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Human Energy Harvesting based on Piezoelectric Transduction using MEMS Technology

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ABSTRACT: A MEMS based spiral shaped piezoelectric transducer has been designed for harvesting energy with human walking motion. The torque obtained by human walk has been subjected to the spiral shaped piezoelectric transducer in order to obtain maximum displacement. A bimorph spiral shaped piezoelectric transducer has been designed to reduce the brittleness of the structure. FEM simulations has been performed with different types of metals and varying dimensions. The bimorph spiral shaped piezoelectric transducer gives maximum displacement of 6.1858x 10^6 µm for 150 Nm torque with nickel as its shim layer and PZT-5H as its upper and bottom layer.

KEYWORDS: Spiral shaped piezoelectric transducer, PZT, Bimorph, MEMS.

I.INTRODUCTION

Energy harvesting is a form of renewable power generation and is a key enabling technology for a whole host of future distributed systems such as wireless sensors, implantable devices and structural health monitoring. Among the possibilities for energy generators, piezoelectric materials have been generally used because of their ability to convert ambient mechanical energy into electrical energy. PZT is available in the form of polymer[2] and ceramic, the disadvantage of using polymer is we cannot obtain a rigid structure so inorder to design spiral shaped PZT we use ceramic material. For an energy harvesting device the output obtained should be as greater as possible, the output power[7] obtained is directly proportional to the mass and inversely proportional to the operating frequency of the device. A harvester needs to be designed for a particular type of energy source with a certain frequency. One difficulty often encountered is that for a common low frequency, e.g., 50-200 Hz, a beam-type harvester operating with the lowest flexural mode usually has a frequency that is too high. Of course one can increase the harvester size to lower its frequency, but usually there is a limit on the device size. The mass of the system is responsible for maximum output power as well as the device to operate at low frequency and a spiral shaped bimorph piezoelectric transducer has large mass but in reduced size and shape which gives maximum displacement and it occupies less space than a rectangular shape piezoelectric transducer of same dimension.

In this paper we propose a spiral shaped bimorph as a low frequency energy harvester based on the availability of ceramic spiral transducers. piezoelectric transducer is available in two types, unimorph and bimorph. A bimorph piezoelectric transducer gives maximum displacement and avoids breakage of structure like spiral shaped. A bimorph type consists of a shim layer (metal) sandwiched between two PZT layer. Simulation of rectangular and spiral shaped bimorph piezoelectric transducer has been done using COMSOL software were spiral shape gives maximum displacement. A spiral bimorph is effectively a long and curved bar or belt and hence has relatively low frequency. Since the long belt has a spiral shape, the largest dimension of the structure still remains small. A spiral shape can be designed with multiple number of arms namely 1 arm spiral and 2 arm spiral. The displacement of 2 arm spiral is more as compared to 1 arm spiral, 2 arm spiral is selected and simulated for different types of shim layer(metal).

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II.DESIGN OF STRUCTURE IN 3D MODEL USING COMSOL

A. Rectangular shaped bimorph piezoelectric transducer

In a rectangular shape, the shim layer (nickel) is sandwiched between two piezoelectric layer (PZT-5H). The structure is fixed at one end and it is known as fixed constraint as shown in the figure.

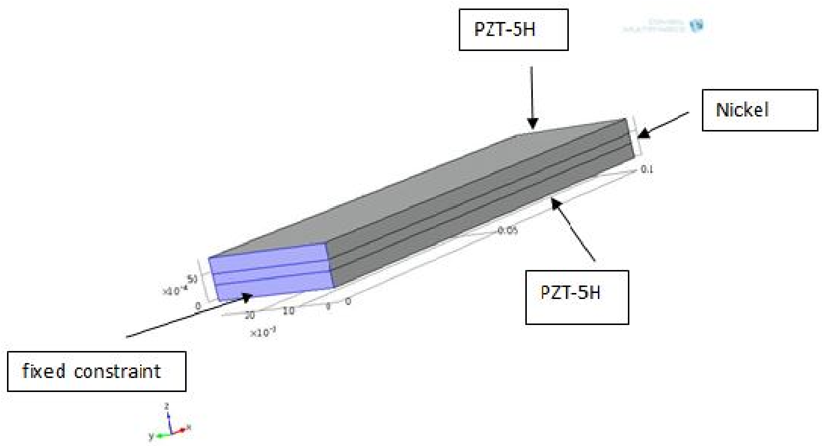

Fig.1: Rectangular shaped bimorph piezoelectric transducer.

In fig 1, the rectangular shaped bimorph piezoelectric transducer is shown were the shaded region with blue colour represents fixed constraint and the upper and bottom layer material used here is PZT-5H and the shim layer material used is nickel.

B. 1 arm spiral shaped bimorph piezoelectric transducer

A long belt is curved in the form of spiral in order to obtain maximum displacement with low operating frequency.

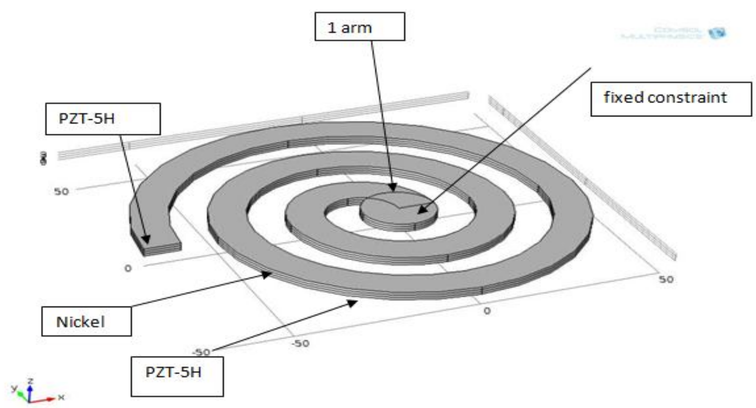

Fig.2: 1 arm spiral shaped bimorph piezoelectric transducer.

In fig 2, the 1 arm spiral shaped bimorph piezoelectric transducer is shown were the small circle in the middle is fixed. The material used in bottom and top layer is PZT-5H and nickel as shim layer.

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C. 2 arm spiral shaped bimorph piezoelectric transducer

Two long belt is curved in the form of spiral in order to obtain maximum displacement with low operating frequency.

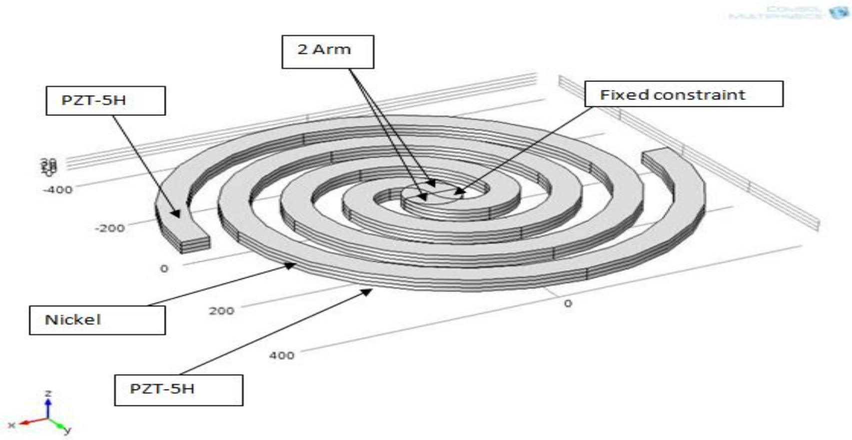

Fig.3: 2 arm spiral shaped bimorph piezoelectric transducer.

In fig 3, the 2 arm spiral shaped bimorph piezoelectric transducer is shown were the circle in the middle is fixed. The material used in the upper and bottom layer of the spiral is PZT-5H and for shim layer the material used is nickel.

III. SELECTION OF MATERIAL

A. Lead Zirconate Titanate

Twenty of the thirty-two crystallographic elements exhibit piezoelectric properties. Only few materials are useful for piezoelectric transducers. Primarily quartz, Rochelle salt, ammonium dihydrogen phosphate (ADP) and ceramics made with barium titanate, dipotassium tartrate, potasssium dihydrogen phosphate and lithium sulfate are some of the materials used in real applications. Lead Zirconate Titanate is a ceramic and it has been choosed for designing spiral shape because stiffness is essential for obtaining spiral shape. There are various types of PZT available out of which we select PZT-5H because youngs modulus is less for this PZT compared to the other types of PZT available like PZT-4, PZT-5A and PZT-8. Youngs modulus is a very important property when it comes for deflection of a material, it determines the rigity of a material and it is different for different materials. A material can give us maximum displacement if the youngs modulus is less and maximum displacement results in greater energy generation hence PZT-5H is selected. Poisson ratio for all these material is 0.31.

Table 1: Comparison of different types of PZT available

MATERIAL	YOUNGS MODULUS (G Pa)
PZT-4	78 G Pa
PZT-5A	66 G Pa
PZT-5H	64 G Pa
PZT-8	99 G Pa

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B. Nickel (shim layer)

The selection of nickel has been taken place after the simulation of the design. The below mentioned materials were used as shim layer placed in between PZT-5H for simulating the spiral shaped piezoelectric transducer. The maximum displacement is obtained with tungsten(W) but the availability of this material is rare in the world so it is avoided next is platinum but 1gm=Rs 3693, it is costly, gold 1gm=Rs 2749 costly, palladium is a rare material. The material which gives highest displacement after the above mentioned material is nickel, displacement=6.1858*10^6 µm. Nickel is readily available and its cost is very less 100gm=Rs 463.309.

Table 2: Displacement of 2 arm spiral shaped bimorph piezoelectric transducer with different shim layer

MATERIALS	DISPLACEMENT (*10^6) µm
Brass	5.7893
Aluminium	5.7951
Silver	5.9351
Gold	6.2183
Chromium	5.9649
Copper	5.9953
Titanium	5.9125
Iron	5.8774
Nickel	6.1858
Lead	5.6229
Palladium	6.2428
Platinum	6.358
Tungsten	6.3805
Stainless steel	6.0232

IV. APPLICATION OF FORCE

The moment of force exerted by the human ankle is a very important factor. Depending upon the moment of force exerted by the human ankle is responsible for the displacement of the spiral shaped piezoelectric transducer. According to Susannah K.S. Thorpe, 1997 the torque exerted by the human leg is calculated with the help of the following formula:

$$Ma = \sum_{k=}^{TS} Ara\sigma a$$

where,

Ma = muscle stress at ankle

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r = joint angle

σ = muscle stress

TS = triceps surae

A = physiological cross-sectional area

with the above formula it has been found that a 30±5.9 year old person with height 1.8±0.07m and mass of 77.5±5.6 can exert 150 Nm.

V.SIMULATIONS

Simulation parameters:

MATERIAL	YOUNGS MODULUS (G Pa)	POISSON RATIO	DENSITY (kg/m^3)
PZT-5H	64	0.38	7500
Nickel (shim layer)	219	0.31	8900

A. Rectangular bimorph piezoelectric transducer:

A rectangular bimorph has been designed with PZT-5H as upper and bottom layer and nickel in between has been simulated.

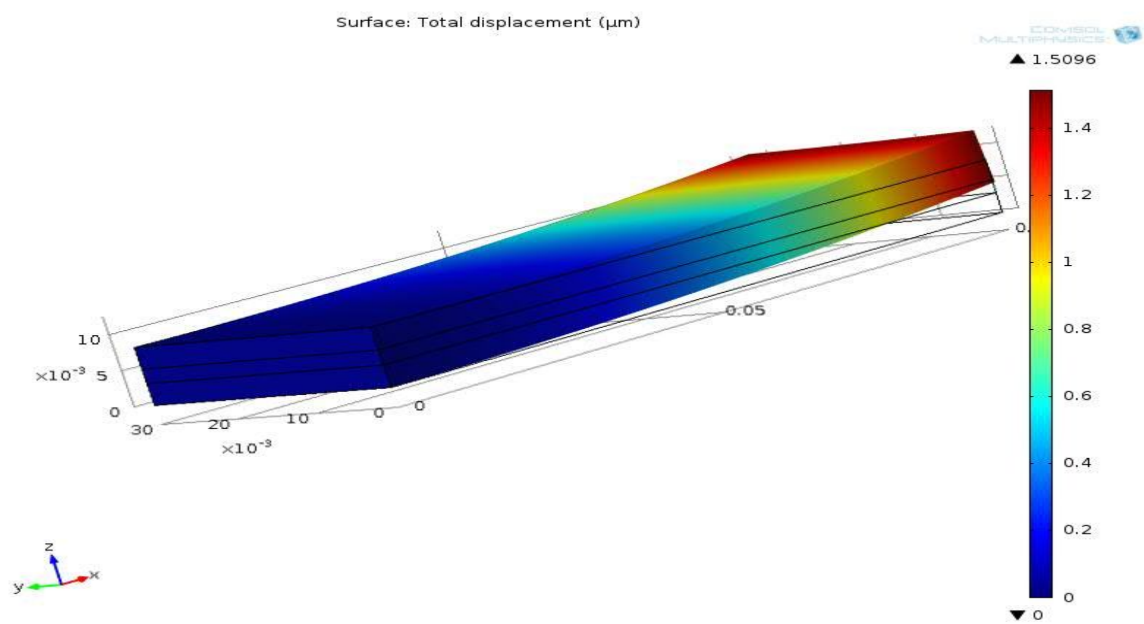

Fig.4:Displacement of rectangular bimorph PZT

In fig 4, the simulation of rectangular shaped bimorph piezoelectric transducer has been performed were we obtain a displacement of 1.5096 µm for a applied torque of 150 Nm.

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B. 1 arm spiral shaped bimorph piezoelectric transducer

A 1 arm spiral shaped PZT designed with nickel sandwiched between PZT-5H has been simulated.

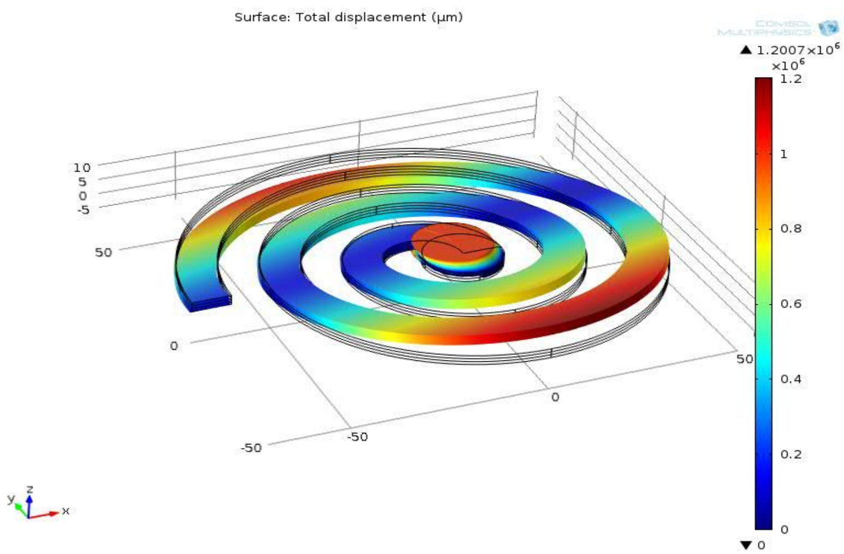

Fig.5: 1 arm spiral shaped PZT

In fig 5, a 1 arm spiral shaped piezoelectric transducer is subjected to a torque of 150 Nm for which a displacement of 1.2007×10^6 µm is obtained.

C. 2 arm spiral shaped piezoelectric transducer

A 2 arm spiral shaped PZT designed with nickel sandwiched between PZT-5H has been simulated.

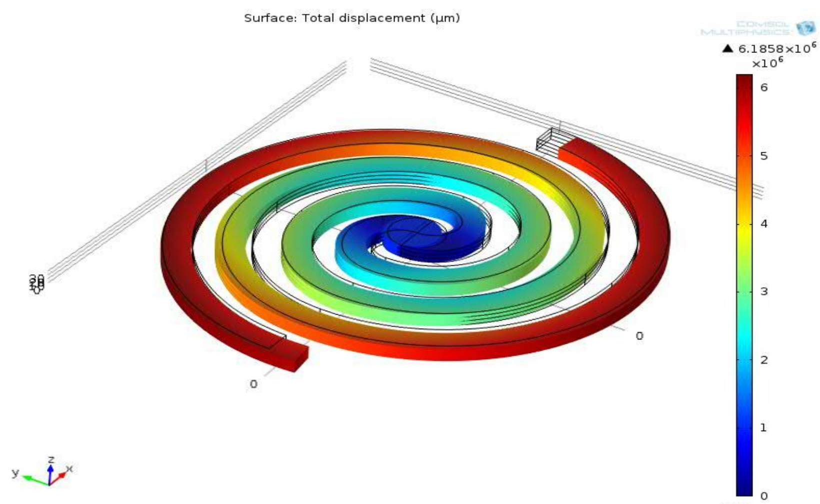

Fig.6: 2 arm spiral shaped PZT

In fig 6, a 2 arm spiral shaped piezoelectric transducer is subjected to a torque of 150 Nm for which a displacement of 6.1858×10^6 µm is obtained.

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VI. RESULTS AND DISCUSSIONS

A spiral shaped bimorph piezoelectric transducer for various shapes and dimensions and for various materials has been simulated and found out that PZT-5H as upper and lower layer and nickel as shim layer has given maximum output displacement of $6.1828*10^6$ µm for application of force of 210Nm.

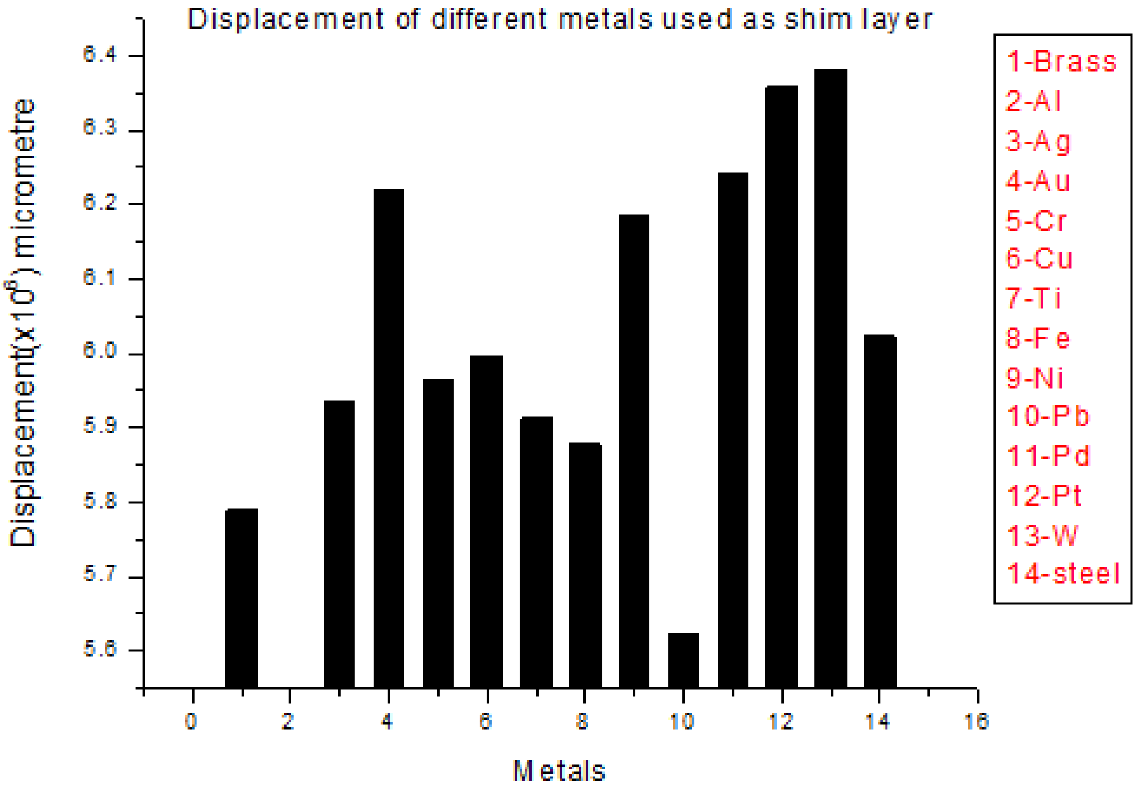

Fig.7: Graph to show the displacement of various metals used as shim layer.

In fig 7, the above graph shows the displacement of 2 arm spiral shaped bimorph piezoelectric transducer with different shim layer(metals). The displacement of tungsten(W), palladium(Pd) is greater than nickel but it comes under the category of rare metal and so the displacement of gold and platinum is greater but it is costly compared to nickel hence nickel is chosen to be the best shim layer material than the other metals according to the simulation results.

VII. CONCLUSION

The performance of a piezoelectric transducer in rectangular and spiral shape has been simulated with COMSOL 4.3 multiphysics software. Spiral shape has been classified into 1 arm and 2 arm were 2 arm spiral shaped bimorph piezoelectric transducer gives maximum displacement of $6.1858x10^6$ µm with PZT-5H as upper and bottom layer and nickel as shim layer.

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