Vibration Analysis of Annular Disc using FFT and Modal Analysis Technique

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Abstract— **The main aim of our project is to study the effect of shape change and angular orientation of holes on Vibration characteristics such as natural frequency and mode shapes. In field of rotating components and structures the circular disc with different size and shapes of holes are used. We will study the change of these shapes of holes on the natural frequency. These holes usually cause change in some of the properties of the components load carrying capacity, decrease in weight of component and stresses developed in the component etc. The 3D model will be drawn with the help of CATIA software. The modal analysis will be carried out with the help of ANSYS software. The experimental testing will be carried out by using Impact Hammer Test & FFT Analyzer. The comparison will be carried out between the experimental and analysis results and then the result & conclusion will be drawn.**

Keywords— Impact hammer test, FFT, FEA, ANSYS.

I. INTRODUCTION

The use of different types and shapes of holes in the various locations of body of annular discs (which intentionally induces residual stresses into the disc) will be analyzed, quantified, and discussed as a means of making annular disc last longer and at the same time help realize solutions to problems with noise, natural frequency and fatigue life of the spinning discs. Knowing the value of the natural frequencies of the static and rotating discs as well as the value of the residual stresses and their locations by using FEA software will help to solve the need to quantify the stress effects and help the disc manufacturers incorporate these modifications into their future designs for better performed rotating machine components and products. Circular plates with holes are widely used in mechanical parts. Circular plates with multiple circular holes have applications in many engineering structures. They are used either to decrease the mass of the structure by keeping vibration properties and material same or to upturn the range of inspection or to satisfy engineering applications. Circular geometries are also used because of the ease of their manufacture.

Rotor system is an essential structure in the aero-engine. Due to the increasing demand for high

speed and high efficiency of rotor systems, the severe vibration or even damaging under complex working conditions may happen. The rotor system consists of a drum, disk, blade, and shaft. The sub-structures have been taken much attention on by researchers.

II. LITERATURE SURVEY

Hassan Heydari et al. [1] The effects of changes in the location and the aspect ratio of a flexible disk on natural frequencies and critical speeds of a rotating flexible shaft-disk system are studied. Free vibration analysis of the system is carried out using the assumed modes method. The disk is modeled by Kirchhoff plate theory. The Euler Bernoulli shaft is supported by two rigid bearings. In modelling the system, gyroscopic moments and centrifugal stiffening effects are taken into account. The results show that the disk flexibility property has a significant influence on the natural frequencies and critical speeds. Moreover, the disk position along the shaft and the aspect ratio of the disk can increase, decrease, or eliminate the disk flexibility effect. Therefore, there are special ranges of and in which the effect of the disk flexibility is completely negligible, so, in this case, the disk can be considered as a rigid body. Two new diagrams are presented for the first time in this study, which show the behaviour of the critical speeds versus and the results emphasize that in order to present a more detailed comment about the disk flexibility effects these parameters must be considered.

Chaofeng Li et al. [2] The drum-disk-shaft system is a significant part of the aero-engine rotor structure and directly influences the rotor dynamics. The dynamic model of a drum-disk-shaft structure was established considering the elastic support, flexible connection and centrifugal effects on the drum due to the rotation. The effects of support stiffness, coupling stiffness and rotating speed on vibration behaviors of the system were investigated. Some results were obtained. It is found that the disk's vibration and the drum's translational motion are coupled whatever the circumferential number (n) is, and the local deformation of the drum is coupled with the disk's vibration only under n =1. When n is equal to 1, the more veering phenomena can be found during the process of the variation of the coupling stiffness, and support stiffness and the mode shapes are plotted to show the phenomena. At last, the effect of rotating speed on the frequencies of the coupling system were investigated. It is shown that the forward and backward traveling waves are generated in all the modes of the system under n=1 due to the rotating speed and coupling effects, but only in the modes of the drum as n is not equal to 1. Also, the coupling stiffness and support stiffness can significantly affect the critical speed of the system.

Hassan Bahaloo-Horeh et al. [3] Out of plane vibration of rotating disks limits their performances especially at certain critical speed. The critical speed of these disks may be affected by the presence of defects such as a circumferential crack. In this paper out of plane vibration of functionally graded (FG) rotating annular disks with a circumferential open crack is investigated. The cracked disk is modeled as two sub-disks, connected at the crack location by translational and rotational line springs, simulating the crack plate response to induced shear force and bending moment at the crack radius. These spring stiffness constants are obtained numerically using the finite element method (FEM) as a function of crack depth and radius. The rotational spring stiffness strongly depends on the disk rotation speed, while the stiffness of the translational spring is found to be independent of the disk speed. Both spring constants depend on the spatial distribution of the disk elastic modulus. The in-plane disk stresses are obtained using a semi-analytical approach. Those in plane stresses are used to obtain the governing equation of out of plane motion of the disk. A finite difference scheme is used to solve the partial differential equation of motion to obtain eigen values, critical speed and associated mode shapes. The lowest critical speed, which is one of the important parameters limiting the performance of the rotating disk, is obtained from the Campbell Diagram. It is found that irrespective of the distribution of the modulus of elasticity in the FG disk, increasing the crack depth or decreasing the crack radial distance from the disk centre decreases the critical speed. The critical speed reduction is more pronounced for the case when the disk material modulus of elasticity is decreasing from the disk centre.

Chen Lina et al. [4] This paper proposes an analytical vibration model of a disk resonator gyroscope (DRG) based on the wave propagation theory, which can predict the key specifications of a DRG rapidly and accurately before fabrication, and can be employed in design optimization. This wave propagation analysis is based on the ray tracing method (RTM) which considers wave propagation and scattering in the formulation. In the RTM, wave transmission and reflection coefficients are the key issues that must be accurately predicted. A novel C-joint is proposed to predict these key coefficients between the rings and spokes with high precision and short estimated time. To verify the soundness of the proposed model, a tentative vibration model for a double-ring (the basic element of a DRG) is established by the RTM and compared with the 3D finite element (FE) model. The two models show excellent agreements in natural frequencies, trend predictions and harmonic displacements. Then, the proposed model is expanded to a multi-ring practical DRG. In addition, taking the advantage of the symmetry in the DRG, the sub structuring and recursive methods are employed to reduce the computational overhead. The numerical experiments show that the proposed analytical vibration model for a DRG meets well with the 3D FE model. For instance, the differences between the calculated resonant frequencies from the 3D FE model and the analytical model are less than 3%. After fabrication, the measured average resonant frequency of the prototypes deviates 6.7% from that of the theoretical prediction.

Sourav Sarkar et al. [5] Computational Fluid Dynamics (CFD) simulations have been performed to understand the effects of different operating and geometric parameters on axial dispersion and pressure drop for single-phase flow in annular pulsed disc and doughnut columns (APDDCs) which are relevant for spent nuclear fuel reprocessing. The first step of the two-step computational approach involves solution of Reynolds Averaged Navier-Stokes (RANS) equations with standard k-ε model of turbulence in 2D axisymmetric computational domain to obtain velocity and pressure fields. In the next step, dilute species transport equation is additionally solved to obtain residence time distribution (RTD) and axial dispersion coefficient. The computational approach has been validated by using experimental data of pulsed disc and doughnut columns (PDDCs) reported in literature. The validated computational approach has been used to perform parametric analysis to understand the effects of flow velocity, amplitude of pulsing, disc spacing, percent open area, the ratio of outer diameter and inner diameter of the annulus and flow cross-sectional area on pressure drop and axial dispersion coefficient.

AnetaUstrzycka et al. [6] This article deals with the influence of boundary conditions on the optimal shape of a rotating, ax symmetric annular disk of given volume that maximizes the ductile creep rupture time. The finite strain theory and physical law in form of Norton’s law generalized for true stresses and logarithmic strains are applied. The optimal shape is found using parametric optimization. The initial shape of the disk is defined by class of polynomial function.

Wei Xu et al. [7] A novel vibration-based fatigue experimental system has been established to study the fatigue properties of titanium alloy annular discs in near resonance conditions. The excitation frequency-response curves are experimentally obtained in order to clarify the large amplitude nonlinear vibration characteristics of the discs. Then a vibration-based fatigue test of the discs and the corresponding 10° segment specimens are conducted respectively to obtain the S-N curves and the fatigue limit stresses. A multi axial fatigue criterion is proposed to predict the fatigue properties of the discs, which is compared with the present experimental results finally. It is demonstrated that the high-cycle fatigue properties of the discs can be obtained by the present vibration-based fatigue test, which is an in-phase biaxial fatigue test. The fatigue limit stress of the discs can be predicted well by the proposed elliptic multi axial fatigue criterion together with the fatigue testing results of the corresponding segment specimens.

Ryoichi Chiba et al. [8] The mean and variance of the temperature are analytically obtained in a functionally graded annular disc with spatially random heat transfer coefficients (HTCs) on the upper and lower surfaces. This annular disc has arbitrary variations in the HTCs (i.e., arbitrary thermal interaction with the surroundings) and gradient material composition only along the radial direction and is subjected to deterministic asymmetrical heating at the lateral surfaces. The stochastic temperature field is analyzed by considering the annular disc to be multi-layered with spatially constant material properties and spatially constant but random HTCs in each layer. A type of integral transform method and a perturbation method are employed in order to obtain the analytical solutions for the statistics. The correlation coefficients of the random HTCs are expressed in the form of a linear function with respect to the radial distance as a non-homogeneous random field of discrete space. Numerical calculations are performed for functionally graded annular discs composed of stainless steel and ceramic, which comprise two types of material composition distributions. The effects of the magnitude of the means of HTCs, volume fraction distributions of the constitutive materials and correlation strengths of the HTCs on the standard deviation of the temperature are discussed.

Kevin Pauza et al. [9] The surfaces of annulus fibrosus tears are known harbingers of inflammatory constituents within intervertebral discs, stimulating sensitized nocioceptors within those tears. Other current treatment options of internal disc disruption neglect to specifically address the surface of these tears. Therefore, this investigation answers the question: does nonautologous fibrin sealant applied to the surface of annulus fibrosus tears mechanically glue and seal annular tears Regarding this query, results suggest nonautologous concentrated fibrin successfully seals annulus fibrosus tears with a “suture-like mechanical sealant,” serving as a safe option for treating symptomatic or non-symptomatic intervertebral disc tears. Sealing tears prevents pain-generating chemicals of the nucleus pulpous from leaking through annular tears.

III. OBJECTIVES

- To design 5 Annular Discs with different shapes and types of holes
- Modelling of these Annular discs with help of CATIA software
- To carry out the modal analysis using FEA.
- To study the effect of various shapes and size of holes on the natural frequency.
- To carry out the Impact Hammer Test.
- The FEA results obtained are validated with experimental results.

IV. METHODOLOGY

Step 1: - I started the work of this project with literature survey. I gathered many research papers which are relevant to this topic. After going through these papers, I learnt about Effect of size of holes on the Natural Frequency of Annular Disk.

Step2: - After that the components which are required for our project are decided.

Step 3: - After deciding the components, the 3 D Model and drafting will be done with the help of CATIA software.

Step 4: - The modal analysis will be carried out with the help of ANSYS software.

Step 5: - The experimental observations will be taken after Impact Hammer Testing, and then the result will be concluded.

III. PROBLEM STATEMENT

The study of the dynamic behavior of circular cutters with free boundary condition but having different numbers of cutting teeth, aspect ratio, effect of radial slots, and enlargement of stress concentration holes is important, as used in several cutting processes. The knowledge of natural frequencies of component is of great interest in the analysis of response of structures to various excitations. Unwanted noise, vibration & accidental failure associated with the cutting process have become an important economic and technological problem in the industry. Hence a circular plate cutter with, fixed at inner edge and free at outer edge is chosen and its behavior is investigated in this project.

CATIA Model of Annular Discs

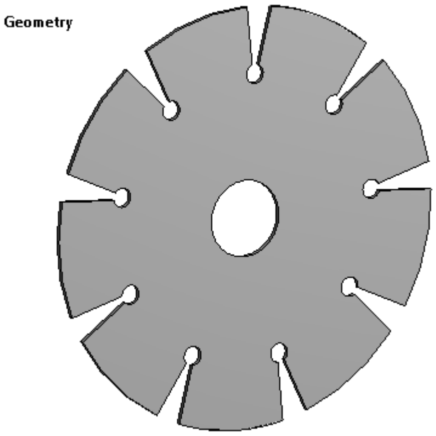


Fig. 1 CATIA model (Disc 1)

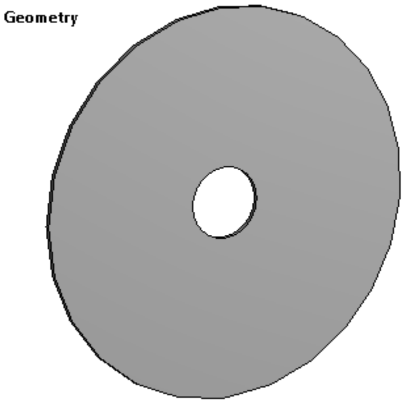


Fig. 2 CATIA model (Disk 2)

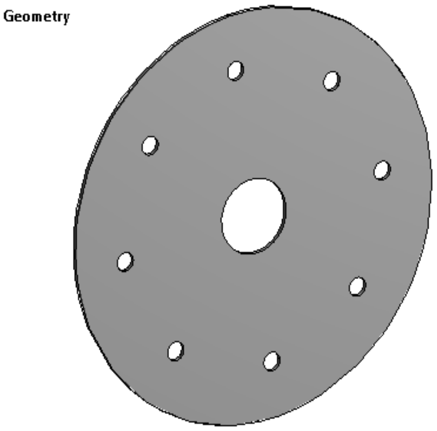


Fig.3 CATIA model (Disc 3)

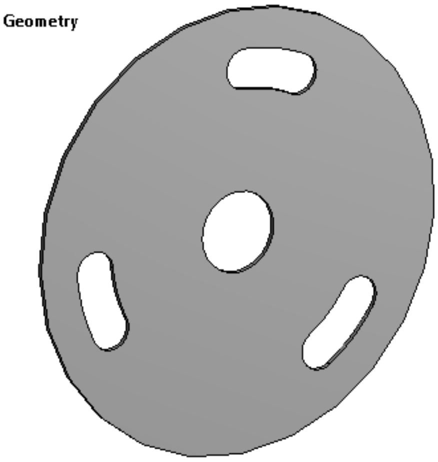


Fig. 4 CATIA model (Disc 4)

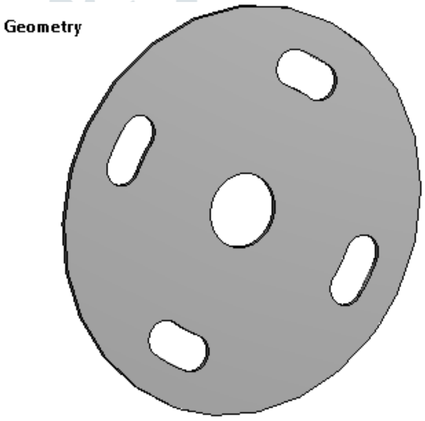


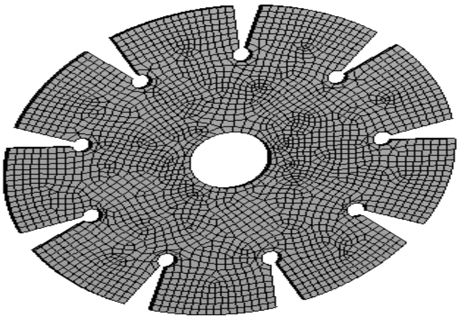
Fig. 5 CATIA model (Disc 5)

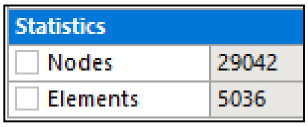
ANALYSYS:

The **finite element method** (**FEM**), is a numerical method for solving problems of engineering and mathematical physics. Typical problem areas of interest include structural analysis, heat transfer, fluid flow, mass transport, and electromagnetic potential. The analytical solution of these problems generally require the solution to boundary value problems for partial differential equations. The finite element method formulation of the problem results in a system of algebraic equations. The method yields approximate values of the unknowns at discrete number of points over the domain. To solve the problem, it subdivides a large problem into smaller, simpler parts that are called finite elements. The simple equations that model these finite elements are then assembled into a larger system of equations that models the entire problem. FEM then uses variational methods from the calculus of variations to approximate a solution by minimizing an associated error function.

MESH

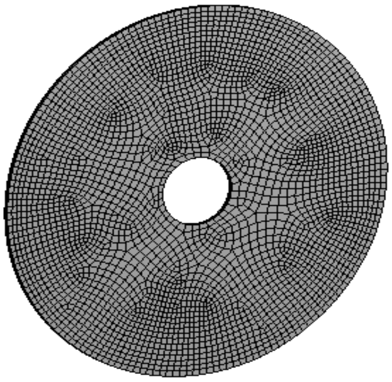
ANSYS Meshing is a general-purpose, intelligent, automated high-performance product. It produces the most appropriate mesh for accurate, efficient Multiphysics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it. The power of parallel processing is automatically used to reduce the time you have to wait for mesh generation.

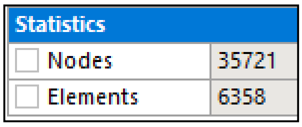




Statistics	
☐ Nodes	29042
☐ Elements	5036

Fig. 6 Meshing of Disk model 1





Statistics	
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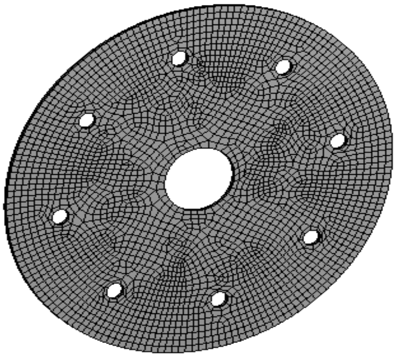
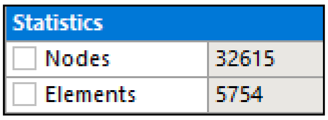
☐ Elements	6358

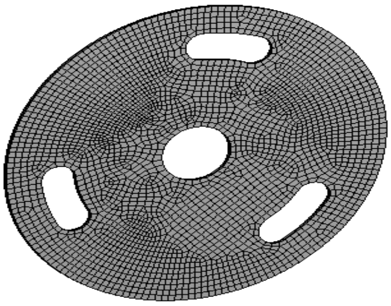
Fig. 7 Meshing of Disk model 2

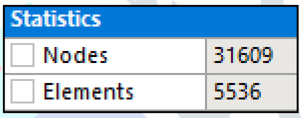




Statistics	
☐ Nodes	32615
☐ Elements	5754

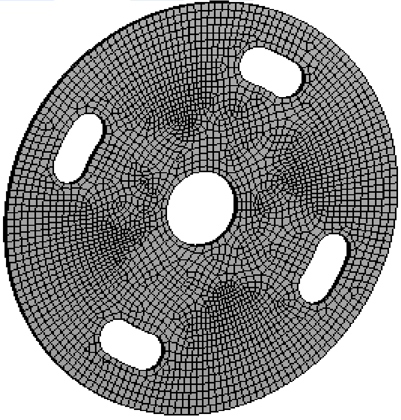
Fig. 8 Meshing of disk model 3

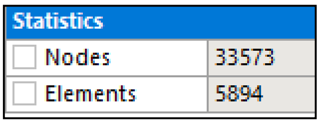




Statistics	
☐ Nodes	31609
☐ Elements	5536

Fig. 9 Meshing of Disk model 4





Statistics	
☐ Nodes	33573
☐ Elements	5894

Fig. 10 Meshing of Disk Model 5

Boundary Condition

A boundary condition for the model is the setting of a known value for a displacement or an associated load. For a particular node you can set either the load or the displacement but not both.

The main types of loading available in FEA include force, pressure and temperature. These can be applied to points, surfaces, edges, nodes and elements or remotely offset from a feature.

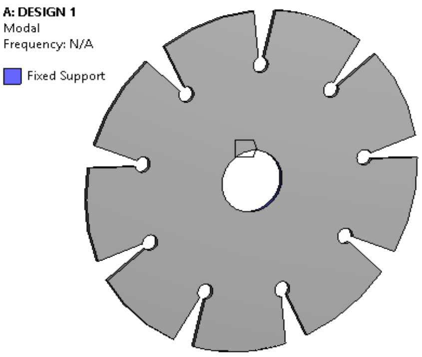


Fig. 11 Boundary Condition of Disk model 1

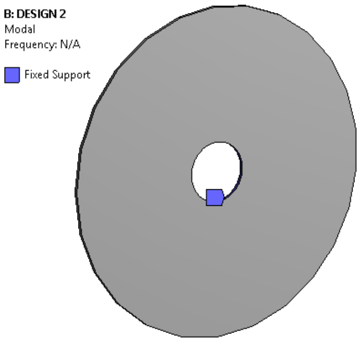


Fig. 12 Boundary Condition of Disk model 2

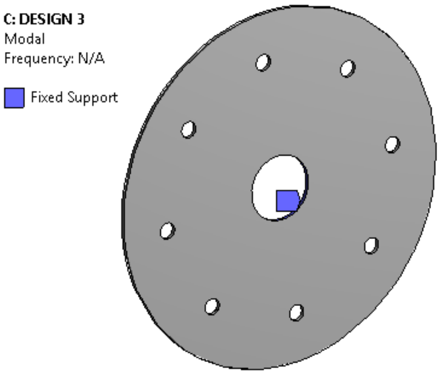


Fig. 13 Boundary Condition of Disk model 3

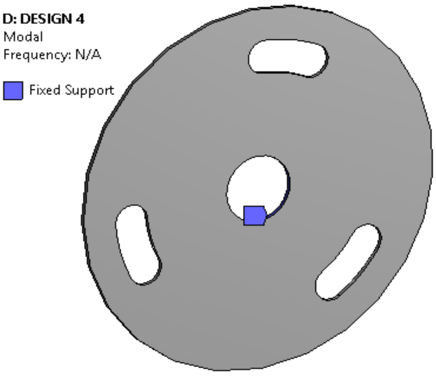


Fig. 14 Boundary Condition of Disk model 4

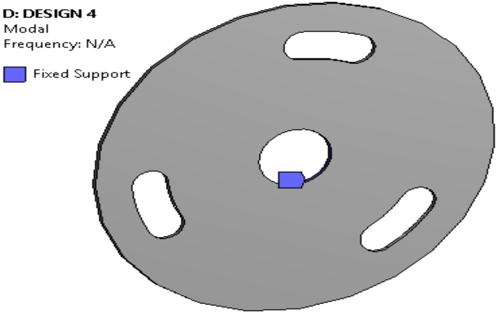


Fig. 15 Boundary Condition of Disk model 5

Total Deformation

The total deformation & directional deformation are general terms in finite element methods irrespective of software being used. Directional deformation can be put as the displacement of the system in a particular axis or user defined direction. Total deformation is the vector sum all directional displacements of the systems.

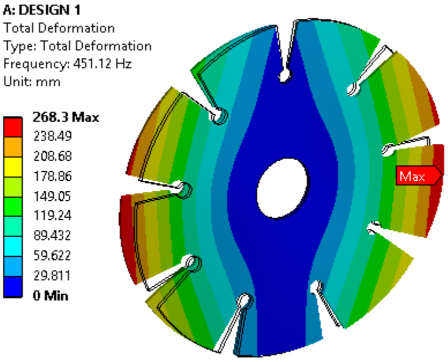


Fig. 16 Total Deformation of Disk model 1

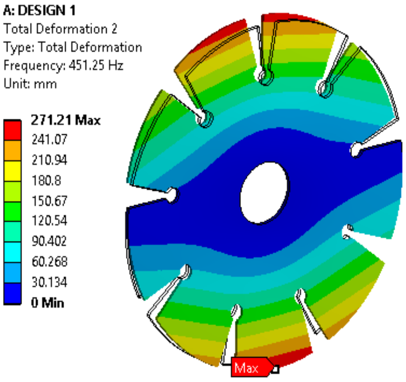


Fig. 17 Total Deformation of Disk model 1

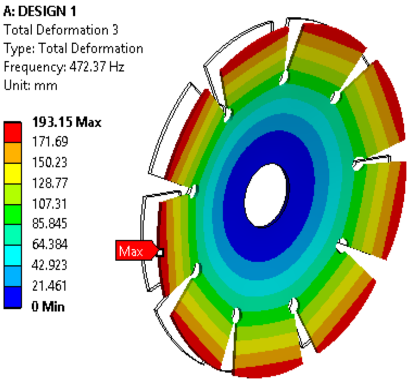


Fig. 18 Total Deformation of Disk model 1

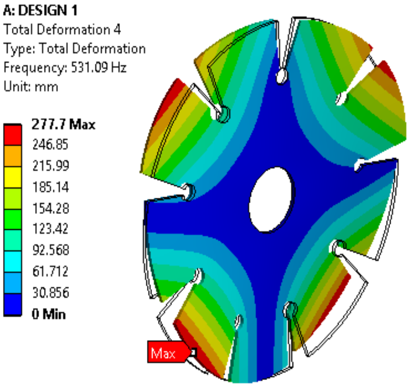


Fig. 19 Total Deformation of Disk model 1

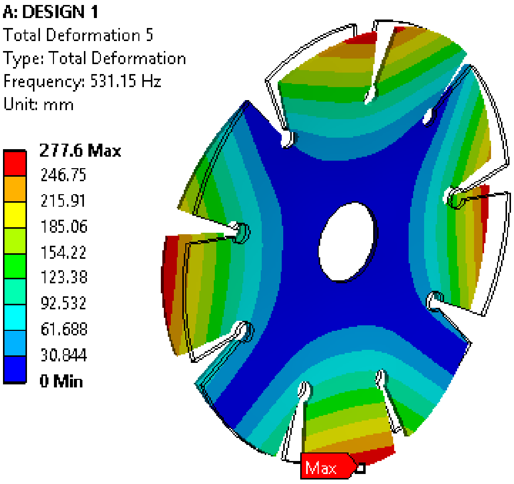
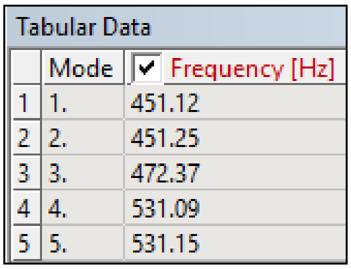


Fig. 20 Total Deformation of Disk model 1


Tabular Data

	Mode	☑ Frequency [Hz]
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2	2.	451.25
3	3.	472.37
4	4.	531.09
5	5.	531.15

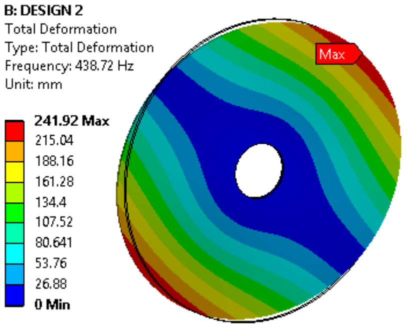


Fig. 21Total Deformation of Disk model 2

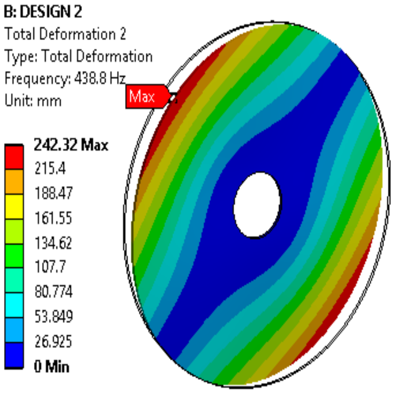


Fig. 22Total Deformation of Disk model 2

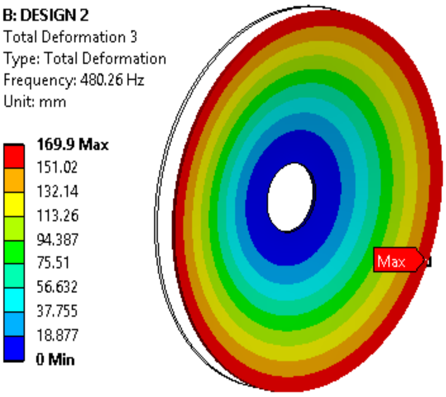


Fig. 23Total Deformation of Disk model 2

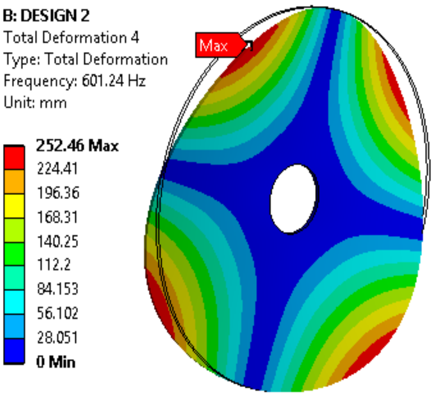


Fig. 24 Total Deformation of Disk model 2

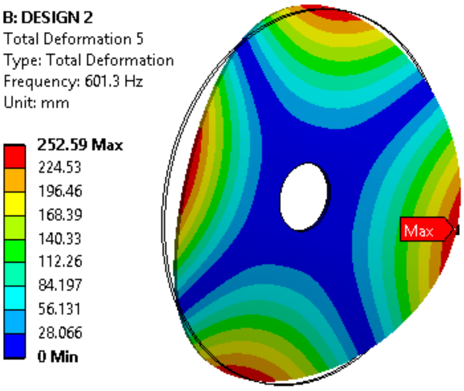
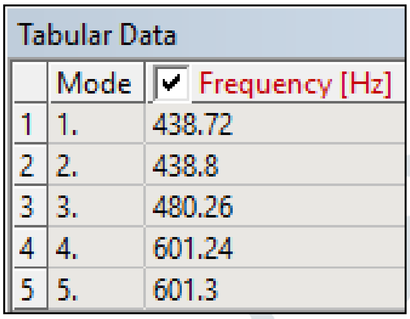


Fig. 25 Total Deformation of Disk model 2



Tabular Data

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4	4.	601.24
5	5.	601.3

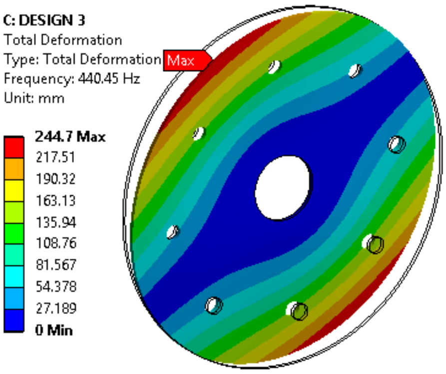


Fig. 25 Total Deformation of Disk model 3

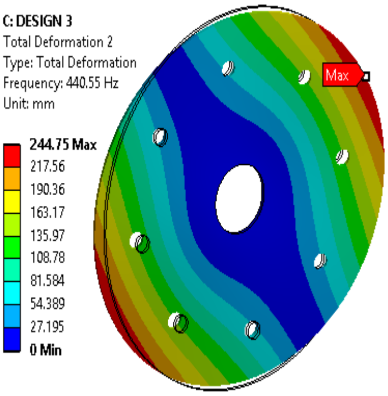


Fig. 26Total Deformation of Disk model 3

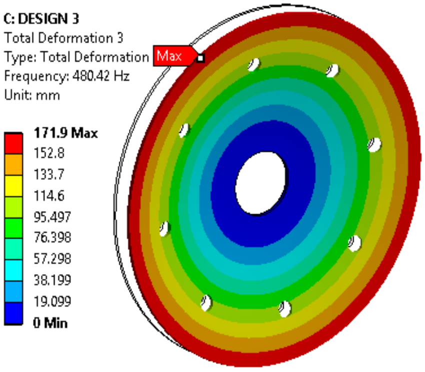


Fig. 27Total Deformation of Disk model

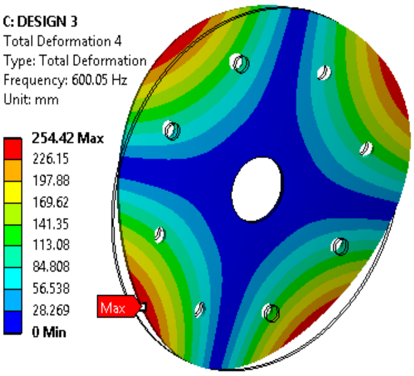
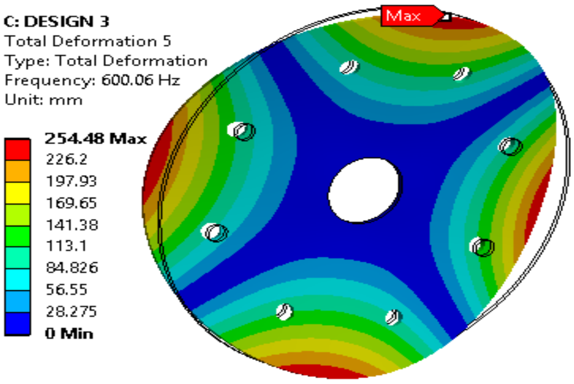
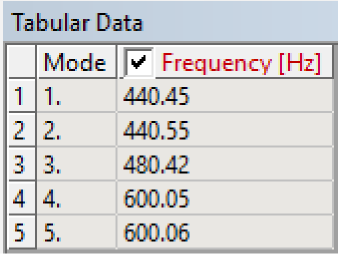


Fig. 28Total Deformation of Disk model 3





Tabular Data

	Mode	☑ Frequency [Hz]
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2	2.	440.55
3	3.	480.42
4	4.	600.05
5	5.	600.06

Fig. 29 Total Deformation of Disk model 3

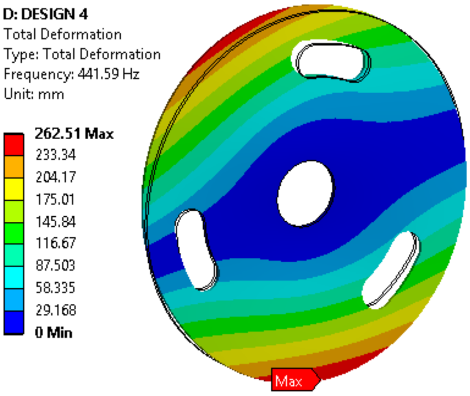


Fig. 30 Total Deformation of Disk model 4

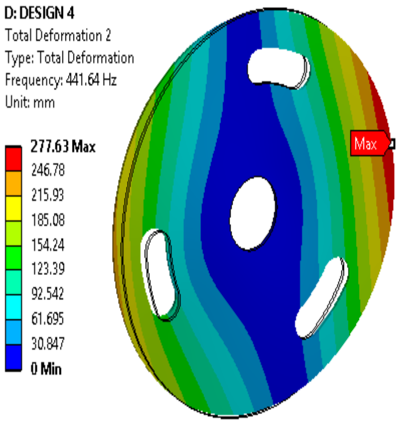


Fig. 31 Total Deformation of Disk model 4

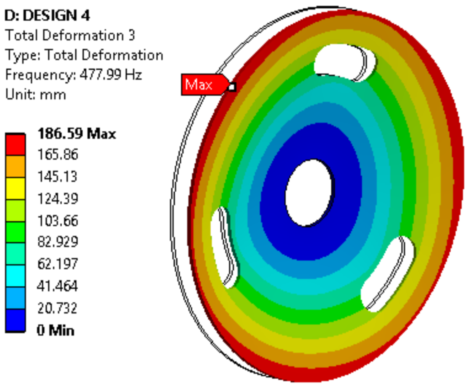


Fig. 32 Total Deformation of Disk model 4

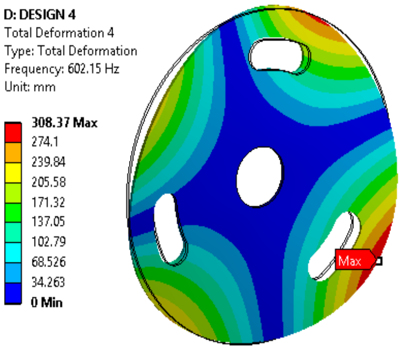
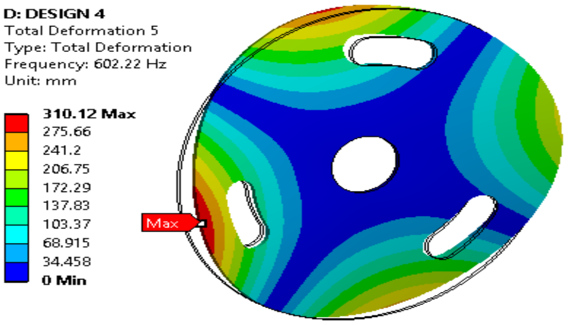
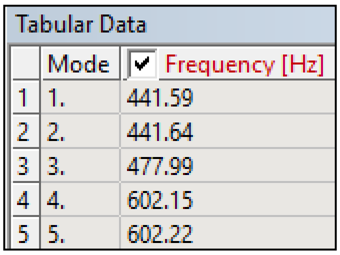


Fig. 33 Total Deformation of Disk model 4





Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	441.59
2	2.	441.64
3	3.	477.99
4	4.	602.15
5	5.	602.22

Fig. 34 Total Deformation of Disk model 4

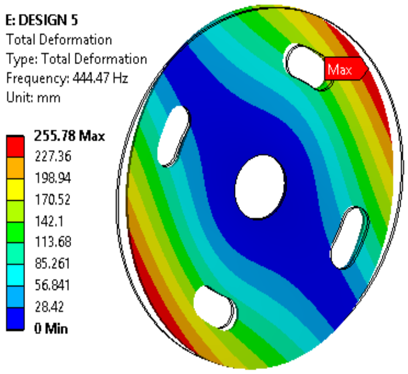


Fig. 35 Total Deformation of Disk model 5

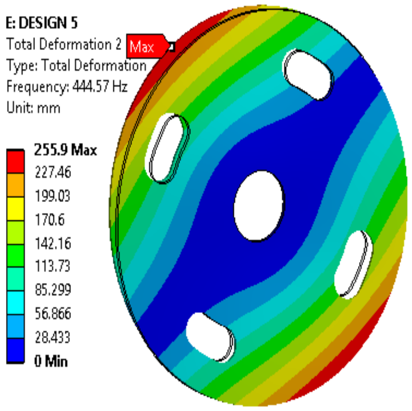


Fig. 36 Total Deformation of Disk model 5

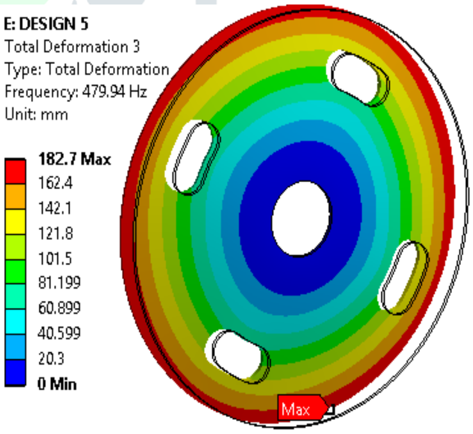


Fig. 37 Total Deformation of Disk model 5

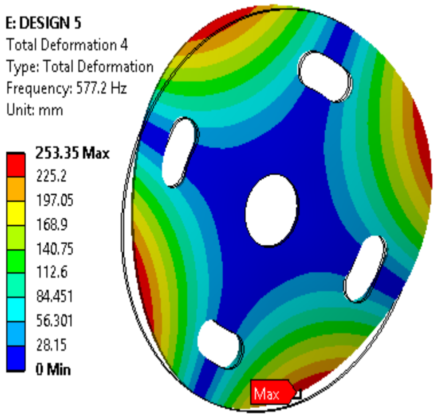
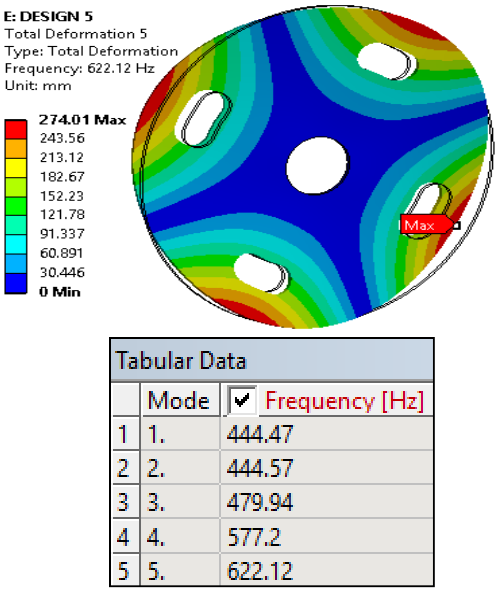


Fig. 38 Total Deformation of Disk model 5



Tabular Data

	Mode	☑ Frequency [Hz]
1	1.	444.47
2	2.	444.57
3	3.	479.94
4	4.	577.2
5	5.	622.12

Fig. 39 Total Deformation of Disk model 5

Disc No.	Frequency1	Frequency2	Frequency3
1	458.984	458.984	458.984
2	419.92	493.16	610.35
3	454.102	473.63	590.92
4	439.45	463.86	605.46
5	438.45	478.51	571.28

RESULT

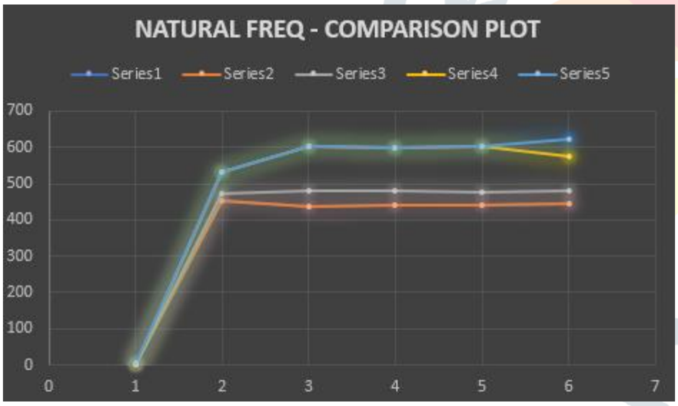
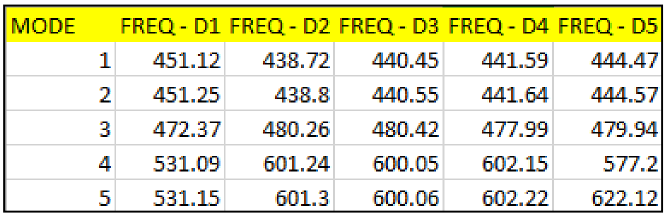


Fig. 40 Graph of Natural Frequency of Analysis Result

Table 1: Natural Frequency of Discs from Analysis Result



MODE	FREQ - D1	FREQ - D2	FREQ - D3	FREQ - D4	FREQ - D5
1	451.12	438.72	440.45	441.59	444.47
2	451.25	438.8	440.55	441.64	444.57
3	472.37	480.26	480.42	477.99	479.94
4	531.09	601.24	600.05	602.15	577.2
5	531.15	601.3	600.06	602.22	622.12

Results from effect of shape change of holes on natural frequency of annular disc shows that, if we add circular holes in geometry of circular disc, natural frequency of disc increases.

EXPERIMENTAL MODAL TEST

Impact hammer test

Clamping was obtained by using two nuts and one bolt is fastened above and below the disc for impact hammer test. Bolt is used to restrict the movement at inner edge of annular plate in x, y and z direction. The fixture was rigidly fixed on heavy weighted I section channel painted by blue colour as shown in fig. 41

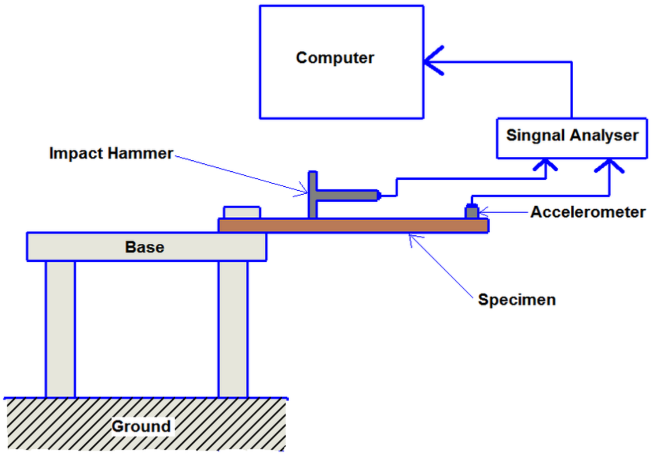


Fig. 41 Fixture for Impact Hammer Test

Table 2: Natural Frequency of Discs by Experimental Test

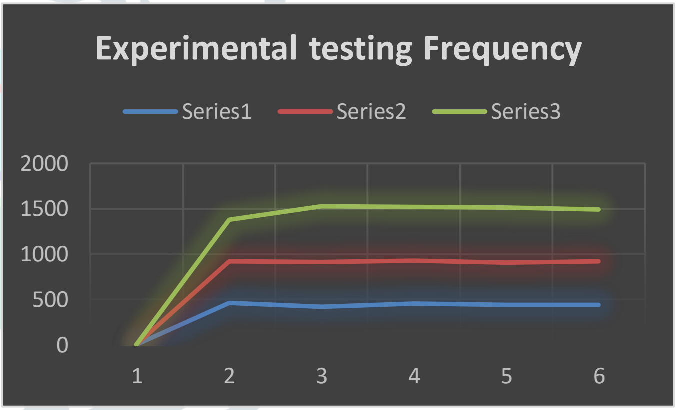


Fig. 42 Graph of Natural Frequency of Experimental Testing

CONCLUSION

- From the Above results it is clear that the natural frequencies obtained after the Analysis & experimental results for all the discs are same.
- Results from effect of shape change of holes on natural frequency of annular disc shows that, if we add circular holes in geometry of circular disc, natural frequency of disc increases.
- From the results obtained it is concluded that the natural frequency is more for Disc 2 (which is a disc with no hole) than the other type of Discs.

Table 3: Natural Frequency of Disk by Hammer Test

Disc	1	2	3	4	5
Natural Frequency	537.1	610.35	600	605.46	577

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