PIMWG generated 2.4 mW (RMS value), and it did not crack within 40 h. In this study, we improved the durability of PIMWGs for real application.

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Keywords: piezoelectric; micro generator; durability; real application; wind power

1. Introduction

Sensor networks and monitoring system are widely used in real applications [1]. Recently, self-powered generators for sensor network application that use piezoelectric transducer have been actively studied [2]. Impact-type piezoelectric generators provide good generation and have higher power generation capacity than vibration-type generators [3.4]. However, the former can easily be damaged because of the brittleness of the piezoelectric device when pressure is applied to the impact-type piezoelectric generator [5]. Therefore, implementing this generator type in real applications is difficult. The purpose of the current study is to increase the durability of piezoelectric impact-based micro wind generators (PIMWGs) in real application.

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2. Design and numerical simulation

2.1 Design

The maximum stress of a cantilever beam occurs at the fixed end, and the stress is reduced closer to the free end. Thus, when a PIMWG generates electrical energy, the fixed end of the generator can easily be damaged. To increase the durability of PIMWGs, the stress distribution must be uniform. To find the uniformed PIMWGs, we compared the six types of PIMWGs, as shown in Fig. 1. Piezoelectric devices (PZTs) were installed at the fixed end, middle, and free end of the substructures. Figs. 1(b), (d), and (e) show the additional device (secondary impacter) installed to apply a larger stress to the free end [4].

2.2 Numerical simulation

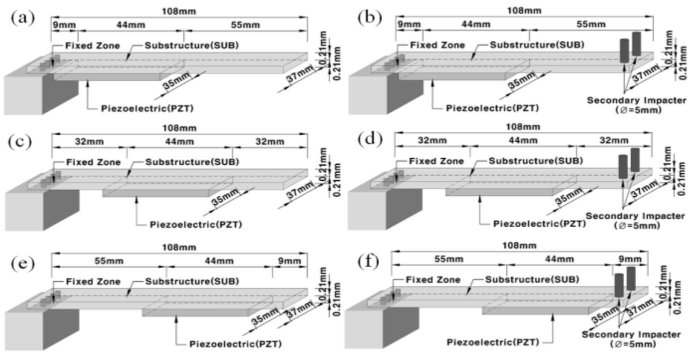

Fig. 1. Geometry and dimensions of PIMWGs.

2.2.1 Validation

In this section, the finite-element (FE) model of a unimorph piezoelectric cantilever is developed using the FE code ABAQUS and is validated through comparison with theoretical data, which is originally developed by Erturk and Inman (2008) [6]. Fig. 2(a) shows the geometric shape and main dimensions of the sample unimorph energy harvester used in this study, and several mechanical and electrical material properties of the harvester are listed in Table 1. . Here, E is the Young's modulus, ρ is the density, d is the piezoelectric constant, and ε is the dielectric permittivity. In addition, subscript 1 denotes the direction of the axial strain, and subscript 3 denotes the polarization direction.

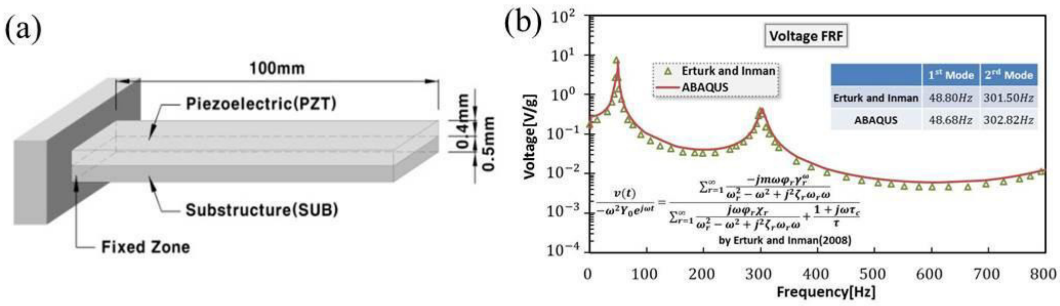

Fig. 2 (a) Geometric shape and dimensions of the harvester for theoretical validation, (b) Validation of the FE model of the piezoelectric energy harvester in comparison with the theoretical values.

Table 1. Material properties of the harvester for theoretical validation.

	Piezoelectric	Substructure
E, (GPa)	66	100
ρ, (kg/m^3)	7,800	7,165
d_{31}, (pm/V)	−190	-
ε_{33}, (nF/m)	15.93	-

Fig. 2(b) shows the validation result. The analytical solution of the electromechanical frequency response functions (FRFs) from Erturk and Inman (2008) is plotted using the equation shown in Fig. 2(b). The numerical results from ABAQUS show excellent agreement with the analytical solutions in both the output voltage and the first and second modes of the natural frequencies.

2.2.2 Numerical Results

Based on the validated model, numerical simulations are performed to analyze the stress distribution of the six PIMWG types. To analyze the stress distribution, we set up the measurement location of the stress in the simulation as shown in Fig. 3(a). A 0.5-N force was applied to the free end of the cantilever beam. Fig. 3(b) shows the relationship between the stress and measurement location of the piezoelectric part (ceramics) along the longitudinal direction under a 0.5-N force in the PIMWGs. The simulation results show that the stress distribution in the c- and d-types of PIMWGs is uniform in comparison with that of the other types.

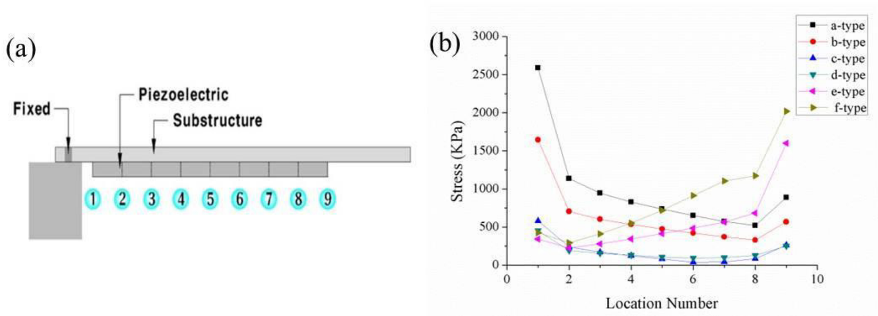

Fig. 3 (a) Measurement locations of the data such as the stress captured from the simulation, (b) Relationship between the stress and measurement location of the piezoelectric part (ceramics) along the longitudinal direction under a 0.5-N force in the PIMWGs.

3. Experiment

For implementation in real application, the wind speed was set to 2 m/s, which is the average wind speed in Seoul (Korea capital), and the blade diameter was 9 cm.

3.1 Comparison of power and durability

To compare the power of the PIMWGs, we measured the power under various resistive loads at a 2-m/s wind-speed condition. From the results of the power comparison under various resistive loads, the matched resistive loads of the PIMWGs were determined. Under the matched resistive load condition, we compared the durability of the PIMWGs. From the comparison results of the PIMWG durability, we chose the most durable PIMWG and ran it for two days.

4. Results and discussion

4.1 Comparison of power and durability

Fig. 4(a) shows the output power of the six PIMWG types under various resistive loads. The a- and f-types generated higher output power than the other PIMWG types. The stress result was proportional to the simulation results shown in Fig. 3(b). Although the d-type PIMWG generated lesser power than the a- and f- types, the former exhibited good generation capability. Fig. 4(b) shows the comparison results of the durability and power in real application. Except for the c- and d- types, all PIMWG types cracked within 100 min. The stress result was proportional to the simulation result shown in Fig. 3(b). Fig. 4(c) shows the output power of the d-type PIMWG with the generation time. The experimental results show that the d-type PIMWG did not crack even in 40 h.

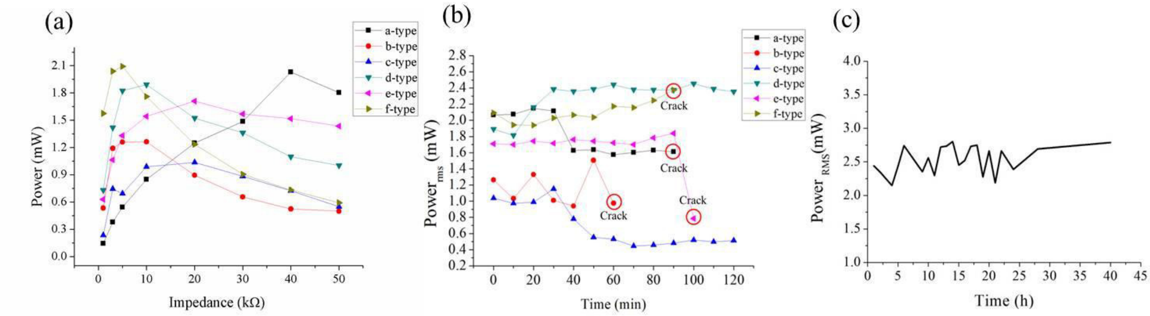

Fig. 4 (a) Output power graph under varying resistive loads, (b) Comparison results of the durability and power in real application, (c) Output power of the d-type PIMWG with the generating time in real application.

5. Conclusion

To increase durability, the PIMWG was designed for real application. Using new PIMWG design, numerical simulation, and experimental comparison analysis, we developed the optimized PIMWG (d-type). The experimental results show that the optimized PIMWG design generated 2.4-mW power (RMS value). When the d-type PIMWG ran, it did not crack even in 40 h. In this study, we improved the durability of PIMWGs for real application.

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