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Modelling and Analysis of a Piezoelectric Gripper Type End Effector

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Abstract:
A microgripper is one of the key elements in micro-robotics and micro-assembly technologies for handling and manipulating micro-objects without damage. An essential component of all microgrippers is the actuator, which provides the required applied force to make the device operate as a gripper. Various prototypes of microgrippers of different actuation methods have been developed, including electrothermal actuators, electrostatic actuators, piezoelectric actuators, electromagnetic actuators and shape memory alloy actuators. Our project is based on inverse piezoelectric effect. By amplifying the displacement obtained from the piezoelectric crystal, the actuation of the tweezer is tried. It involves the observation of the displacements of different piezoelectric crystals for a fixed voltage with different tweezer material. It also includes observations of different orientations of the nested structure.

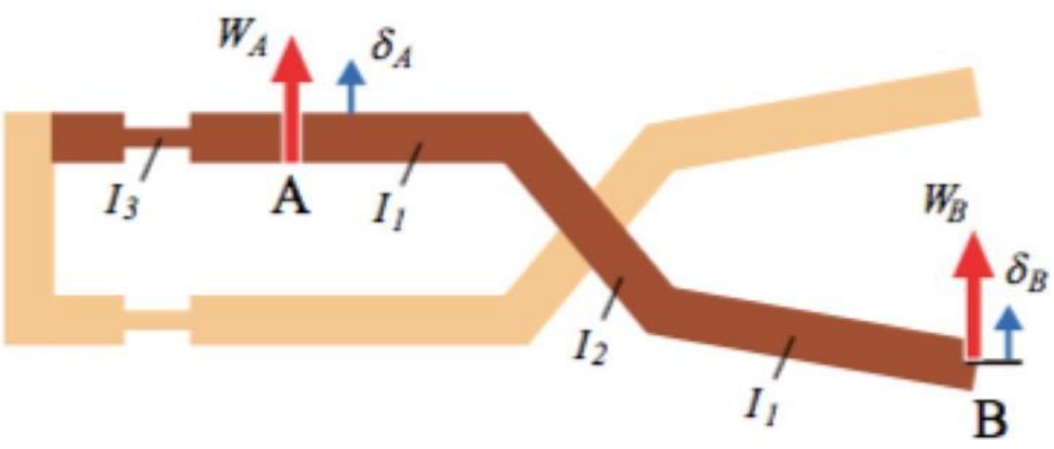
Keywords: Piezo, Piezostack actuators, Piezoelectric crystals, Piezoelectric Tweezers

I. INTRODUCTION

The piezoelectric effect was discovered by Jacques and Pierre Curie in 1880. An actuator is essentially a motor, or a generator of motion, usually linear and limited in range. The amount of movement that a piezo device can yield is equal to the amount of voltage applied times the d33 or the piezo electric coefficient. This piezoelectric coefficient, d33, is a figure of merit for the piezo material relating to the efficiency of the material in transferring the electrical energy to mechanical energy Please note that this movement does not depend on the dimensions of the piezo element. Therefore, when one stacks piezo elements together, there is a multiplying effect on the amount of movement that is achieved. However, the amount of voltage that can be applied will depend on the material and the thickness of each element. A stack of 2 piezo elements will have twice the movement at the same applied voltage as a single piezo element, and a stack of 3 piezo elements will exhibit 3 times the movement as a single element with the same applied voltage, etc. This is the basis for multilayer actuators.

An effective mechanical micromanipulator should possess the ability to grasp objects of different shapes steadily with high positioning accuracy. The manipulators should be able to accurately control grasping forces in order to avoid any damage to the small-size delicate objects, which are less than 1 mm in diameter.

- Displacement equations for tweezer



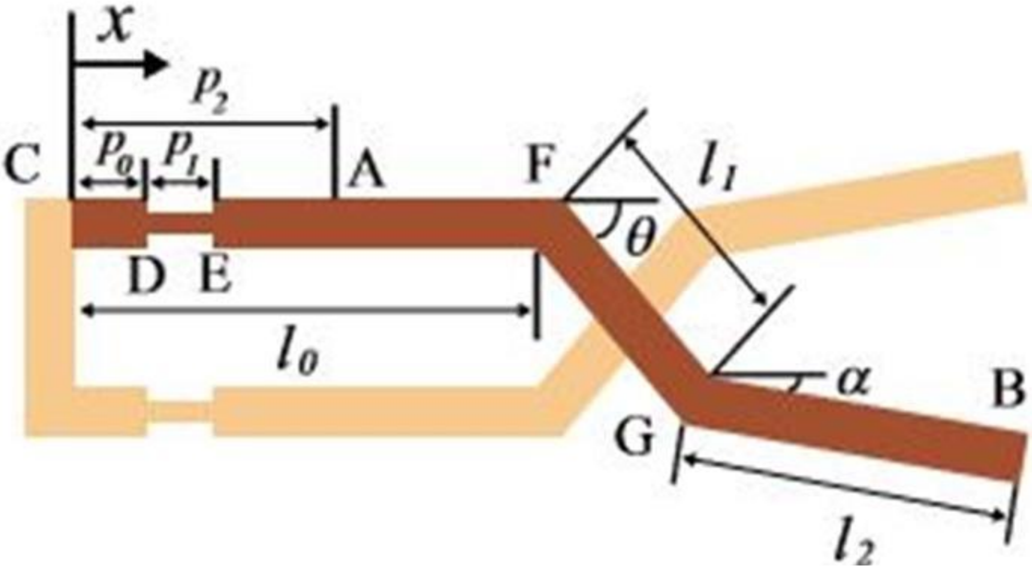
$$\delta_A = \left(\frac{C_{A2}}{2EI_1} + \frac{C_{A4}}{2EI_3}\right) \cdot W_A + \left(\frac{C_{A1}}{2EI_1} + \frac{C_{A3}}{2EI_3}\right) \cdot W_B$$

$$\delta_B = \left(\frac{C_{B2}}{2EI_1} + \frac{C_{B5}}{2EI_3}\right) \cdot W_A + \left(\frac{C_{B1}}{2EI_1} + \frac{C_{B3}}{2EI_2} + \frac{C_{B4}}{2EI_3}\right) \cdot W_B$$

Coefficients from castiglano's theorem.

$$\begin{aligned}
C_{A1} = & -\tfrac{2}{3}\left\{p_0^3 + (p_2 - p_0 - p_1)^3\right\} \\
& +(l_0 + l_1\cos\theta + l_2\cos\alpha)p_0(p_0 - 2p_2) + p_2p_0^2 \\
& -(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0 - p_1)(p_2 - p_0 - p_1)^2 \\
& +(p_2 - p_0 - p_1)^3 \\
C_{A2} = & \tfrac{2}{3}\left\{p_0^3 + (p_2 - p_0 - p_1)^3\right\} \\
& +2p_2p_0(p_2 - p_0) \\
C_{A3} = & -\tfrac{2}{3}p_1^3 + (p_2 - p_0)p_1^2 \\
& +(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0)p_1(p_1 - 2p_2 + 2p_0) \\
C_{A4} = & \tfrac{2}{3}p_1^3 + 2(p_2 - p_0)p_1(a - p_0 - p_1) \\
C_{B1} = & \tfrac{2}{3}\left\{p_0^3 + (p_2 - p_0 - p_1)^3\right\} \\
& +\tfrac{2}{3}(l_0 - p_2)^3 + \tfrac{2}{3}l_2^3\cos^3\alpha \\
& +2p_0(l_0 + l_1\cos\theta + l_2\cos\alpha) \\
& \times(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0) \\
& +2(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0 - p_1)(p_2 - p_0 - p_1) \\
& \times(l_0 + l_1\cos\theta + l_2\cos\alpha - p_2) \\
& +2(l_0 - p_2)(l_0 + l_1\cos\theta + l_2\cos\alpha - p_2) \\
& \times(l_1\cos\theta + l_2\cos\alpha)
\end{aligned}$$

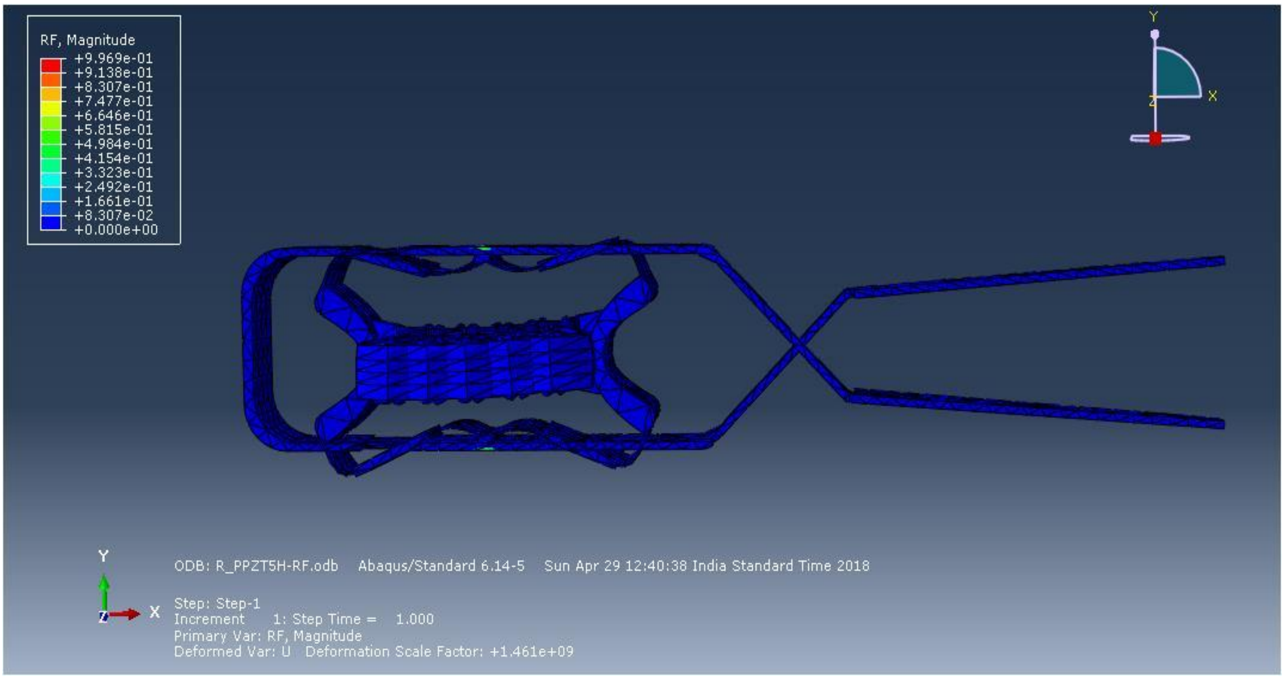
$$\begin{aligned}
C_{B2} = & -\tfrac{2}{3}\left\{p_0^3 + (p_2 - p_0 - p_1)^3\right\} \\
& +p_2p_0^2 + (p_2 - p_0 - p_1)^3 \\
& +p_0(l_0 + l_1\cos\theta + l_2\cos\alpha)(p_0 - 2p_2) \\
& -(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0 - p_1) \\
& \times(p_2 - p_0 - p_1)^2 \\
C_{B3} = & \tfrac{2}{3}l_1^3\cos^3\theta \\
& +2l_1\cos\theta l_2\cos\alpha(l_1\cos\theta + l_2\cos\alpha) \\
C_{B4} = & \tfrac{2}{3}p_1^3 + 2p_1(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0) \\
& \times(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0 - p_1) \\
C_{B5} = & -\tfrac{2}{3}p_1^3 + (p_2 - p_0)p_1^2 \\
& +p_1(l_0 + l_1\cos\theta + l_2\cos\alpha - p_0)(p_1 - 2p_2 + 2p_0)
\end{aligned}$$



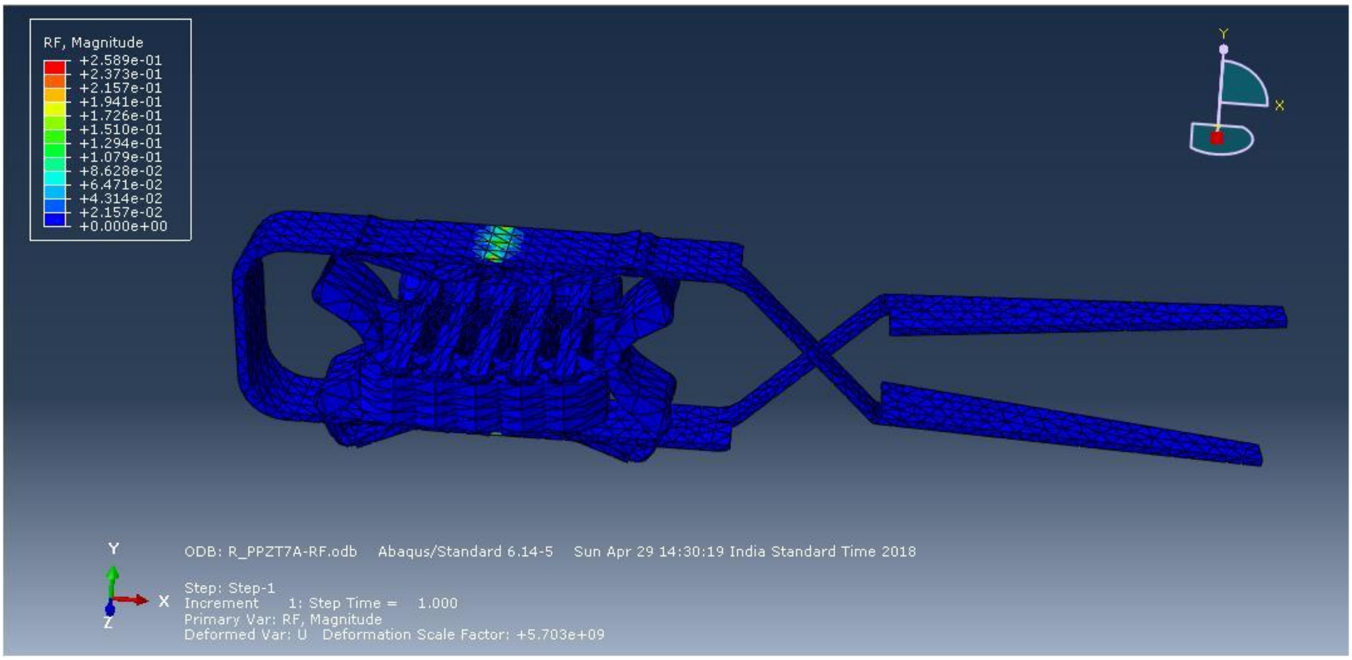
where p0,p1,p2 are the lengths between C and D, D and E, C and A respectively, l0,l1,l2 are the lengths between C and F, F and G, G and B respectively, and θ,α are the angles

On FEA Analysis

- Phosphor Bronze and PZT-5H: 0.9969N is the displacement PZT-5H as the piezoelectric materials are the most suitable materials respectively.
- Reaction forces were obtained by constraining moving parts of the tweezer.



Phosphor Bronze and PZT-7A: 0.2589N



Results and Conclusion

- Horizontal nested structure gives better displacement values than a vertical nested structure.
- Phosphor Bronze material gives more displacement than Aluminum material.
- After analyzing different piezoelectric materials and tweezer material in order to get 10 mm displacement for 1 N force, Phosphor Bronze as the tweezer material and PZT-5H as the piezoelectric material are the most suitable materials respectively.
- Reaction forces were obtained by constraining moving parts of the tweezer.

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