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FINITE ELEMENT MODELING OF PIEZOELECTRIC PATCHES FOR VIBRATION ANALYSIS OF STRUCTURES

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Abstract - *Finite element modeling and analysis is one of the important tool for analysis and this report or study explains the recent development of modeling and numerical analysis of piezoelectric material and also piezoelectric system , using one of the finite element modeling and analysis software as ANSYS. The analyst to get knowledge about how to control the structure from vibration by getting possible results of static and dynamic analysis and simulations when using piezoelectric patches. These piezoelectric patches used mainly in delicate places that is Aero space structures, complex shapes or complex structures etc because these are light in nature and activate with voltage. Finally, the study concentrate on a simple plate structure and apply an unity voltage to understand the concept clearly. And piezoelectric patches use to study the vibration analysis of structure using an ANSYS software. The system of steel plate and piezoelectric patch gives the clear knowledge about how to apply the patches to study the vibration analysis for further controlling purpose. The study continues for one step ahead i.e this patch can be able to use on composite materials using same step.*

Key Words: Finite element technique, composite plates, piezoelectric material.

1. INTRODUCTION

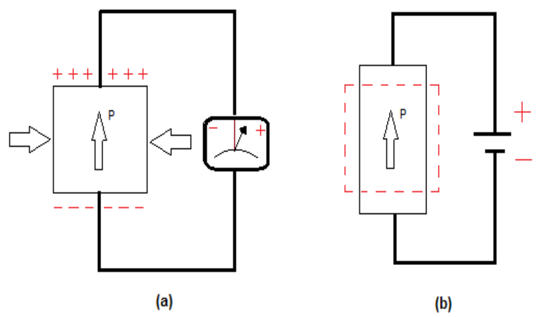
The project work presents the fundamental conceptual knowledge about piezoelectricity, piezoelectric effect and its different domains, piezoelectric materials, piezoelectric patches and finally works strategy. The objective of the present project work is to study the vibration analysis of structure with the help of piezoelectric patches by application of voltage, using one of the strong tool finite element modeling and analysis software as ANSYS. The shape and size of the material and patches, are used in delicate places like aerospace and how it works then it gives the proper results. These results gives the basic knowledge about piezoelectric patches. In older days the fundamental concept about conversion of mechanical energy into electrical energy this is generally achieved by DYNAMO.

Piezoelectricity: Now the present invention on the piezoelectricity, deals with the physical phenomena that can convert mechanical movement into electricity. This work is made by Pierre curie and Paul Jacques in 1880.

Piezoelectric effect: Now moving to the next concept, that is piezoelectric effect. This is one of the concept exist in two main aspects like, direct and indirect (converse) piezoelectric effect.

Direct effect: Ability of the material to mechanical strain is converts into electrical charge.

Indirect effect: Ability to electric potential energy transform into mechanical strain energy.



a) Direct effect b) converse effect

Fig1 piezoelectric effect

Piezoelectric materials: Different materials are used as a piezoelectric materials naturally exist in Quartz. The Quartz material possess properties for production of electricity in a very small quantity. Now a days PZT (Lead Zirconate Titanate) is used as the artificial piezoelectric material. Compare to Quartz to PZT (Lead Zirconate Titanate) gives more advantageous characteristics of generating more electricity. Apart from these materials some other materials are also used like Topaz, Rochelle salt, wood, Gallium orthophosphate (Gapo4), Langasite(La3Ga5Sio4).

Piezoelectric patches: The above discussion is made only for knowledge about piezoelectric related concept. Now we deal with piezoelectric patches in detail, like how it works, their applications…etc.,

Development of piezoelectric materials have established a revolution in actuation and sensing application in recent years. Because it requires (i.e piezoelectric patches) little power consumption , large bandwidth, make piezoelectric materials increasingly popular as its potentiality more suites for sensor and actuators.

Usages of piezoelectric patches: The piezoelectric patches are mainly used in many structures including aerospace, MEMs applications ….etc. In recent study explains the piezoelectric patches are more useful in flexible structure because of its more withstanding capacity of vibration. Piezoelectric patch has got a very good precision quality to control the noise and vibration and enhances the smooth flow of linear motion.

Patches are used in measuring the precision deflection analysis, to control and to predict the structure response.

In this work using a steel plate structure having dimensions 0.6*0.4 (l_x*l_y) in m and also $1*10^{-3}$ m. mesh and analyze the model to get a frequency range. using piezoelectric patch to a plate for a vibration analysis for a further study means after getting results , in our required frequency range we have to control the vibration in at particular point or we have to jump the frequency range. The reference paper is carried out a study on the simple steel plate now we want to study the topic as the paper says and made a validation for study for both results after that we want to adopt a method to a composite materials and make it as a best project.

The aim of this project is " Application of piezoelectric patch to composite structures for study of vibration analysis, adapt same method as applied by the steel plate structures". Composites are one of the useful and ongoing technique and most helpful in engineering works.

These Composite materials have wonderful advantage in the engineering work. Composite materials are in heterogeneous nature, made up of two or more components like reinforcing fibers having a compactable matrix. Some matrix origin like metallic, polymeric or ceramic.

In the present days the composite materials most used in some important industries like Aerospace, automobile and other engineering applications because of they exhibit outstanding strength. Like that most commonly used composites are Glass, Graphite, Kevlar, Boron or Silicon carbide fibers in polymeric matrices have been studied because of some outstanding properties like strength and weight aspects, used in most application in aerospace and space vehicle technology.

The selected composite materials are glass fiber ,graphite fiber and for both fibers epoxy is the common resin.

Fiberglass

In the present days the composite materials most used in some important industries like Aerospace, automobile and other engineering applications because of they exhibit outstanding strength. used in most application in aerospace and space vehicle technology. But the fiberglass to use because of, Less stiff and less brittle Raw material are much less expensive. Compare to metals it has less weight. Epoxy is the thermosetting plastic and used in our present work.

Fig2 glass fiber

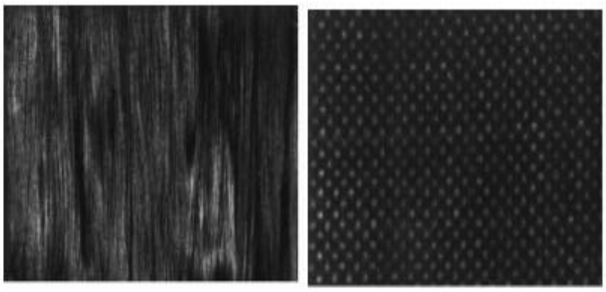
Fine ground, chopped these are different forms of Glass reinforcements used and supplied.

In the final structure the glass fiber are used for insulation then the structure will be strong, as this permits the fibers to reach GPa (Giga Pascal) tensile strengths. The fiber surface almost have no defect throughout the model. The model (bulk piece) has no defect then it is strong as compared to glass fiber. Be that as it may, it is for the most part unrealistic to create mass material in a no deformity state outside of research facility conditions.

Graphite fiber

Graphite fibes are commonly used in the aircraft component. It has some properties like, High modulus & strength, Low coefficient of thermal expansion, High specific strength, Have the drawback of high cost Low impact resistance, high electrical conductivity.

For the most part graphite filaments are assembling from three antecedents materials i.e Rayon, Polyacrylonitrile (PAN) and Pitch. Skillet is the most utilized material as a part of the assembling graphite strands. It has 99% of carbon substance. In the present days the composite materials most used in some important industries like Aerospace, automobile and other engineering applications because of strength and weight.



a)Unidirectional graphite b) Plane wave graphite.

Fig3 graphite fiber

2. METHODOLOGY AND ANALYSIS

The study is carried out on the vibration analysis of a structure with the help of piezoelectric patches. Here the work is carried out and performed using the ANSYS software 14.5, the material properties chosen for this evaluation are structural, linear, elastic, isotropic material and this analysis can also be adopted for composite materials.

1. Model or structure modeling
2. Specify material properties
3. Meshing the created model
4. Analysis made before application of piezoelectric patch
5. Apply piezoelectric patch
6. Once again carry out the analysis
7. Apply voltage
8. Obtain the results.
9. Adopt to a composite structure.

MODEL USED

We are considering a simple plate structure having dimensions 0.6 * 0.4 and thickness 1*E-1 in meters.

Table 1 plate material properties

	Piezoelectric		
Properties	**Sensor**	**Actuator**	**Plate**
E (Young's modulus)	2	69	207
ρ (Density)	1780	7700	7870
ν (Poisson)	0.3	0.3	0.29
h (Thickness)	0.205×10^{-3}	0.254×10^{-3}	1×10^{-3}
ξ^S (Piezo dielectric)	1.06×10^{-10}	1.6×10^{-8}	----
e (Piezoelectric strain)	0.046	-12.5	----
C (Capacitance)	5.2×10^{-9}	6.3×10^{-7}	----
Geometry ($L_x\times L_y$)	0.1×0.1	0.1×0.1	0.6×0.4

After modeling a plate structure have to attach the piezoelectric patches according to this table.

Table 2 position of patches

	Material		
Position (*m*)	**1**	**2**	**3**
x_1	0.25	0.15	0.35
y_1	0.05	0.25	0.25

Using above tables the final system is shown as

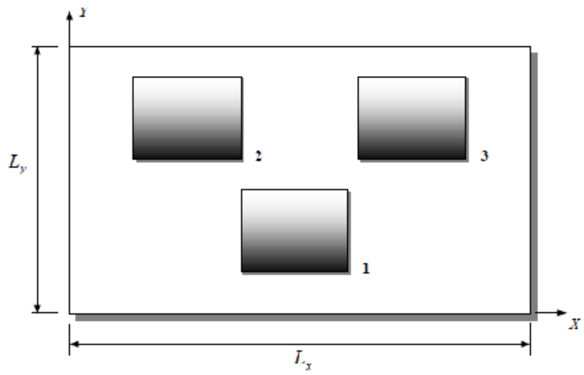


Fig4 piezoelectric actuator test configuration

After application of patch as an actuator we have to apply voltage to get results.

1. FINITE ELEMENT METHOD

With the rapid advancement of technology, the complexity of the problem to be dealt by a design engineer is also increasing. This outline demand speedy, efficient and optimal design from an engineer. To be continuous developing and ensure better output, the engineer today resorting to numerical methods. For the problems that have complex shapes, material properties and complicated boundary conditions, it is very difficult to obtain analytical solutions. Numerical methods provide approximate but acceptable solutions to such a complex problems.

Finite element analysis is one of such numerical method for analyzing and solving wide range of complex engineering problems which are to solve by any of the available classical analytical methods.

The computer is the backbone of the procedure since in involves the solution of many simultaneous algebraic equations, which can be solved easily and quickly by the computer. Basically Finite Element Method was originated as a method of stress analysis. But today the applications are numerous. Now a days, each and every design is developed through Finite Element Method. The numerous applications include the fields of Fluid flow, Heat transfer, Electric and Magnetic field, Seepage and other flow problems. The various areas of application include design of buildings and bridges, aircraft structures, electric motors, heat engines, spacecrafts etc. With the advances in interactive CAD systems complex problems can be modeled with relative ease. Several alternative configurations can be tried out on a computer before the final prototype is built.

Finite Element Method of analysis complex region of a continuum is descretized into number of simple geometric shapes called finite elements. The material properties and governing relationships are considered over these elements and expressed in terms of unknown values at the corners of the element. As assembly process, duly considering the loading and constraint results in a set of equations. Solutions of these equations give approximate behaviour of the continuum.

2. RESULTS AND DISCUSSIONS

First we have to study the steel plate to know the concept for how to apply and study the composite structure.

To make a steel plate structure with required mechanical properties and Apply Meshing with the help of ANSYS 14.5 software.

Modal analysis

Shows the result by using ANSYS with same load and boundary conditions.

SET,LIST Command
File

***** INDEX OF DATA SETS ON RESULTS FILE *****

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
1	0.0000	1	1	1
2	0.0000	1	2	2
3	0.0000	1	3	3
4	100.21	1	4	4
5	186.99	1	5	5
6	367.87	1	6	6

Assembled system when meshing takes place the three of the piezoelectric patch used and Apply boundary conditions to piezoelectric patches

Element type= brick 8 noded 185

Dof $k_1=U_x U_y U_z$ volt

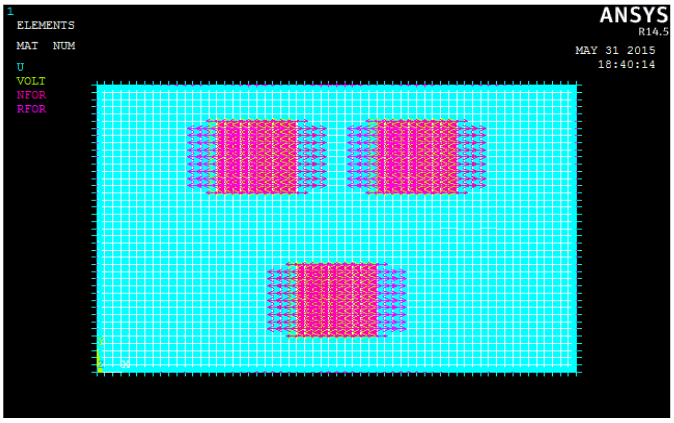


Fig5 boundary condition on patch

STATIC DISPLACEMENT DISTRIBUTION

Total plate displacement amplitude calculated by using closed form , using FEM and ANSYS software ,when a static input voltage (ϕ_a) is applied to actuators (1,2 & 3)for the following magnitude and the result will be shown below. (ϕ_a) = {-1 1 1}

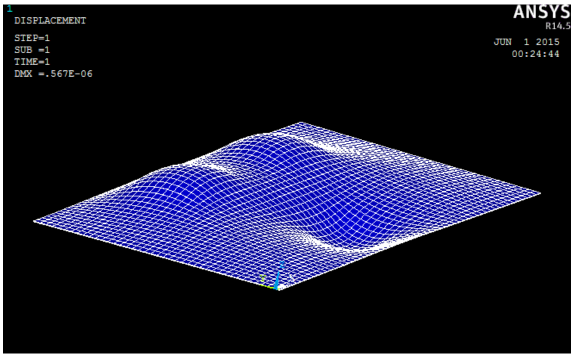


Fig6 displacement under action of voltage

The static displacement distribution is calculated by using numerical techniques for two particular section of the plate i.e ($y=L_y/2$ and $x=L_x/2$) as shown below.

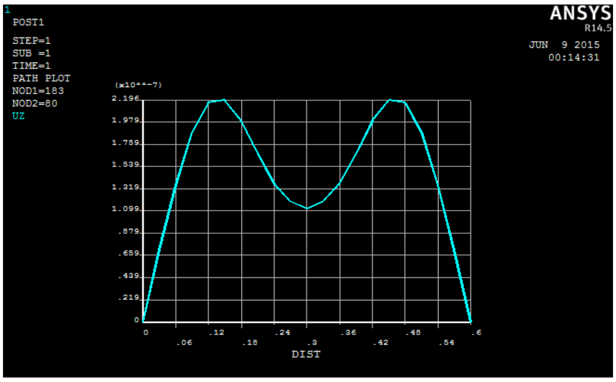


Fig7 static displacement distribution (section $y=L_y/2$)for numerical technique

Comparison of the static displacement distribution (section $x=L_x/2$)for numerical technique.

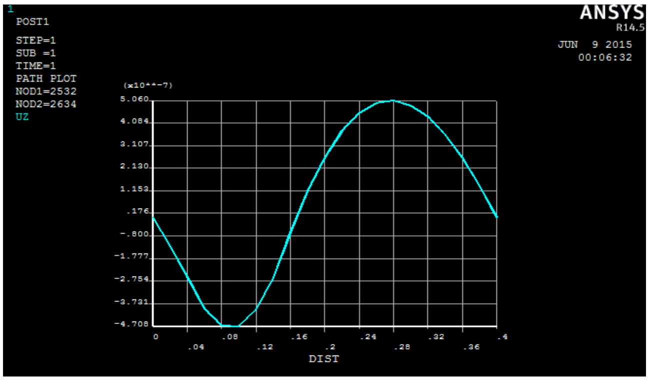


Fig8 static displacement distribution (section $x=L_x/2$)for numerical technique

Nodal solution for this system is,

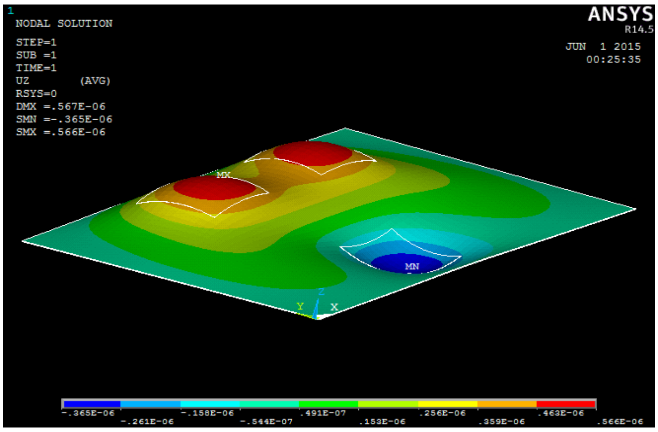


Fig9 deformed under voltage action for steel plate & Nodal solution

Piezoelectric action under composite material.

Used materials are

1. Glass fiber with epoxy resin

2 .Graphite fiber with epoxy resin

Table 4 properties of composite materials

Composite materials	Specific Gravity	**Young's modulus 'E'** (GPa)	**E/ρ** (GPa-m³/kg)	**$E^{1/2}$/ρ** (Pa-m³/kg)	**$E^{1/3}$/ρ** ($Pa^{1/3}$-m³/kg)
Graphite/ epoxy	1.6	181.00	0.1131	265.9	3.535
Glass/epoxy	1.8	38.60	0.02144	109.1	1.878

Shell type element

Element type = 8 noded solid 5 (couple field)

Dof k_1=Ux Uy U_z voltS

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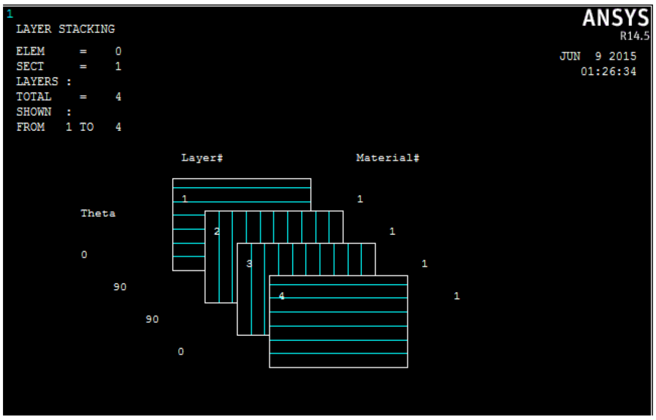

Fig 10 composite arrangement

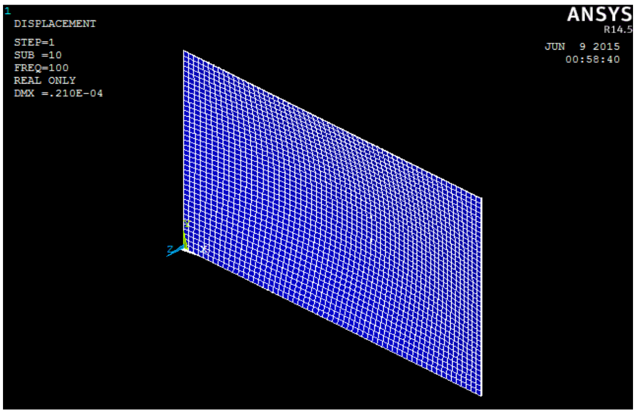

Fig 11 displacement at frequency 100Hz

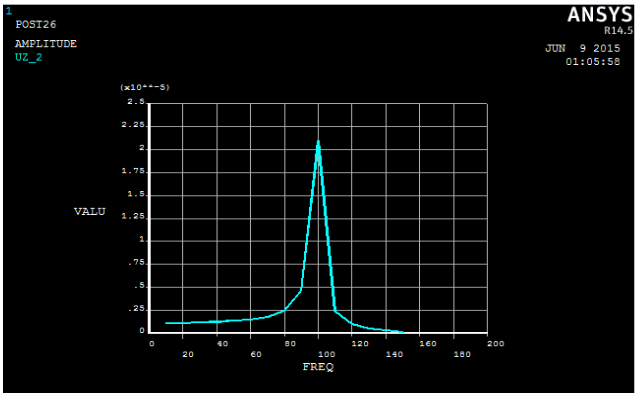

Fig 12 amplitude at 100Hz

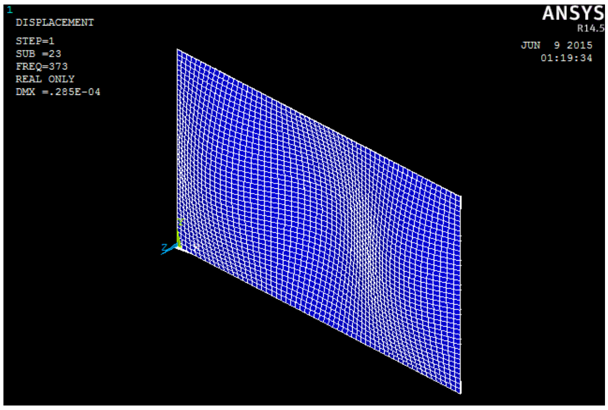

Fig 13 displacement at frequency 373Hz

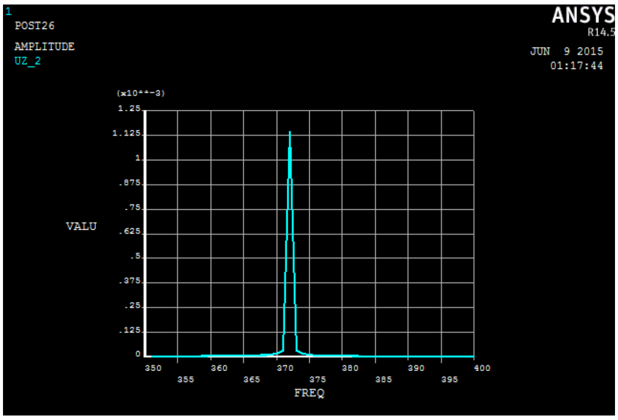

Fig 14 amplitude at 373Hz

Glass epoxy

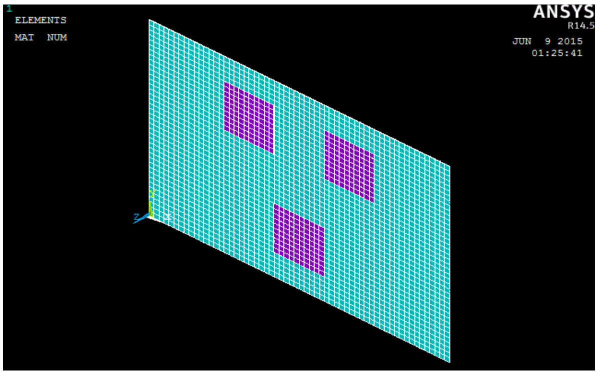

Fig 15 arrangement of patch and composite plate

Deformed shape

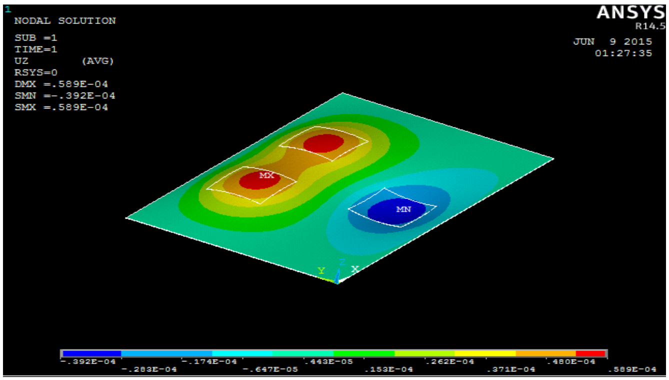

Fig 16 deformed under voltage action for glass epoxy plate

Graphite epoxy

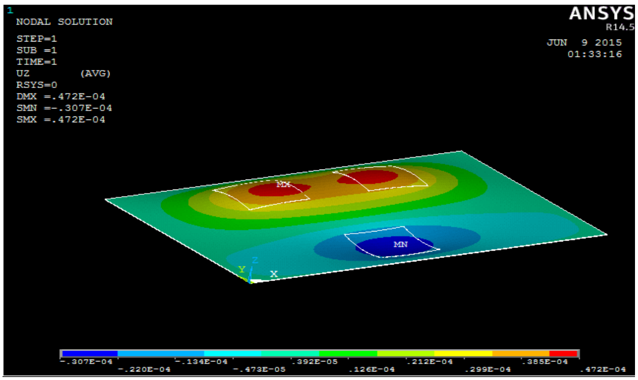

Fig 17 deformed under voltage action for graphite epoxy plate

3. CONCLUSION

In this work, All important steps were presented for clear understanding purpose. Because to understand the modeling easily and clearly. Here, various computational tests were performed demonstrating the efficiency for that used by this methodology. Results were show and clarifies for a rectangular slim plate energized by different rectangular actuators reinforced on the sides of the plate. The present FE procedure demonstrate the static and element examination for obliged results. With those from the definite arrangements and programming ANSYS. The present arrangements are most valuable for comprehension the electromechanical coupling in astute and brilliant structures under element conditions. The present strategy is helpful for the configuration of vibration investigation and also control structures.

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