



# Contactless Excitation of Piezoelectric Device through Curvilinear shaped Electric Field Generator

Tanaya Nayak, Dipti Patnaik, Biswaranjan Swain, Praveen Priyaranjan Nayak, Satyanarayan Bhuyan

**Abstract:** Contactless excitation of piezoelectric (PZT) component through focused E-field has been investigated in this work. In the intended technique, E-field is focused to ground electrode from a curvilinear-shaped potential electrode so that maximum E-field can penetrate sufficiently through PZT component which is positioned inbetween the electrodes. Simulation analysis shows that the contactless energization of PZT component is due to electric resonance as well as piezo-electric resonance. The maximum vibration occurs across the PZT components when the E-field generator operating frequency ( $f_0$ ) matches with the mechanical resonance frequency ( $f_m$ ). The max output power across the contactless energized PZT component mainly rely on operating frequency, resonance, position & resistive load. The output power achieved across the contactless excited PZT component by focused E-field generator is higher than the output power achieved across the contactless excited PZT component by capacitor like E- field generator. The max output power of 9.9mW is obtained across PZT component at 1295 kHz resonance frequency ( $f_r$ ) and 19.5 k $\Omega$  optimum loads with an input of 50 V and 8 mm electrode separation. By enactment of this excitation methods provide free actuation of PZT component so as to overcome the difficulties associated with the confined motion for different applications.

**Keywords:** Curvilinear structure, PZT component, contactless excitation, resonance frequency.

## I. INTRODUCTION

The further extensive research on PZT component surfaced rising research interest on contactless excitation of PZT plate to overcome the difficulty associated with the conventional drive of PZT component [1]. PZT actuators have unique ability to change electric energy to mechanical vibration and vice-versa. The possibility of remotely invigorating the PZT component isn't exactly new. It has just been to the front line as of the fact that the PZT component are utilized regularly in various fields on account of their high-power density [2], smaller shape and size and lower power utilization. As a rising innovation, they have been used in the numerous applications for example, lower frequency microsystems [3], the

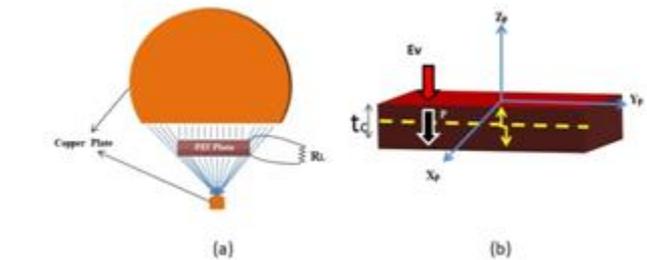


Figure 1. (a) Simulation model for contactless drive a PZT component, (b) Configuration of the PZT component.

biomedical implantable electronics [4-5], microactuator [6], high precision positioner [7], sensors [8] and particle manipulation [9]. But in the most application of PZT component, electrical supply is applied via soldered lead wires which may break down at higher temperature and may encumber its continuous and reliable operation. There is also inconvenience in the conjoining of lead wires onto the miniaturized and nano-PZT components as the device become increasingly smaller which may influence the

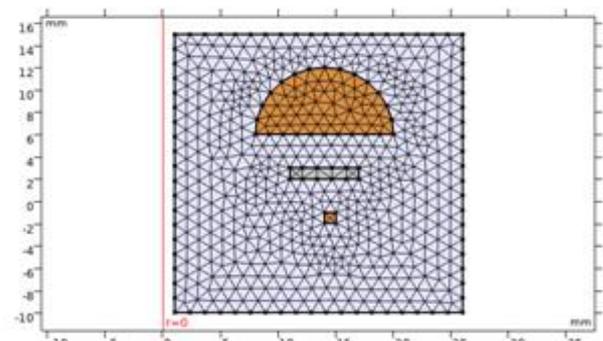


Figure 2. Mesh analysis of focused curvilinear-shaped E-field stimulation model.

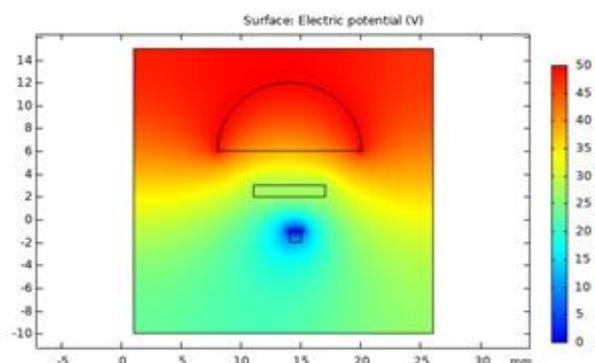


Figure 3. Electric potential developed in PZT component.

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properties of micro and nano-scale devices. The issues faced by connected wires for direct drive of PZT component have brought about an action to investigate an elective way for reliable and continuous functioning of the PZT component dealt with various potential applications. Thus, there is a need to develop a contactless approach for excitation of PZT component. Although earlier there exists contactless energy transfer approach to excite single PZT component, but it is necessary to develop a relatively effective contactless excitation electric energy transfer model to enhance its applications. In this proposed work to take care of the above-stated issues, a compact focused curvilinear- shaped structure for contactless excitation of single PZT component is explored. A simulation model has been done to give profound physical bits of knowledge and help to build up a superior contactless drive of PZT components. The intended approach enhances the energy transmission effectively. In contactless driven of PZT plate the E-field strength and pattern on PZT plate surface was analyzed by finite element method (COMSOL Multiphysics).

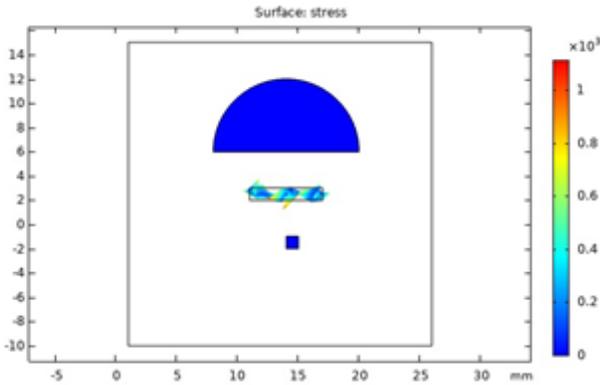


Figure 4. Stress developed in PZT component.

## II. RESULT AND DISCUSSION

Stimulation model of focus curvilinear-shaped E-field generator for contactless drive PZT component is shown in Figure. 1(a) and Figure. 1(b) shows the basic configuration of PZT component operating in thickness ( $t_c$ ) vibration mode. We perform 2-D asymmetric electrostatic mode using finite element method (COMSOL Multiphysics) to study briefly about the E-field pattern and magnitude of increased power and voltage in contactless excited of PZT component through focused curvilinear-shaped like structure. The following simulation condition is considered that are distance ( $d$ ) between the two electrodes is 8 mm; the medium between them for energy transfer is air. As discussed earlier, the PZT component is positioned equidistantly inbetween two copper electrodes and there is no direct contact between them which is illustrated in Figure 2 mesh analysis plot. At the point when E-field penetrates the PZT plate, then by converse-PZT effect a mechanical vibration is energized in PZT component. When the  $f_o$  of E-field generator matches with the  $f_m$  of the PZT component a moderately enormous voltage is obtained at the terminal of PZT plate due to direct-PZT effect as shown in Figure 3. Figure 4 demonstrate the stress developed in PZT component even if there is no direct contact between curvilinear plate and PZT plate. The streamline electric field plot with an input voltage of 50 V is depicted in Figure 5. Figure 6 shows the simulated frequency characteristics plot of the output power across PZT terminal. The max output power of 9.9 mW is obtained by the PZT plate at the  $f_r$  of

1295 kHz. Here the output power peaks are observed because of piezo-electric resonance. When the  $f_m$  of the PZT component is close to the frequency of the alternating source, then by the converse PZT effect a generally large vibration can energize PZT plate which generate a substantial voltage i.e. 18.9 V across the output terminal of the PZT component by the piezoelectric effect as shown in Figure 7. The dependency of output power in contactless driven PZT component on the resistive load at  $f_r$  is shown in Figure 8. The output real power ( $P_{load}$ ) transfer to the load at  $f_r$  is determined where  $R''_{mech}, L''_{mech}, C''_{mech}$  are equivalent

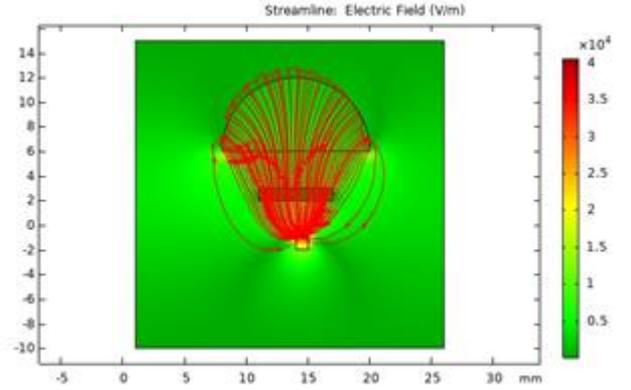


Figure 5. Streamline plot of focused E-field pattern through PZT component.

resistance, inductance and capacitance and  $n$  is the number of turn ratio is given by [11]

$$P_{load} = \frac{(\omega_f E' A_r)^2 R'_{load} \left[ R''_{mech} + \left( \omega_f L''_{mech} - \frac{1}{\omega_f C''_{mech}} \right)^2 \right]}{\left( R''_{mech} + n^2 R'_{load} - \omega_f^2 C_d' R'_{load} L''_{mech} + \frac{C_d' R_{load}}{C''_{mech}} \right)^2 + \left( \omega_f L''_{mech} - \frac{1}{\omega_f C''_{mech}} + \omega_f C_d' R'_{load} R''_{mech} \right)^2} \quad (1)$$

The PZT component vibration profile operating in thickness vibration mode can be modeled by one dimensional two constitutive equations as in Figure 11 [10] which is illustrated in Figure 9;

$$T_3 = c_{33}^E S_3 - e_{33} E'_3 \quad (2)$$

$$D_3 = \epsilon_{33}^{S'} E_3 + e_{33} S_3 \quad (3)$$

where,  $S_3$ - Mechanical strain,  $T_3$ - Stress,  $d_{33}$ - piezoelectric coefficient,  $\epsilon_{33}^{S'}$ - piezoelectric permittivity constant.

We get from equation (2);

$$S_3 = \frac{T_3}{c_{33}^E} + \frac{e_{33} E'_3}{c_{33}^E} \quad (4)$$

By using boundary condition to solve further is that at edges the stress i.e.

$$T_3 = 0 \text{ and } x(-tc/2) = x(tc/2) \quad (5)$$

Hence, we get;

$$S_3 = \frac{e_{33} E'_3}{c_{33}^E} = \frac{\partial u}{\partial x} \quad (6)$$

Using equation (5) and (6) we get;

$$\frac{\partial u}{\partial x} \text{ at } x(tc/2) = \lambda \left( -A \sin \lambda(tc/2) + B \cos \lambda(tc/2) \right) = \frac{e_{33} E'_3}{C_{33}^E} \quad (7)$$

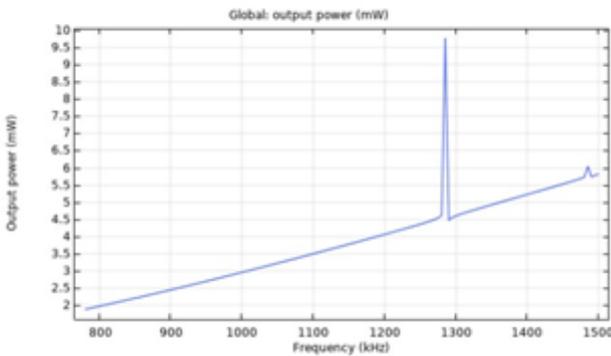


Figure 6. Frequency dependent output power across PZT terminal.

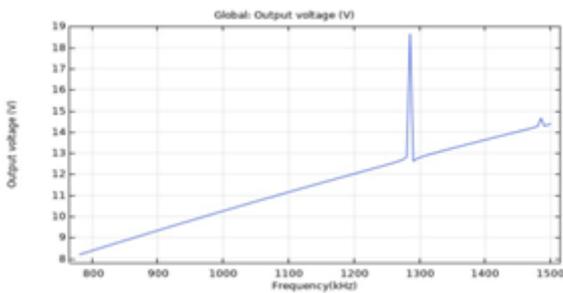


Figure 7. Frequency dependent output voltage across PZT terminal.

$$\frac{\partial u}{\partial x} \text{ at } x(-tc/2) = \lambda \left( -A \sin \lambda(-tc/2) + B \cos \lambda(-tc/2) \right) = \frac{e_{33} E'_3}{C_{33}^E} \quad (8)$$

Solving equation (7) and (8), we get [7];

$$u = \frac{e_{33} E'_3}{C_{33}^E} \frac{1}{\cos \lambda(tc/2)} \sin \lambda x \quad (9)$$

The max output power of 9.9 mW is achieved at optimum load resistance at  $f_r$  1295 kHz, where  $V_{in} = 50$  V. The dependency of output power on the distance between PZT component and the copper electrodes is shown in Figure 10. The max output power at the output terminal of contactless excited PZT terminal is inversely proportional to the gap between the copper electrodes and PZT component. With

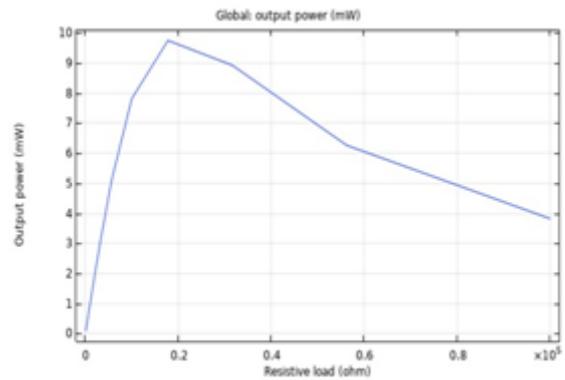


Figure 8. Resistive load dependent output power across PZT terminal.

electric potential  $V_{in} = 50$  V and distance thickness ( $d$ ) between PZT component and copper electrodes, the electric field i.e.  $E = \frac{V_{in}}{d}$  decrease with increase in distance. So, across the PZT component the max output power decreases. It has been observed that an output power of 9.9 mW with an optimal load has been achieved at  $f_r$  1295 kHz and  $V_{in} = 50$  V and distance between copper electrodes of 8 mm of the curvilinear-shaped focused E-field structure.

## V. CONCLUSION

A focused curvilinear-shaped E-field generator for contactless drive of PZT component is proposed. In this method a ground electrode is used for focusing of E-field from curvilinear-shaped potential electrode for contactless energy transfer to PZT component. Simulation analyses have been done so as to acquire proper comprehension on contactless drive. It has been noticed that the contactless excitation capability of the PZT component relies on operating frequency, load resistance and the gap between the PZT component and copper electrodes. The E-field strength and pattern analysis on the surface of the PZT component is done by finite element method simulations (COMSOL Multiphysics). The max power can be increased wirelessly by decreasing the thickness gap ( $d$ ) between the copper electrodes of the parallel plate capacitor structure and piezoelectric plates. The max output power is 9.9 mW and electric potential 18.9 V across the output terminal of PZT component have been observed at  $f_r$  of 1295 KHz with input potential of 50 V and 8 mm thickness gap between electrodes. The developed technique not only can increase the energy transmission efficiency but also can be used as actuators, sensors, motors and implantable biomedical electronics. Further investigation will be carried out to increase the non-contact energy transmission efficiency.

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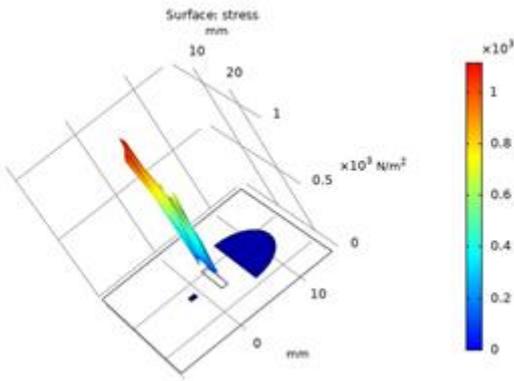


Figure 9. Vibrational Displacement of PZT component.

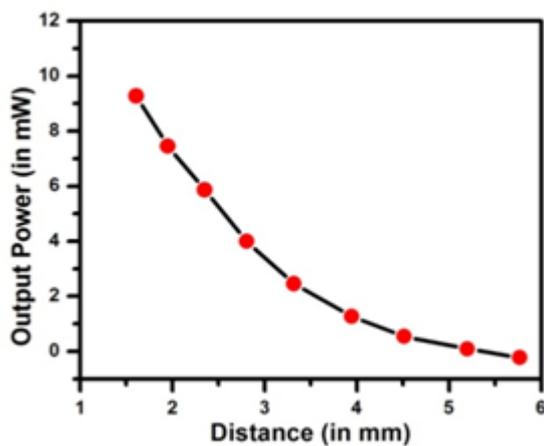


Figure 10. Distance between electrodes and PZT plate dependent output power.

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