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FINITE ELEMENT ANALYSIS FOR MEASURING DISPLACEMENT AND BLOCKING FORCE OF PIEZOELECTRIC UNIMORPH AND COMPARISON OF DIFFERENT ACTIVE MATERIALS

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ABSTRACT

In this paper, displacement and blocking force of piezoelectric unimorph is measured by finite element analysis. Five unimorph of same size is formed. Five different piezoelectric material of same dimension is used as active layer in those unimorph. They are - [001] poled PZN-(6-7)%PT, [001] poled PZN-4.5%PT, [100] poled PZN-(6-7)%PT, PZT4, and PZT-5H. The dimension of the active layer is 5 mm in length, 1 mm in width, and 140 μm in thickness. A steel material of 5 mm in length, 1 mm in width, and 80 μm in thickness is used as inactive layer or elastic layer. A voltage of same magnitude is applied across the thickness of active layer of each unimorph. As a result bending deformation occurred. The maximum displacement and blocking force is measured by finite element analysis using ABAQUS software of version 6.5-1. A comparison is done to select the proper active material for getting maximum displacement and blocking force.

Keywords: Unimorph, Piezoelectric, Blocking Force

1. INTRODUCTION

Piezoelectric unimorph has become a centre of attraction due to its great potential. It offers today's motion engineering a practical way to achieve extremely high positioning accuracy in a wide variety of applications. A few of many applications of piezoelectric unimorph are - audio and ultrasonic alarm devices, relay motors, positioning devices, motion detectors, and instrumentation pick-up indicators [1].

A unimorph is composed of a single layer of piezoelectric material (active layer) with another layer of elastic material (passive layer). It is constructed in laminated cantilever beam. Steel or titanium is usually chosen for the elastic layer. Piezoelectric materials have special properties that exhibit an interaction between electrical and mechanical response i.e. they generate an electric charge when strained (direct piezoelectric effect), and they deform (strain) when an electric field is applied (the converse piezoelectric effect) [2]. It utilizes piezoelectric coefficient to generate deformations. When a voltage is applied across the thickness of the piezoelectric layer, longitudinal and transverse strain develops. The elastic layer opposes the transverse strain which leads to a bending deformation [3].

Different types of piezoelectric material can be used in unimorph. The deflection and blocking force of unimorph varies for different piezoelectric materials. Setti *et al* constructed piezoelectric unimorph of sizes 5 × 1 × 0.220 mm^3. The active layer was PZN-4.5%PT plate of 5mm in length, 1 mm in width, and 140 μm in thickness, and the elastic layer was steel plate of 5mm in length, 1 mm in width, and 80 μm in thickness. They found deflection of 135 μm and blocking force of 142 mN after applying a voltage of 250 V [4]. In this paper, five different piezoelectric material of same dimension is used as active layer in five unimorph; their displacement and blocking force is measured by finite element analysis, and comparison is made.

2. DESIGN OF UNIMORPH

Five unimorph of same sizes (5mm × 1mm × 0.220mm) is designed using five piezoelectric materials as active layer. They are - [001] poled PZN-(6-7)%PT, [001] poled PZN-4.5%PT, [100] poled PZN-(6-7)%PT, PZT4, and PZT-5H. Steel is used as elastic layer. The size of active layer is 5mm × 1mm × 0.140mm, and the size of elastic layer is 5mm × 1mm × 0.080mm. A schematic diagram of the unimorph is shown in Fig.1.

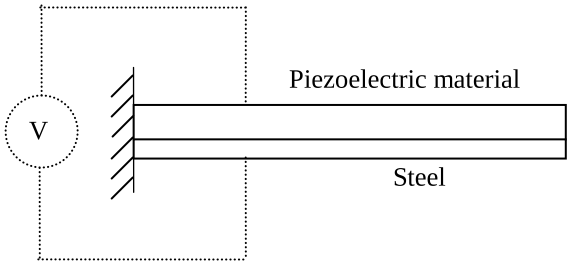

Fig 1. Schematic diagram of Unimorph

3. FINITE ELEMENT ANALYSIS AND RESULTS

The properties of elastic layer (steel) and active layer (five piezoelectric materials) are listed below [5]-[7].

Steel

Density (ρ) = 7850 kg/m^3, Young's modulus = 210 GPa, Poisson ratio = 0.3

[001] poled PZN-(6-7)%PT

Density (ρ) = 8350 kg/m^3,
Elastic matrix (N/m^2): E_{11}=1.422E+011, E_{12}= 8.87E+010, E_{22}=1.422E+011, E_{13}=1.029E+011, E_{23}=1.029E+011, E_{33} =9.9E+010, E_{44} =4.2E+009, E_{55} =1.093E+011, E_{66} = 1.093E+011.
Piezoelectric matrix (C/N): d_{11} = 2.23E-010, d_{12} = 2.23E-010, d_{31} = -1.559E-009, d_{32} = -1.559E-009, d_{33} = 2.721E-009

[001] poled PZN-4.5%PT

Density (ρ) = 8000 kg/m^3,
Elastic matrix (N/m^2): E_{11}=1.422E+011, E_{12}= 8.87E+010, E_{22} = 1.422E+011, E_{13} = 1.5E+010, E_{23} = 1.5E+010, E_{33} = 9.9E+010, E_{44}= 4.2E+009, E_{55} = 1.093E+011, E_{66} = 1.093E+011.
Piezoelectric matrix (C/N): d_{11} =2.23E-010, d_{12} =2.23E-010, d_{31} = -9.5E-010, d_{32} = -9.5E-010, d_{33} =2.721E-009

[100] poled PZN-(6-7)%PT

Density (ρ) = 8207 kg/m^3,
Elastic matrix (N/m^2): E_{11} = 1.8E+011, E_{12} = 8E+010, E_{22} = 1.8E+011, E_{13} = 4.8E+010, E_{23} = 4.8E+010, E_{33} = 1.71E+011, E_{44} = 5E+010, E_{55} = 1.6E+010, E_{66} = 1.6E+010.
Piezoelectric matrix (C/N): d_{11} = 6.2E-009, d_{12} = 6.2E-009, d_{31} = -3.5E-011, d_{32} = -3.5E-011, d_{33} = 9.3E-011

PZT4

Density (ρ) = 7600 kg/m^3,
Elastic matrix (N/m^2): E_{11} = 1.39E+011, E_{12} = 7.78E+010, E_{22} = 1.39E+011, E_{13} = 7.43E+010, E_{23} = 7.43E+010, E_{33} = 1.15E+011, E_{44} = 3.06E+010, E_{55} = 2.56E+010, E_{66} = 2.56E+010.
Piezoelectric matrix (C/N): d_{11} = 4.5E-010, d_{12} = 4.5E-010, d_{31} = -1.09E-010, d_{32} = -1.09E-010, d_{33} = 3E-010

PZT-5H

Density (ρ) = 7500 kg/m^3,
Elastic matrix (N/m^2): E_{11} = 1.39E+011, E_{12} = 7.78E+010, E_{22} = 1.39E+011, E_{13} = 6.1E+010, E_{23} = 6.1E+010, E_{33} = 1.15E+011, E_{44} = 3.06E+010, E_{55} = 2.56E+010, E_{66} = 2.56E+010.
Piezoelectric matrix (C/N): d_{11} = 4.5E-010, d_{12} = 4.5E-010, d_{31} = -3.2E-010, d_{32} = -3.2E-010, d_{33} = 3E-010

In finite element analysis, hexahedral elements are used for both the active and inactive material. C3D20RE is used for piezoelectric material which is a 20-node quadratic piezoelectric brick reduced integration element and C3D20R is used for steel material which is a 20-node quadratic brick reduced integration element. Mechanical boundary condition is encastre of all nodes of the fixed end surface of unimorph where U1 = U2 = U3 = UR1 = UR2 = UR3 = 0.

An electrical load of 250 V is applied across the thickness of active layer of each unimorph. The displacement of each cases is observed. To measure the blocking force, a mechanical force is applied to the opposite direction of the displacement. The amount of force that makes the displacement zero after applying electric voltage is measured as blocking force.

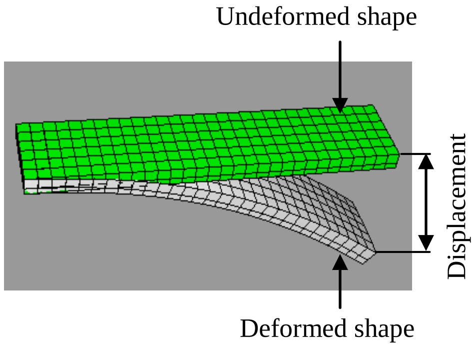

Fig 2. Meshing model of undeformed and deformed shape

Figure 2 shows the finite element modeling of undeformed and deformed shape of unimorph. The color map of displacement of [001] poled PZN-(6-7) %PT unimorph is shown in Fig.3. It shows that the maximum displacement is 173 μm when a voltage of 250 V is applied.

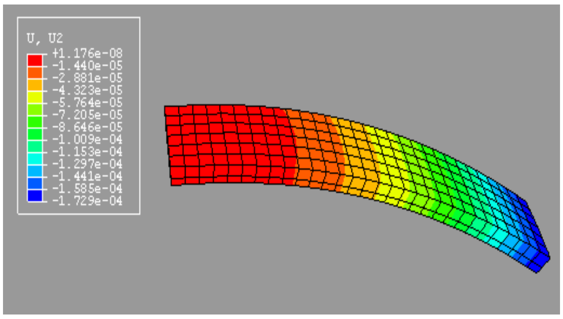

Fig 3. Color map of displacement of [001] poled

PZN-(6-7) %PT unimorph after applying 250 V.

Blocking force is measured for this unimorph by applying a mechanical force to the opposite direction of the dispalecement to make the displacement zero. It was found 252 mN.

Similarly, displacement of [001] poled PZN-4.5%PT unimorph, [100] poled PZN-(6-7)%PT unimorph, PZT4 unimorph and PZT-5H unimorph is measured by finite element modeling that are shown in the Fig. 4, 5, 6 and 7 respectively. Blocking force of these unimorphs is also measured.

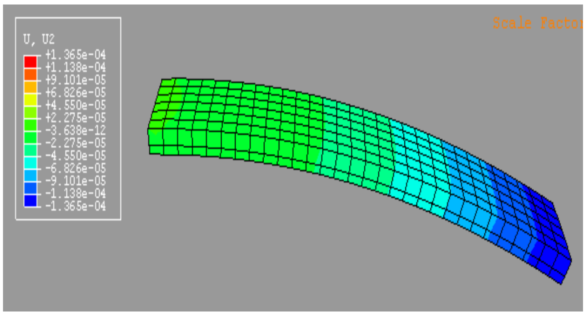

Fig 4. Color map of displacement of [001] poled PZN-4.5%PT unimorph after applying 250 V

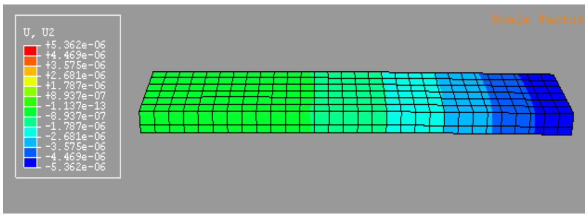

Fig 5. Color map of displacement of [100] poled PZN-(6-7) %PT unimorph after applying 250 V

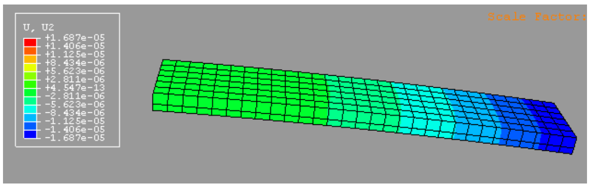

Fig 6. Color map of displacement of PZT4 unimorph after applying 250 V

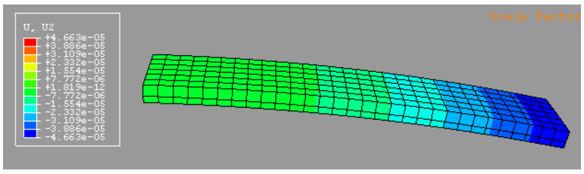

Fig 7. Color map of displacement of PZT-5H unimorph after applying 250 V

The measured displacement and blocking force of all five unimorph is shown in Table 1. A comparison is made among all of unimorph in terms of displacement and blocking force as shown in figure 8.

Table 1: Displacement and blocking force of five unimorph of same sizes but different active material under same electric load of 250 V

Unimorph	**Displacement (µm)**	**Blocking force (mN)**
[001] poled PZN-(6-7)%PT unimorph	173	252
[001] poled PZN-4.5%PT unimorph	136	145
[100] poled PZN-(6-7)%PT unimorph	5	15
PZT4 unimorph	17	50
PZT-5H unimorph	47	130

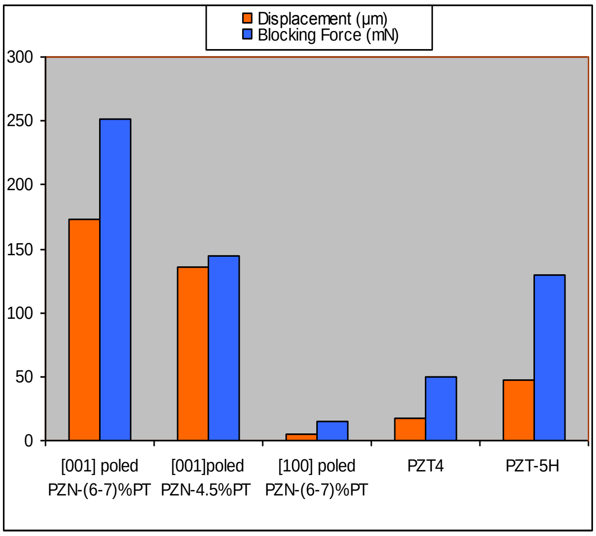

Fig 8. Comparison of displacement and blocking force of five unimorph

4. DISCUSSION

From Figure 8 it is shown that [001] poled PZN-(6-7)%PT unimorph produced higher displacement and blocking force from all other unimorph. It indicate that [001] poled PZN-(6-7)%PT is very potential active material for unimorph application.

Setti *et al.* fabricated [001] poled PZN-4.5%PT unimorph with same size of ours and found displacement of 135 µm and blocking force of 142 mN after applying a voltage of 250 V [4], whereas we have found displacement of 136 µm and blocking force of 145 mN which is very close.

5. CONCLUSION

Piezoelectric unimorph is a very significant parts of robotic mechanism. Selection of suitable unimorph is very important to achieve the optimum efficiency. Different piezoelectric materials produce different displacement and blocking force when it is used in unimoprh. A study is carried out by finite element analysis to determine the displacement and blocking force of five different unimorph made with five different active materials: [001] poled PZN-(6-7)%PT, [001] poled PZN-4.5%PT, [100] poled PZN-(6-7)%PT, PZT4, and PZT-5H. The analysis shows that the unimorph made with [001] poled PZN-(6-7)%PT active material exhibits displacement of 136 μm and blocking force of 145 mN when a electric voltage of 250 V is applied, which is higher than the rest four unimorph.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning	Unit
PZN-PT	Pb (Lead) Zirconate Niobate – Pb Titanate	
PZT	Pb (Lead) Zirconate Titanate	
V	Voltage	Volt
ρ	Density	Kg/m^3
E	Young’s Modulus	N/m^2
d_{31}, d_{33} etc	Piezoelectric coefficient	C/N

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