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REDUCTION OF VIBRATION USING PIEZOELECTRIC RINGS ON STEPPED SHAFT BY APPLICATION OF FEM AND OPTIMIZE THE RINGS FOR MAXIMUM REDUCTION IN VIBRATION

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ABSTRACT

Piezoelectric ceramic rings are used to generate electricity by using vibration energy from rotating shaft. In present study piezoelectric ring made by PZT-8 material. These rings are coupled with stepped shaft to produce electricity by vibration energy generated by shaft during its free modal analysis. The whole research study is carried out by Ansys APDL solver. In general piezoelectric modeling is not present in APDL solver so proper code is generated to invoke piezoelectric materials effect. To optimize the rings performance various rings configurations are used like single ring application, multiple rings application having different gaps among tow successive gap of rings. In present study the six mode shapes of vibrations are analysis for simple stepped and shaft with rings. The shaft material used in present study is SS-316. The main outcome of present study is that by application of piezoelectric rings on shaft can capable to reduce the vibration in shaft by producing the electrical output.

KEYWORDS: FEM, Stepped shaft, Modal analysis, natural frequency, Piezoelectric Rings, PZT-8, Optimization of Rings.

I. INTRODUCTION

Vibration is available in innumerable day by day life applications, and all the more frequently, vibration is profoundly unwanted. Bothersome vibration may diminish the presentation of the item and cause wellbeing or monetary issues. Vibration damping incorporates dynamic, detached, and half and half damping strategies. Understand that aloof damping can be proficient in damping out high-recurrence excitation, while dynamic damping can be utilized to control low-recurrence vibrations]. Dynamic vibration-diminishing methods end up being a reality for a wide assortment of uses. A functioning strategy coordinates sensors and actuators with an adaptable structure, worked by a control conspire. A basic issue in dynamic control frameworks is sensor and actuator determination. The ever-expanding utilization of keen composite materials in cutting edge regions, for example, aviation, car, and athletic gear has spurred specialists to investigate conduct and execution attributes

Scaled down piezoelectric components are broadly utilized as sensors and actuators in nondestructive testing gadgets, electro-optic modulators, and electro-acoustical hardware. As of late, high productivity piezoelectric vitality collectors have been applied to low power electronic gadgets. In the plan of such transducers, guaranteeing great electromechanical exchange capacity requires nitty gritty particulars with respect to vibration attributes, and piezoceramic plates have demonstrated important in such manner. The outspread, unrelated, and transverse vibrations of single-layer piezoceramic round plates were broke down utilizing the partition of factors strategy and the limited component technique (FEM), and the comparing resonant frequencies were in acceptable concurrence with hypothetical forecasts. Numerous applications utilize piezoelectric plates or rings mounted on metal or fiber fortified composite as a unimorph piezoceramic structure. A piezoelectric circle mix with a glass reflect was intended to deliver diverse vibration modes on an adaptable mirror utilizing divided anodes. The vibration shapes got by twofold presentation holographic interferometry were utilized to decide the connection between energized voltage and vibration dislodging.

II. AIM OF PRESENT RESEARCH

The aim of present study is to find the role of piezoelectric materials to reduce the vibration in shaft. In present study piezoelectric rings are used to find the effect of these rings on vibration frequencies. Various combinations of rings are used to find the vibration frequencies using FEM modeling tool. Single ring, double ring, three ring and four ring configurations of piezoelectric materials are plan to design for this research study. In three and four ring configurations the gap has two values first has 10 mm and second configuration is 20 mm gap. Ansys APDL FEM design tool is used for this piezoelectric modeling. Simple material code is required to develop for this study.

III. STEPPED SHAFT DETAILS

In present study first part of research is to conduct modal analysis on simple stepped shaft which is show in figure 1, then after various combinations of rings with shaft is used for modal analysis and present in figure 2 for all possible combination.

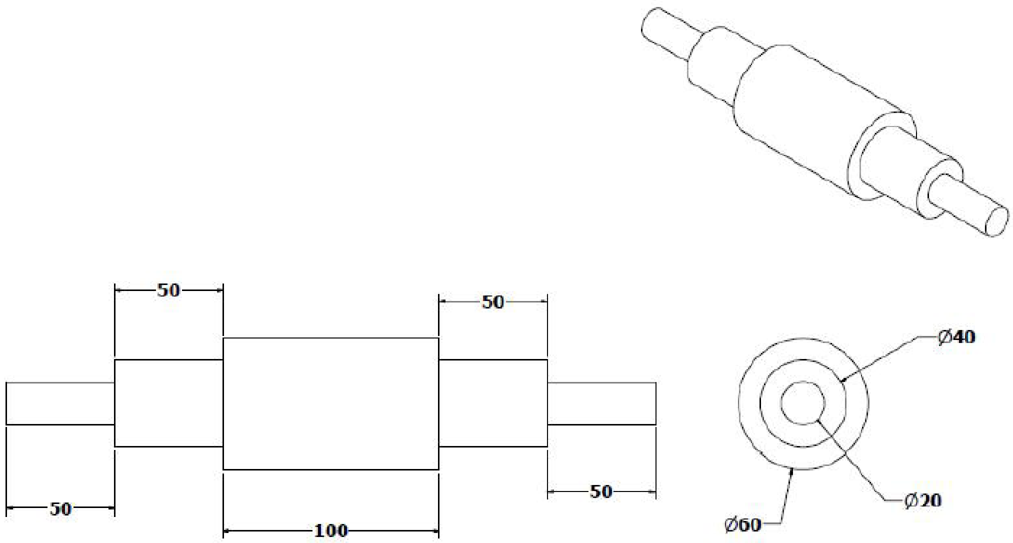

Fig-1: Stepped Shaft dimensions used for current study

As seen in figure the shaft has length of 300 mm with different diameters of shaft segments like outer segments are 20 mm diameter, intermediate segment has 40 mm diameter and most inner segment has 60 mm diameter.

(a) Single Ring stepped shaft

(b) Two Ring stepped shaft

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The piezoelectric rings are installed at outer most shaft segment which are show in figure 2 (a) to figure 2 (f). The thickness of ring is 10 mm and the dimensions are set as per shaft diameters of outer shaft segment.

(c) Three Ring stepped shaft at 10 mm gap

(d) Three Ring stepped shaft at 20 mm gap

(e) Four Ring stepped shaft at 10 mm gap

(f) Four Ring stepped shaft at 20 mm gap

Fig-2: All possible combinations of rings installed at stepped shaft

IV. SHAFT AND PIEZOELECTRIC RING MATERIAL PROPERTIES

Geometric parameters are present in previous section for stepped shaft and for ring configurations. In this section material properties are present in table 1 and table 2 for shaft and ring made by piezoelectric material.

The shaft is made with SS-316 and rings are made with PZT-8 materials which are general used material for piezoelectric ring making.

Table-1: Mechanical Properties of SS-316

Properties	Value	Unit
Density	8000	Kg/m3

Young Modulus	190	GPa
Shear Modulus	75	GPa
Yield Strength	200	MPa
Tensile Ultimate Strength	480	MPa
Poisson Ratio	0.265	NA

Table-2: Mechanical Properties of PZT-8

Properties	Value	Unit
Density	7600	Kg/m3
C_{11}^{E}	1.32E+11	Pa
C_{12}^{E}	7.3E+10	Pa
C_{13}^{E}	7.1E+10	Pa
C_{33}^{E}	1.15E+11	Pa
C_{44}^{E}	2.6E+10	Pa
e_{31}	-4.0	C/m2
e_{33}	13.8	C/m2
e_{15}	10.4	C/m2
e_{11}/e_0	898	-
e_{33}/e_0	582	-

The properties are set as per Ansys APDL design language tool for both materials used for this research study. The PZT-08 materials properties are collected by literature available in digital platform and verified by various data's then use in this research study.

V. FEM MODELING PROCESS

Ansys WB (Version 14.5) is used in this study and the final modeling steps for this study is discuss in this section and present in table 3 in detail.

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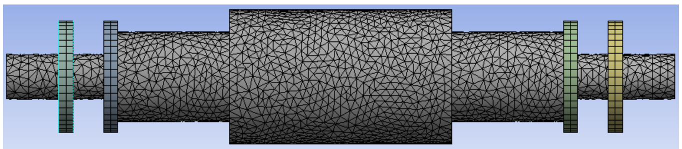
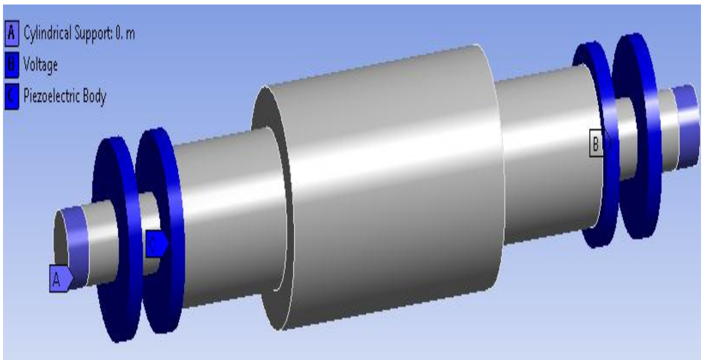
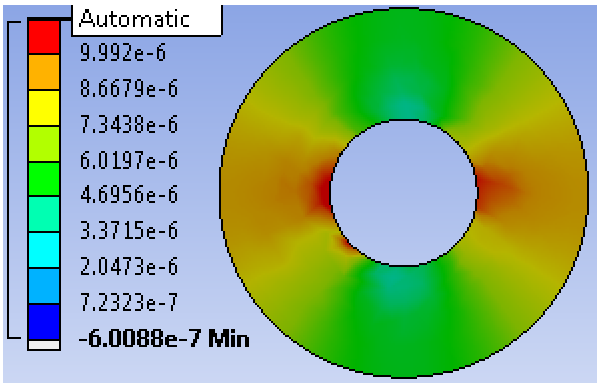
Table-3: Modeling steps of FEM simulation

Steps	Graphical view	Description
I: CAD Generation		Autodesk Inventor software is used for CAD file generation
II: Mesh Generation		Total Element=36979
III:Material Selection	**SS-316 and PZT-08**	Properties in table 1 and table 2
IV: Boundary Conditions		Cylindrical support present Bearing effect
V: Analysis Setting	Six mode shape with piezoelectric modeling couple by APDL language code	Rotor Dynamics is OFF
VI: Solver	Direct Solver is applied for this research study for more accuracy of results	APDL Solver
VII: Post Processing		Voltage generation, Mode Shapes, Campbell Diagram

The mesh quality is also checked for present study and results of mesh quality is present in table 4 for some important mesh quality tools.

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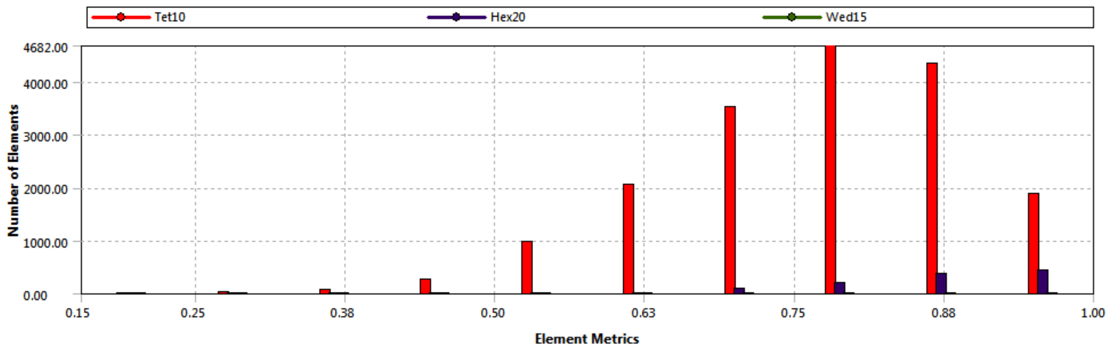
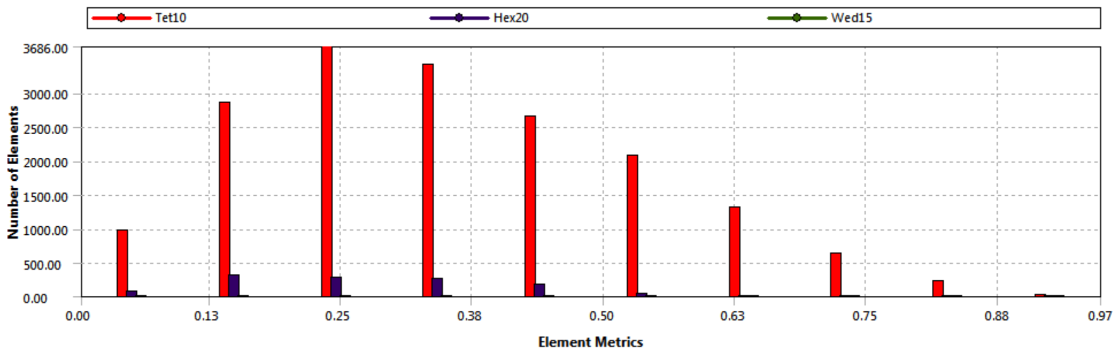
Table-4: Mesh Quality analysis for four ring based stepped shaft

Element Quality



Skewness Quality



Element quality must be range towards 1 for better mesh quality and Skewness must be towards zero for better mesh quality. So in present study the mesh quality is in better agreement for simulation work. The mesh quality is improved by using advanced size function available in Ansys WB meshing tool.

VI. RESULT AND DISCUSSION

In present study the main focus is that by application of piezoelectric rings on stepped shaft to find the role on vibration frequency investigation. So APDL design language is used to introduce the piezoelectric modeling with Modal analysis or say couple among these two physics is done for this research study. There are various ring installation configurations are used which already present in figure 2 are discussed. The mode shape results for different ring arrangements are present in table 5.

Table-5: Mode shape results for different ring combinations used for stepped shaft (Hz)

Mode Shape	Stepped Shaft	R-1	R-2	R-3 gap 10 mm	R-3 gap 20 mm	R-4 gap 10 mm	R-4 gap 20 mm
I	1029.2	357.5	55.8	8.3	13.3	8.4	9.1
II	1040.1	1030.7	357.5	10.6	17.5	9.9	12.2
III	1040.2	1042.7	1030.7	55.8	55.8	10.6	13.3

IV	2783.9	1043.0	1044.6	357.4	357.4	13.8	17.6
V	2784.2	2754.5	1045.0	1030.7	1030.7	55.8	55.9
VI	3944.0	2755.6	2723.5	1041.4	1043.1	357.5	357.5

As seen in table 5, the vibration frequencies going to change by using piezoelectric rings. The most wide change are present in last case which has four rings with 20 mm gap among the rings (R-4 gap 20 mm). The only reason to change the frequencies is the change of vibration energy into electrical energy by piezoelectric rings. The modeling is although an-isotropic in nature but some error can be possible in these results which can be verified by experiments.

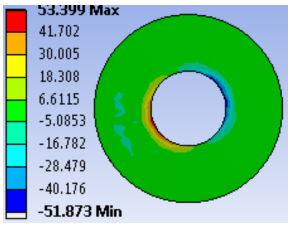
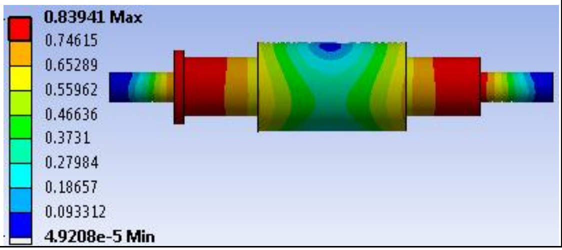
The voltage generation due to piezoelectric rings are present for different mode shapes are discuss here for all possible combinations The voltage generated using FEM coupling analysis is present in table 6 for all possible cases of rings.

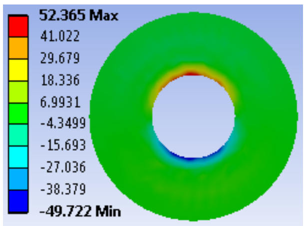
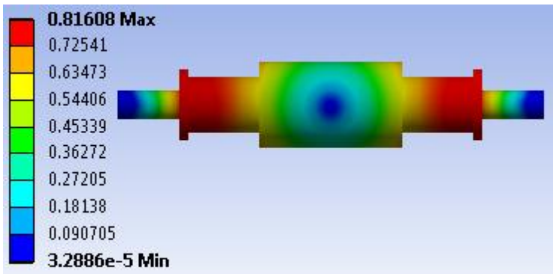
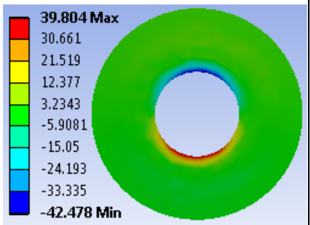
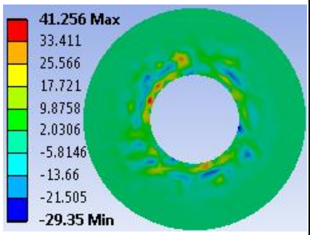
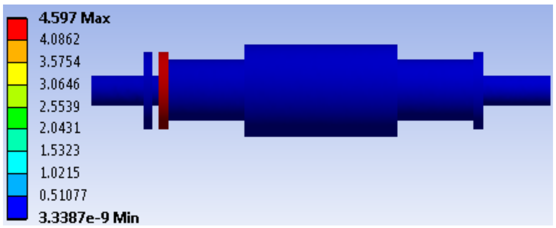
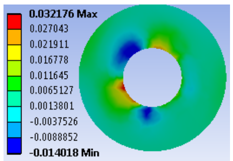
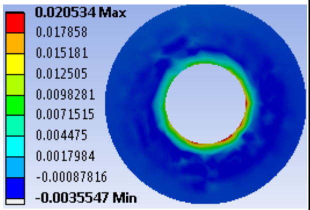
Table-6: Piezoelectric results for different ring combinations used for stepped shaft (Voltage analysis)

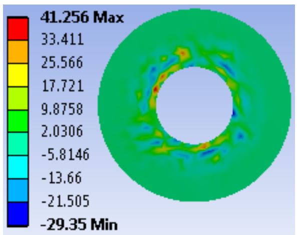
Mode Shape	R-1	R-2	R-3 gap 10 mm	R-3 gap 20 mm	R-4 gap 10 mm	R-4 gap 20 mm
I	41.25	0.51	0.47	0.78	0.47	0.51
II	6.67	41.25	0.34	0.91	0.001	0.66
III	13.07	6.68	0.52	0.51	0.34	0.78
IV	13.81	13.71	**41.26**	**41.25**	0.003	0.91
V	51.61	13.68	6.66	6.68	0.51	0.51
VI	**53.39**	**52.36**	13.80	13.73	**41.26**	**41.26**

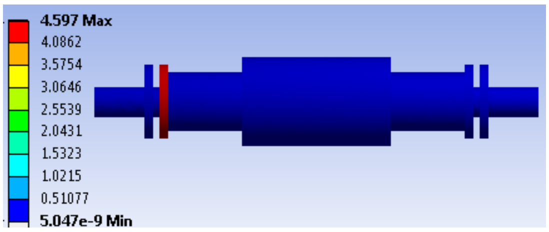
As seen in table 6, the voltage is generated for different mode shapes during modal analysis coupled with piezoelectric modeling equations. As seen in table as user increased the rings quantity, the voltage generation is also distributed to rings and magnitude of voltage is going to change from (R-1) to (R-4 gap 20 mm) case. The visual presentation of voltage generation for selective cases simulated are present in table 7 for all combinations of rings on stepped shaft.

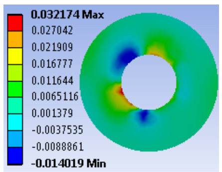
Table-7: Visual results for different rings cases for deformation and voltage

R-1 for Mode Shape-6 (Highest Voltage)		
Ring-1 (V)	**Stepped Shaft (Deformation micro m)**	**Ring-3 (V)**
		NA

<table>
<tr><td>Ring-2 (V)</td><td rowspan="2"></td><td>Ring-4 (V)</td></tr>
<tr><td>NA</td><td>NA</td></tr>
<tr><td colspan="3">R-2 for Mode Shape-6 (Highest Voltage)</td></tr>
<tr><td>Ring-1</td><td>Stepped Shaft (Deformation micro m)</td><td>Ring-3</td></tr>
<tr><td>
</td><td rowspan="3">
</td><td>NA</td></tr>
<tr><td>Ring-2</td><td>Ring-4</td></tr>
<tr><td>
</td><td>NA</td></tr>
<tr><td colspan="3">R-3 gap 10 mm for Mode Shape-4 (Highest Voltage)</td></tr>
<tr><td>Ring-1</td><td>Stepped Shaft (Deformation micro m)</td><td>Ring-3</td></tr>
<tr><td>
</td><td rowspan="3">
</td><td>
</td></tr>
<tr><td>Ring-2</td><td>Ring-4</td></tr>
<tr><td>
</td><td>NA</td></tr>
<tr><td colspan="3">R-4 gap 10 mm for Mode Shape-6 (Highest Voltage)</td></tr>
<tr><td>Ring-1</td><td>Stepped Shaft (Deformation micro m)</td><td>Ring-3</td></tr>
</table>

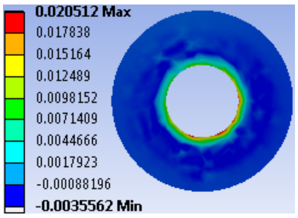


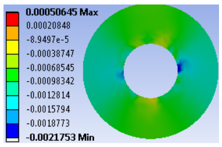




Ring-2

Ring-4





As seen in table 7 the voltage generation for each ring is different because of load generation capacity of shaft is same, so electrical output is distributed in all rings and that's why the outcome of rings are changed. In this table only highest voltage visual analysis is presented to reduce the repeatably of same results.

VII. CONCLUSION

In present study stepped shaft with piezoelectric rings are simulated with coupled FEM and electrical modeling using Ansys APDL. and the main conclusions are following:

I) On the basis of modal analysis, for stepped shaft with different rings installation, the maximum reduction in frequency of vibration is seen in four ring combination for 20 mm lateral gap and maximum frequency is seen at one ring combination but all rings simulated data has lower frequencies then simple stepped shaft. .

II) Voltage generation for each cases is differ then mode shape, so maximum voltage generation for each case is different then other combination. In general maximum voltage is generated in one ring only at a time.

VIII. REFERENCES

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