Finite Element Analysis for the Design of a Protective Layer of a Disc Piezoelectric Energy Harvester

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DOI: https://dx.doi.org/10.51584/IJRIAS.2025.100900098

Received: 16 August 2025; Accepted: 23 August 2025; Published: 25 October 2025

ABSTRACT

In this paper, an energy harvester using piezoelectric is designed and ANSYS simulation results are reported. The energy harvester was made in the form of a disk. The top and bottom surfaces of the piezoelectric disk ceramics were made by combining metal shields. The effectiveness of the protective layer was evaluated by simulating the actual pressure distribution on the piezoelectric when the energy harvester with the protective layer was subjected to pressures of 0.05, 0.1, 0.3, 0.5, and 1 MPa.

Keywords: energy harvester, ANSYS simulation, disc, piezoelectric ceramics, protective layer

INTRODUCTION

Pb(Zr(1-x)Tix)O3(PZT) has been used for many applications such as sound generation, detection, high pressure generation, vibrating devices, energy harvesting, etc., due to both static and inverse piezoelectric effects. In particular, PZT materials have the ability to convert mechanical energy into electrical energy [1-3].

The piezoelectric energy collector can convert small vibrations into electrical energy and has high conversion efficiency. It also has the advantage of generating electricity in the dark and at night without sunlight. Hence, it is always possible to generate electricity where vibration, pressure or force is applied [3,4]. To obtain electrical energy from mechanical vibrations, a piezoelectric plate that does not break even at high external pressures has to be developed. The most important challenge in designing and developing PZT piezoelectric devices for energy generation is to have a structure that is not destroyed by the strong mechanical forces applied to the piezoelectric devices repeatedly.

Since it is important to perform an optimal structural design by performing simulations prior to actual manufacturing of the device, many researchers have used simulation programs such as ANSYS, MATLAB, COMSOL, and ABAQUS. ANSYS, one of the finite element analysis programs, is the most effective program for the analysis of structures, heat, fluids, electromagnetic, stress distributions, acoustic fields and their coupling problems, and has found wide application in various fields of science and technology [5].

Therefore, we aim to simulate and analyze the stress distribution and voltage evolution in the case of the copper plate coated with the protective layer of PZT and to design a suitable copper plate protective layer structure.

Structure and operating principle of piezoelectric energy harvester

The charge generated by pressure changes is not long-lasting and soon disappears, so it is used for the observation of transient changes. The static pressure effect is a voltage-generating phenomenon, in which the electric signal is generated by applying an external stress and a vibration displacement to the piezoelectric. It is applied to a piezoelectric device for ignition, such as a gas igniter. And the reverse piezoelectric effect is a displacement generation phenomenon, in which the piezoelectric is subjected to external voltage, which causes mechanical deformation, and is mainly applied to the actuator. The static pressure and the inverse pressure

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IX September 2025

effects are collectively called piezoelectric effects, and the energy harvesting technique uses static pressure effects.

Figure 1 is a model of a disk piezoelectric device coated with a protective layer of 0.3 mm thick copper.

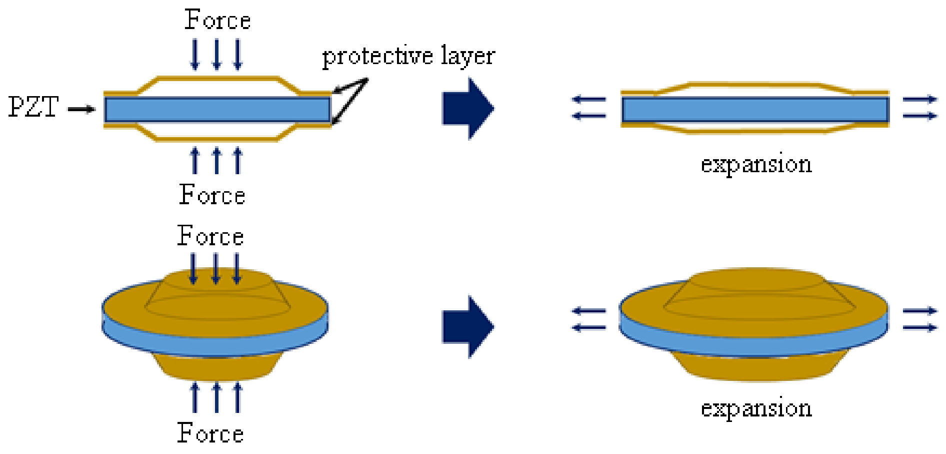

Figure. 1. Structure and Principles of Disc Energy Harvesters.

The first one in Fig. 1 is the absence of F on the piezoelectric device, so that the ceramic diameter does not increase. The second showed that F was applied to the disc plate, and the vertical force F was transferred, leading to an increase in the ceramic diameter. This force causes the charge to be generated by the polarization of the lower and upper electrodes by g31. By this construction and principle, electric energy can be collected by installing piezoelectric elements in the presence of vibrations such as road floors.

Table 1. Characteristic parameters of PZT used in this paper

parameters	**notice**	**value**
density	ρ(g/cm³)	7.80
permittivity at constant stress (polarization direction) **(vertical direction)**	$\varepsilon_{33}{}^{T}/\varepsilon_0$ $\varepsilon_{11}{}^{T}/\varepsilon_0$	1450 1400
curie temperature	T_c(°C)	345
dielectric dissipation factor	tanδ(10^{-3})	20
coupling factor	k_p k_t k_{31} k_{33}	0.62 0.48 0.35 0.69
piezoelectric charge coefficient	d_{31}, d_{32} d_{33} d_{24}, d_{15}	-165($\times 10^{-12}$C/N) 360($\times 10^{-12}$C/N) 497($\times 10^{-12}$C/N)

piezoelectric voltage coefficient	g_{31}, g_{32} g_{33} g_{24}, g_{15}	-12.9($\times 10^{-3}$Vm/N) 27($\times 10^{-3}$Vm/N) 38.9($\times 10^{-3}$Vm/N)

Finite element analysis

Using the finite element analysis software ANSYS 16.0, the piezoelectric energy harvester was simulated to consider various characteristics and select the optimum size and shape. The elastomer was fixed with a brass thickness of 0.3 mm, a diameter of 28 mm and a height of 3 mm. Piezoelectric ceramics were used with PZT with the characteristic values shown in Table 1.

The first simulation analyzed the actual stress distribution in the piezoelectric under 0.05, 0.1, 0.3, 0.5, and 1 MPa of pressure applied to the energy harvester with the protective layer. The piezoelectric thickness was 1 mm and the refraction angle of the copper plate was fixed at 15°. The second simulation simulated the stress distribution by varying the angle of bending of the protective layer copper plate at 1 mm thickness and applied pressure of 0.1 MPa at 5°, 15°, and 45°. The third simulation was performed by varying the piezoelectric thickness to 0.5 mm, 1 mm, 1.5 mm and 2 mm at applied pressure of 0.1 MPa and angle of refraction of the shield copper plate.

Experimental results and discussion

Fig. 2 shows the results of the stress distribution simulation with the pressure variation applied in the designed assembly. The piezoelectric thickness was 1 mm and the angle of refraction of the shield was 15°.

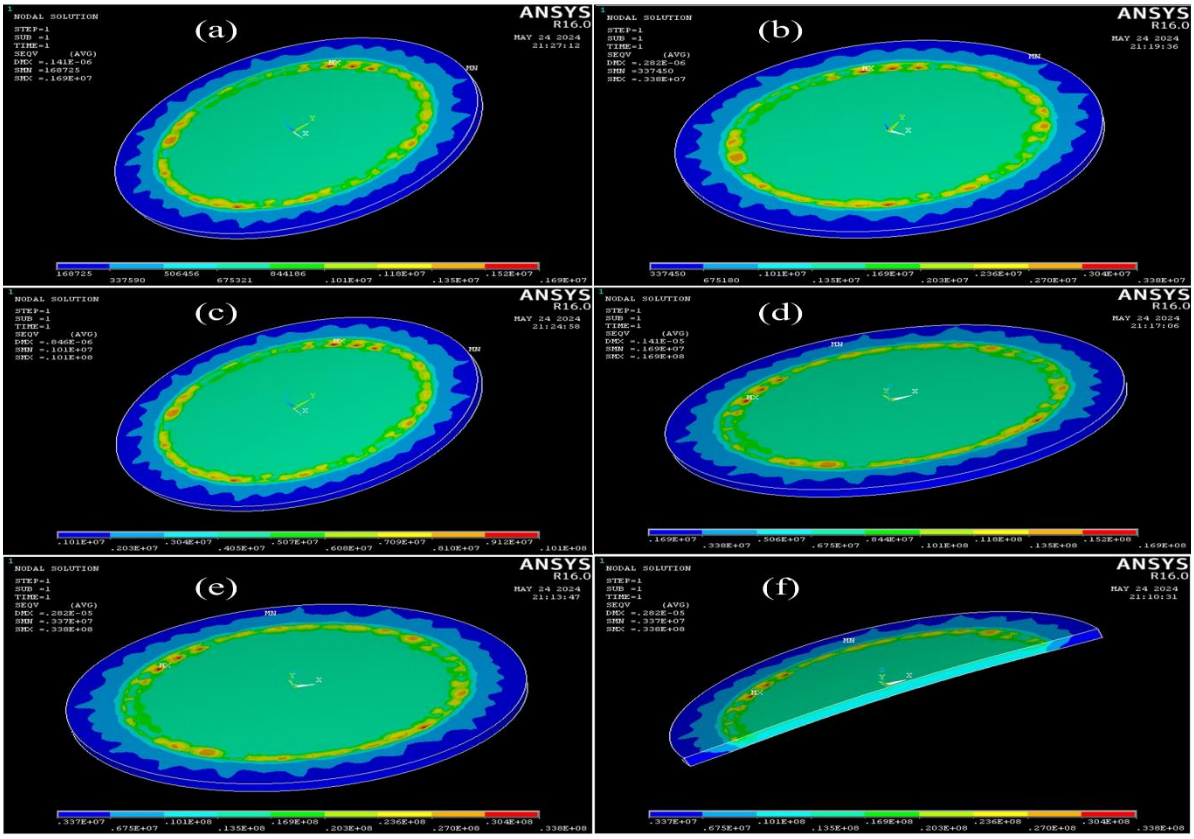

Figure. 2. Stress distribution with variation pressure applied in the designed assembly device

(piezoelectric thickness of 1 mm, angle of break of protective copper plate 15°),

(a)-0.05 MPa, (b)-0.1 MPa, (c)-0.3 MPa, (d)-0.5 MPa, (e)-1MPa, (f)-1 MPa

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IX September 2025

As can be seen, the force applied perpendicular to the piezoelectric element by a copper plate protective layer with a folded structure was applied by the horizontal decomposition. Also, the force on the indenter increases with increasing applied pressure, and the vertical force increases above 1 MPa, which results in the piezoelectric bending. Thus, it is shown that the designed piezoelectric device can be damaged above 1 MPa.

Fig. 3 shows the results of the simulation of stress distribution along the angle of refraction of the shielded copper plate. The piezoelectric thickness was 1 mm and the applied pressure was 0.1 MPa. The simulation results showed that the force acting in the horizontal direction decreased as the angle of refraction of the shield plate increased, while the force acting in the vertical direction became larger and larger. Finally, when the angle of refraction is 5°, the force acting in the horizontal direction is the largest.

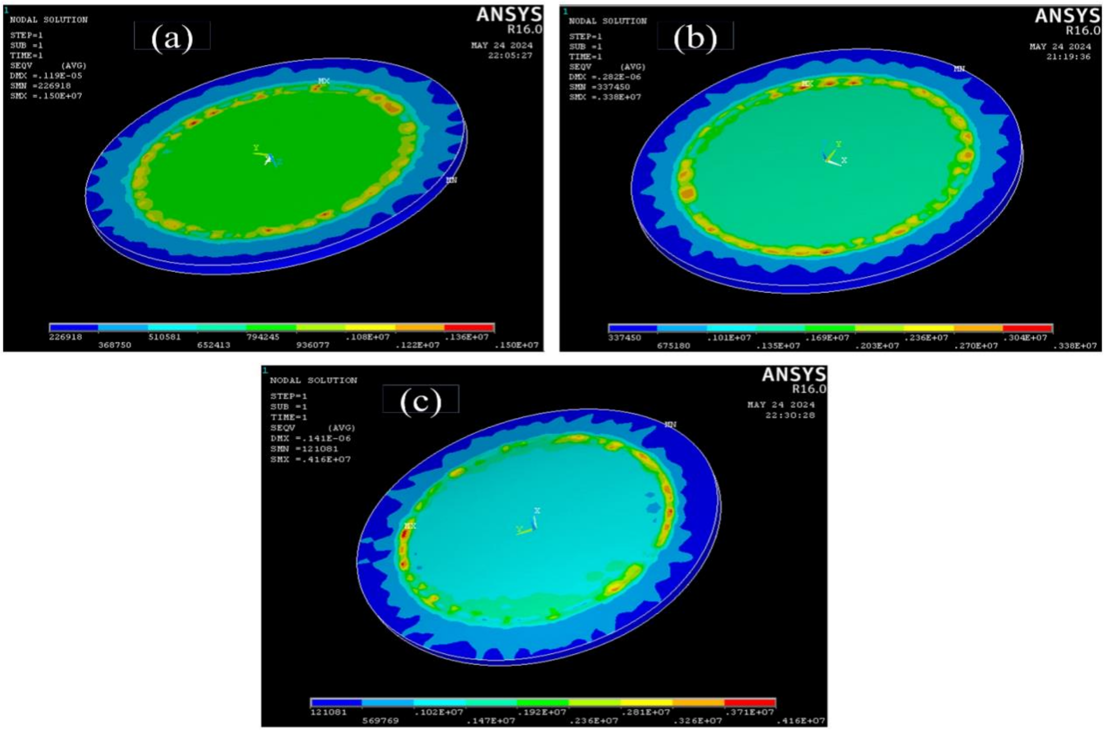

Figure3. Stress distribution along the angle of refraction of protective copper plates in the designed assembly (piezoelectric thickness of 1 mm, applied pressure of 0.1 MPa), (a)-5°, (b)-15°, (c)-45°

Table 2 shows the results of the power voltage simulation with the variation of the thickness of the piezoelectric. The angle of refraction of the shield copper plate was 15° and the applied pressure was 0.1 MPa. The simulation results showed a maximum value of 3.80767 V when the thickness was 0.5 mm and a minimum value of 2.16208 V when the thickness was 2 mm. That is, the generation voltage tended to decrease as the thickness of the piezoelectric increased.

The voltage generated in the piezoelectric can be calculated by the following equation:

$$V = \frac{d}{\varepsilon_0 \varepsilon_r} \times \frac{F \cdot t}{A} \quad (1)$$

where d is the piezoelectric coefficient, A is the area of the piezoelectric under the force, F is the force acting on the piezoelectric, and t is the thickness of the piezoelectric. As can be seen from this equation, the voltage generated increases as the thickness of the piezoelectric increases.

However, in our proposed piezoelectric device, the power voltage decreases despite the increase in the thickness of the piezoelectric. This is because the force applied in the vertical direction is decomposed by a protective copper plate with a folded structure into a horizontal force, and a voltage is generated. The larger the thickness of the piezoelectric, the larger the area under which the horizontal force is applied, the smaller the generated voltage. Thus, in the proposed piezoelectric energy harvester, the generated voltage increases with

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume X Issue IX September 2025

smaller piezoelectric thickness and larger diameter. However, it is important to take into account the voltage generation and the breaking strength, since too small a thickness of the piezoelectric can easily break down even under small forces.

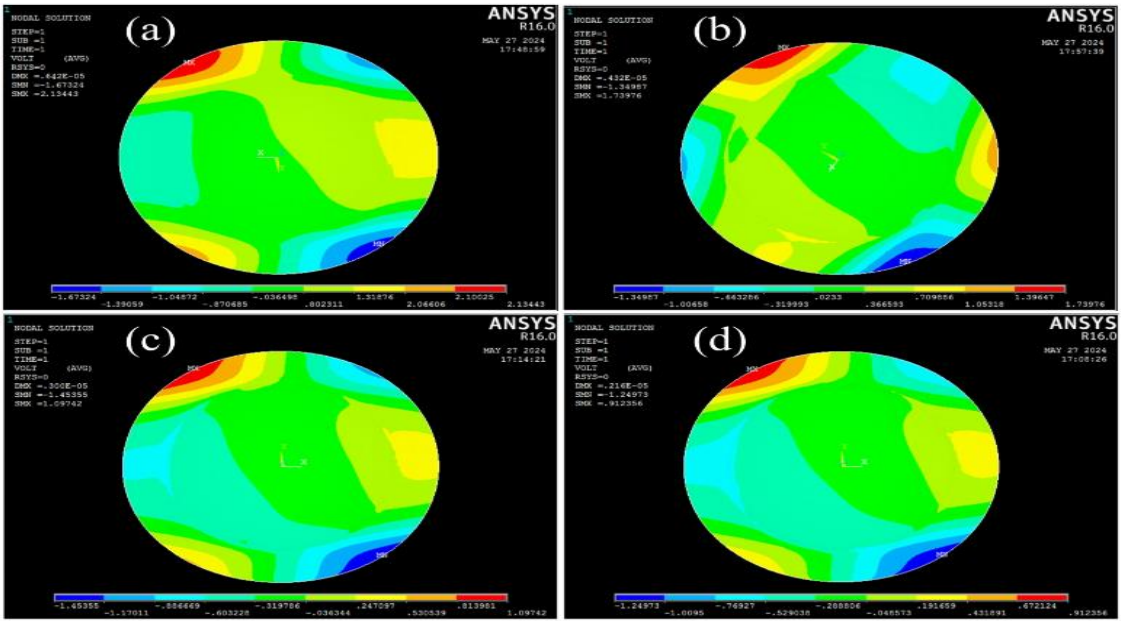

Fig.4. occurrence voltage with varying thickness of piezoelectric in the designed assembly

(15° of protective layer angle, 0.1 MPa of applied pressure), (a)-5°, (b)-15°, (c)-45°

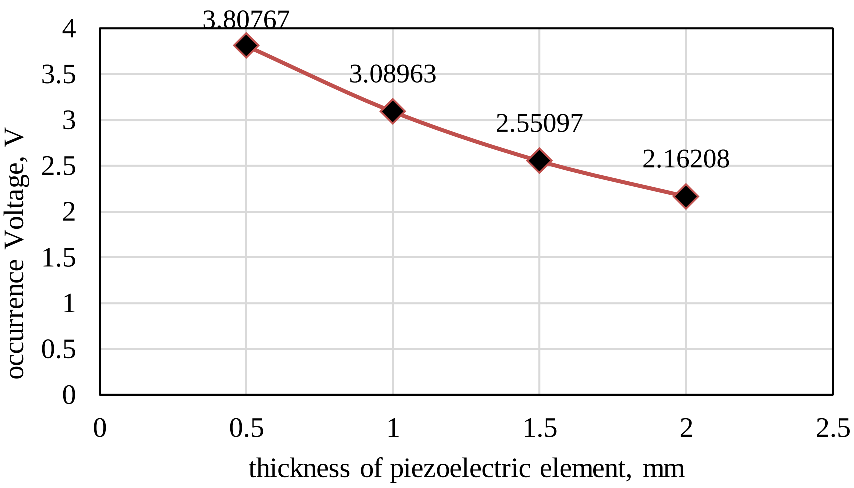

Fig.5. Variation of power voltage with thickness of piezoelectric element

Table 2. Variation of the generated voltage with the thickness of the piezoelectric element

thickness of piezoelectric, mm	occurrence voltage, V
0.5	3.80767
1	3.08963
1.5	2.55097
2	2.16208

CONCLUSIONS

The protective layer proposed in this paper is a protective action of piezoelectric and a horizontal decomposition of the vertical force. The generated voltage with the thickness of piezoelectric ceramics decreases with increasing thickness of ceramics. This is because the piezoelectric device with the proposed structure generates a voltage by a radial force. Thus, in our designed piezoelectric device, the smaller the thickness of the piezoelectric, the larger the generated voltage. The generated voltage along the angle of refraction of the protective copper plate was highest when the angle was 5°. However, the increase in energy harvester size is a drawback to maintain a constant gap between protective copper plates and piezoelectric ceramics and to maintain a 5° angle of refraction of protective copper plates. Future work will focus on the appropriate device structure and protective layer material to achieve optimum angle of refraction of the protective layer.

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