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Finite Element Analysis of Casing Stability and Radial Growth of a Steam Turbine Disc

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ABSTRACT

In the present work, disc assembly used for an industrial power generation turbine is used for finding the structural safety. Casings are provided on the turbine disc assembly to protect it from falling of dust particles and also to provide lubrication and other controls. The main objective of the present work is to check the radial deformation of the turbine disc for closing gap between the disc and the casing. Initially casing analysis has been carried out to check the stability and the disc is analyzed for the radial deformation and structural stress condition. Also modal analysis has been carried out to find the structural dynamic stability. Further simplified geometries are built to find the effect of inclination of ribs on the stress and deformation generated under rotational load of 11000 rpm. The analysis has been carried out in the cyclic symmetry domain due to repetitive segments. Similarly analysis has been carried out with cutouts which are similar to the practical problems. The results for uncut geometry show lesser influence of inclination of ribs on the stress and deformation generation. But in case of cutouts it shows a certain influence on the deformation and stress generation. The rib inclination increases the stress and deformation in the problem along with reduction in the natural frequencies. So inclination is not a desirable feature with turbine discs. The same thing is proven with real geometries built and analyzed at the end.

Keywords *– Casing, Turbine Disc, Radial Deformation, Inclination of Ribs, Rotational Load.*

1. INTRODUCTION

Steam turbine is the prime mover used in the power plant, mills and also in the process industries for the energy conversion .Steam turbine is an engine which converts the heat energy of the steam in to useful work. The conversion is accomplished by the transforming the kinetic energy of the steam particles to the useful work by rotating the rotor as it slides over the blades. In order to use the steam energy effectively a progression of steps are arranged. Each step/progression contains a set of moving blades and nozzles are known as a stage. The turbine contains more than the two stages are known as multi-stage turbine. The steam turbine contains various components like casing, disc, high Speed Coupling, over speed trip, nozzles and diaphragm, moving blades, sealing glands, oil seals, journal bearing, thrust bearing.

The steam enters from one end of turbine known as steam end and it flows relatively axial with the rotor to the exhaust end. As the steam emerges from the exhaust end it passes through the condenser for cooling and is returned back to the boiler as feed water for reuse. For maximum efficiency, a high speed is needed for the turbine rotor, while generally low speed is needed for the machine to be driven. In such condition, a speed reduction gear box is necessary between the turbine and driven machine. To support the rotor a frame or base plate with pedestal having the bearing is necessary. The rotor is surrounded by the casing to contain the steam. The casing is arranged in such a way that it is in concentric with the rotor and is supported on the base plate. Then casing is divided all along length horizontally by plates containing nozzle known as Diaphragm.

2. METHODOLOGY

Step 1: The literature survey is conducted on the stress and radial growth/ displacement of steam turbine disc and the problem is defined.
Step 2: The data required for the modelling and analysis is collected.
Step 3: The casing and disc are modelled in catiav5 and meshed in Hypermesh.

Step 4: The casing is analysed for checking stability under the given loading conditions.
Step 5: The analysis of ribs and its orientation on the real model is difficult hence the simple models are assumed in cyclic symmetry conditions to study the effect of rib and its orientation on the stress and radial displacement calculation using finite element analysis.

1. Analysis for hallow disc and theoretical validation using cyclic symmetry.
2. Analysis of disc without cutouts for straight and inclined ribs for rotational load
3. Analysis of disc with cutouts for straight and inclined ribs for rotational load

Step 6: Application in the actual problem.
Step 7: Theoretical validation.
Step 8: Report generation.

3. MATHEMATICAL FORMULATION

The mathematical formulas are derived from the annular disc having internal diameter of ‘a’ and outer diameter of ‘b’. The standard formulas of annular disc are taken they are.

1. Radial stress

$$(\sigma_r)_{max} = \left(\frac{3+\gamma}{8}\right) * \rho * \omega^2 * (b-a)^2$$

$$= 0.4125*7800*1152.06^2*0.0064$$

$$(\sigma_r)_{max} = 27.33MPa$$

2. Hoop stress

$$(\sigma_\theta)_{max} = \left(\frac{3+\gamma}{4}\right) * \rho * \omega^2 * \left(b^2 + \left(\frac{1+\gamma}{3+\gamma}\right) * a^2\right)$$

$$(\sigma_\theta)_{max} = (0.825)*7800*1152.06^2*(8.139*10^{-3})$$

3. Radial displacement

$$U = \varepsilon_\theta * r = \frac{(\sigma_\theta - \sigma_r)}{E} * r$$

$$Umax = \frac{(69.51-27.33)*10^6*(0.09*0.01)^{1/2}}{200*10^9}$$

$$= 6.3*10^{-6}m$$

4. FINITE ELEMENT MODEL DEVELOPMENT

The finite element model development includes process from taking the models, material used, element selection, meshing of models, boundary plots.

3.1 Casing with Meshed Model and Boundary Plot

The fig 1 shows the casing dimension with the Catia model. The casing is provided in the turbine to prevent it from the dust falling inside. The casing is having inside and outside 201mm and 354mm respectively.

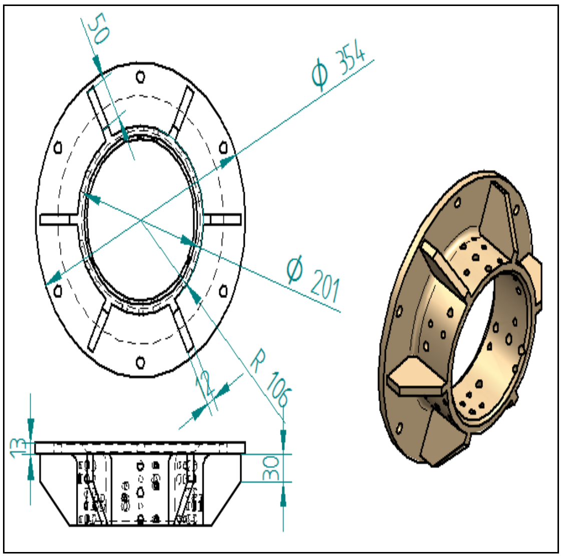

Fig 1: Casing Model

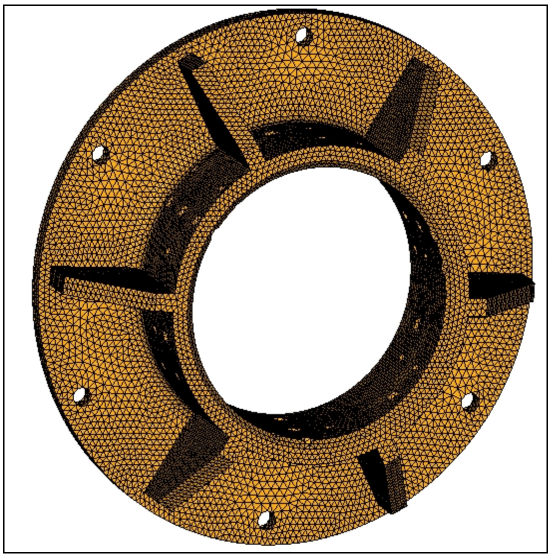
Fig 2: Meshed Model

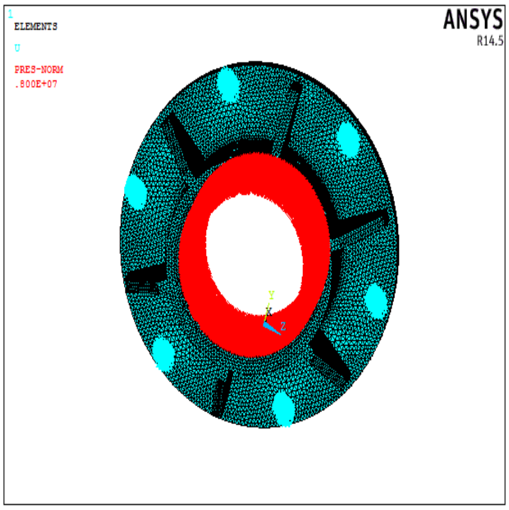

Fig 3: Boundary Plot

The fig 2 shows casing meshed model. The meshing is carried out in the Hypermesh software. The model is meshed using solid brick and tetra element. The meshed casing contains about 148155 elements and 3559 nodes.

The fig 3 shows applied boundary conditions in the problem. Maximum pressure of 8Mpa is applied at the inner boundary. The inner diameter of the hole regions are constrained in all the directions. Hypermesh face options are used for application of loads through collectors creation.

4.2 Disc

The fig 4 represents the actual disc model of 68mm thickness. Disc contains 36 ribs circumferentially. The inner and outer diameter is 21mm and 190mm respectively. But for theoretical calculation and simpler analysis we assumed a simplified model as shown in fig 5 in the cyclic symmetry condition to study the effect of rib and its orientation on stress and radial displacement and later it is applied on the real model. The material used for casing and disc are as follow.

- Material : steel [alloy cast steel=16MnCr5 (Disc) and G17CrMo511 (Casing))]
- Modulus of elasticity : 200GPa
- yield stress are: 588MPa and 550MPa
- Poison's ratio : 0.3
- Density : 7800kg/m^3

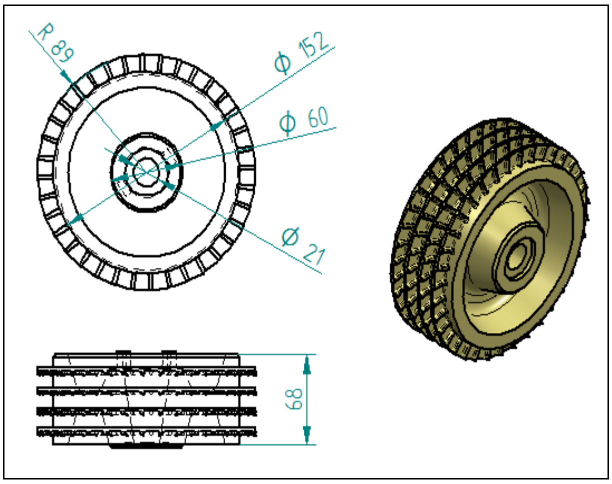

Fig 4: Actual Disc Model.

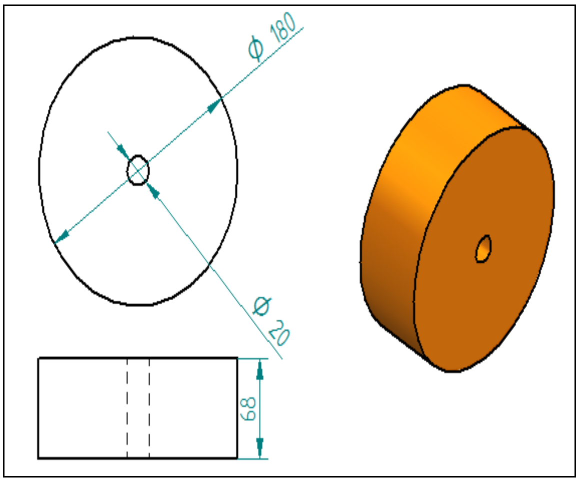

Fig 5: Simplified Disc.

5. RESULTS AND DISCUSSION

5.1 Casing Analysis

5.1.1 Displacement and von-Mises Stress Analysis

The casing is analyzed with the internal pressure of 8MPa and the obtained results are captured, and are shown in the below fig.

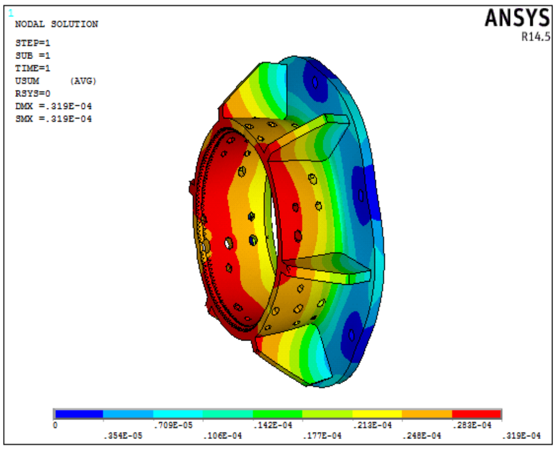

Fig 6: Displacement Plot

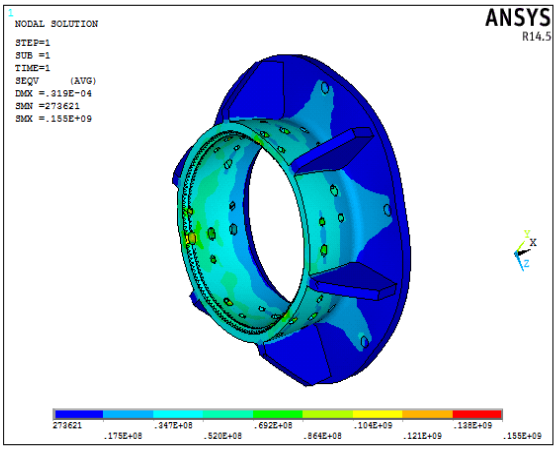

Fig 7: Vonmises Stress Plot

The fig 6 & 7 shows the displacement value of .031mm and the vonmises stress of 155MPa under the application of internal pressure of 8MPa.

5.1.2 Modal Analysis

The modal analysis is carried out to dtermine the natural frequency of the component to prevent it from the resonsnce. The casing is modal analysed and 5 non-zero natural frequency values are noted below in table 1.

Set No	Frequency (Hz)
1	1679.7
2	1868.6
3	1871
4	2101.8
5	2103.7

Table 1: Natural Frequencies of Casing

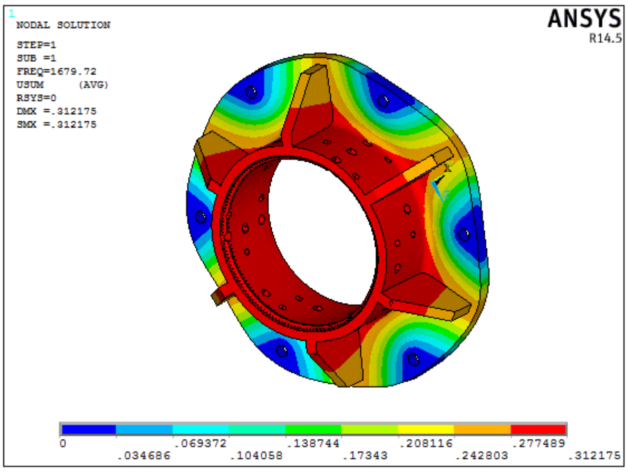

Fig 8: Mode Shape Corresponding to First Natural Frequency

The fig 8 shows the mode shape of the casing corresponding to the first natural frequency of 1679.7Hz. Thus similarly with other natural frequencies.

5.2 Disc Analysis

Disc has been analysed for theoretical validation conditions. Straight ribs are applied and results are obtained. The effect of inclined ribs also studied on the problem. The summary results are as follows.

5.2.1 Case 1: Analysis of Hallow Disc for Validation

Initially for validation purpose the disc has been analysed under cyclic symmetry. Cyclic symmetry is used for problems with repetitive geometry. After the analysis the result corresponding to radial stress, hoop stress and radial displacement are captured they are as below.

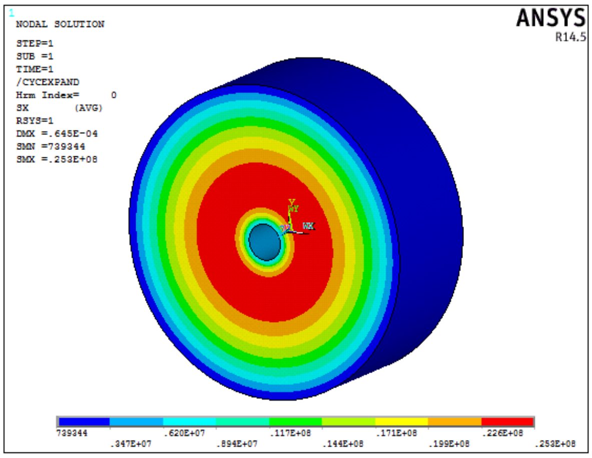

Fig 9: Radial Stress.

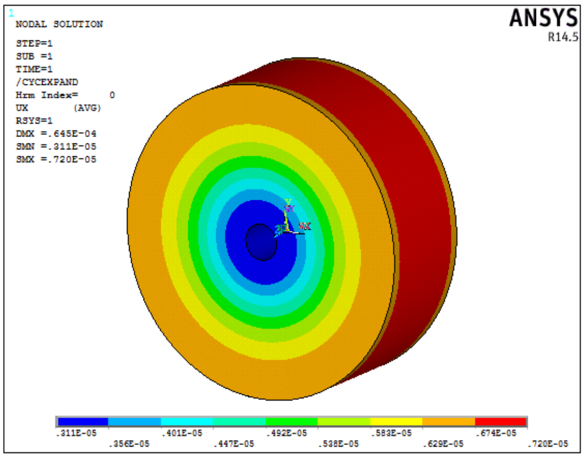

Fig 10: Radial Displacement.

The fig 9 & 10 shows the radial stress of 25.3MPa and radial displacement of 7.2 microns.

5.2.2 Case 2: Analysis without Cutouts

The simplified disc without cutouts having ribs mounted circumferentially is analysed at different rib orientation under rotation load of 11000 rpm. The analysis is carried out to know the radial growth or radial displacement and von-Mises stresses at different rib orientation like straight rib, 5 degree, 10 degree, 15 degree and 20 degree. Thus the result for straight rib case is plotted below and similarly with other rib degree angles.

i. *For Straight Rib*

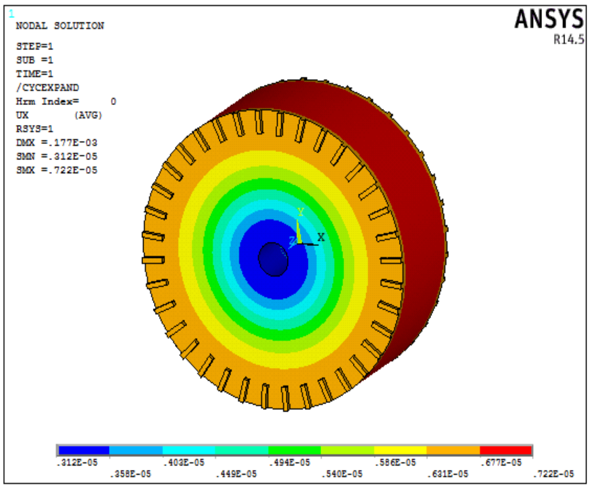

Fig 11: Radial Displacement

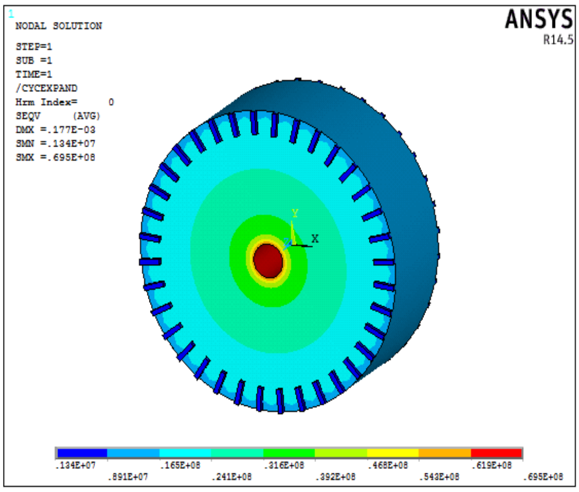

Fig 12: von-Mises stress

The above fig 11 & 12 shows the radial displacement of 7.2 micron and von-Mises stress of 69MPa. Similarly the analysis is carried out for disc without cutouts at different rib angles of 5, 10, 15 and 20 degree and results are compared.

5.1.3 Case 3: Analysis with Cutouts

The simplified disc without cutouts having ribs mounted circumferentially is analysed at different rib orientation under rotation load of 11000 rpm. The analysis is carried out to know the radial growth or radial displacement and vonmises stresses at different rib orientation like straight rib, 5 degree, 10 degree, 15 degree and 20 degree. Thus the result for straight rib case is plotted below and similarly with other rib degree angles.

i. For Straight Rib

The below fig 13 & 14 shows the radial displacement of 3.0 micron and von-Mises stress of 10.6MPa. Similarly the analysis is carried out for disc without cutouts at different rib angles of 5, 10, 15 and 20 degree and results are compared.

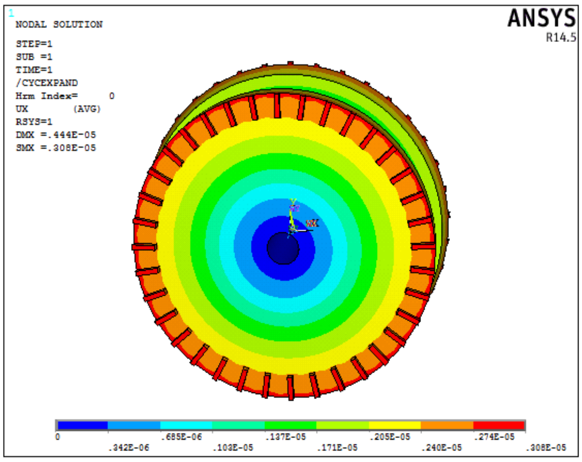

Fig 13: Radial Displacement

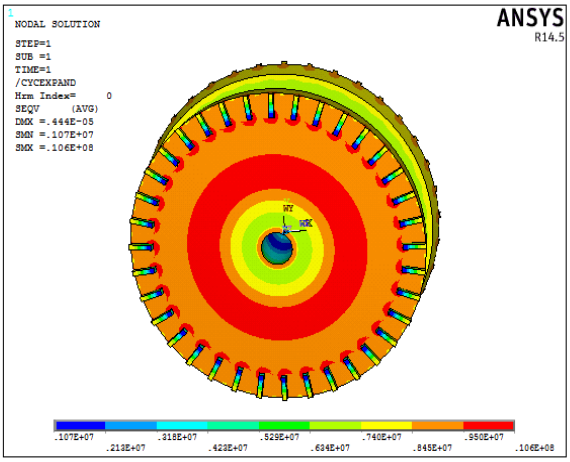

Fig 14: von-Mises Stress

5.2.4 Analysis of Actual Problem

The analysis is carried know the radial displacement and von-Mises stress of the actual problem under rotational load of 11000 rpm. The analysis is carried out at different rib orientation of straight and 20 degree inclined and both radial displacement and vomises stress are plotted at each step. The analysis result of actual disc with straight rib is captured below as follow.

i. For Straight Rib

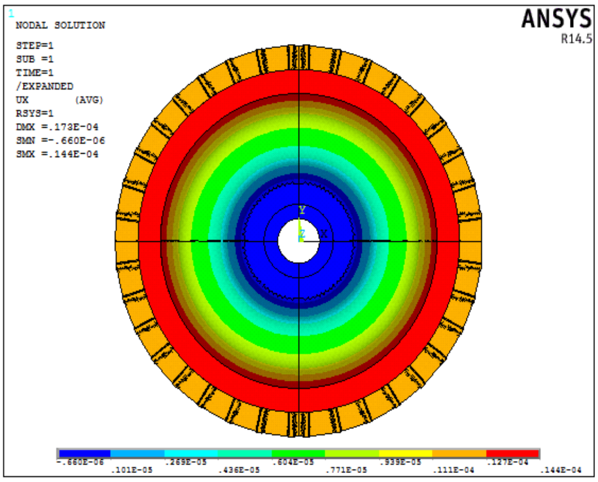

Fig 15: Radial Displacement

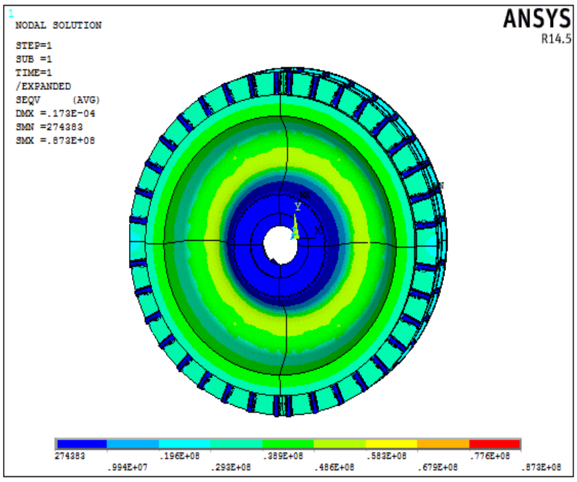

Fig 16: von-Mises Stress

The above fig 15 & 16 shows the radial displacement of 14.4 micron and vonmises stress of 87.3MPa. Similarly the analysis is carried out for actual disc at different rib angles 20 degree and results are compared.

5.2.5 Modal Analysis

The modal analysis is carried out to dtermine the natural frequency of the component to prevent it from the resonsnce. The actual disc model at different rib orientation (straight and 20 degree angle) are modal analysed and 5 non-zero natural frequency values are noted below in table 5.2. the modal shape of actual problem with straight rib are as shown in fig 17 below and similarly with 20 degree inclined rib.

Set No	Frequency(Hz)
1	493
2	1125
3	1250
4	1725
5	1829

Table 2: Natural Frequencies of Disc with 20 Degree Inclined Ribs.

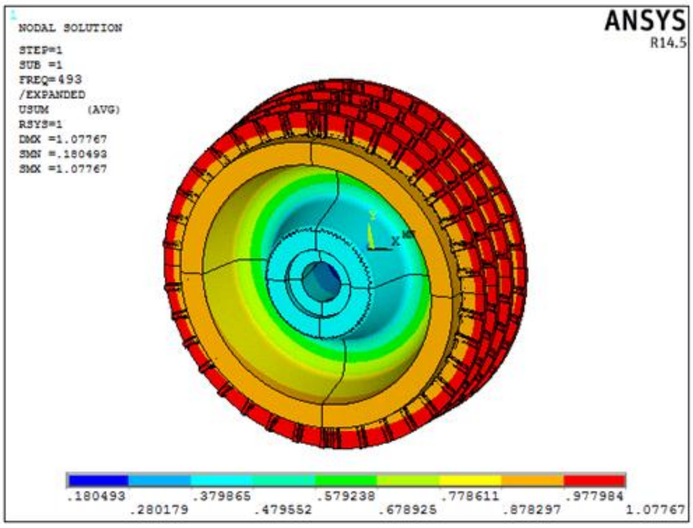

Fig 17: Mode shape corresponding to first natural frequency.

The above fig 17 shows the first mode shape corresponding to first natural frequency of 493Hz and similar with the 20 degree inclined rib.

5.3 Discussion

Rotating members are common with mechanical industry. Few times, this high rotations create lots of problems like higher centrifugal force, imbalance etc. Due to higher centrifugal forces, there is possibility of breaking of the equipment. So before implementing in the actual process, it is always better to check the structural members for safety. In the project, initially the casing is analysed with the internal pressure of 8MPa. The stress induced in the material is lesser than the allowable stress. Then the disc is analysed with considering simplified model because the finite element process consumes lot of time for the complicated geometry. So an effort is done to simplify the problem for finding the effect of rib on the structural integrity of the problem. Similarly cut-out effect is also carried out. The results comparison is as follows.

Rib Orientation	Radial Displacement (microns)	von-Mises Stress (MPa)
Straight	7.2	69
5	7.22	69
10	7.22	69.7
15	7.22	69.7
20	7.22	69.7

Table 3:Results without Cut-out.

Rib Orientation	Radial Displacement (microns)	von-Mises Stress (MPa)
Straight	3.0	10.6
5	3.11	10.7
10	3.16	11.4
15	3.22	12.6
20	3.30	13

Table 4: Results with Cut-out.

Actual Problem	Radial Displacement (microns)	von-Mises Stress (MPa)	Modal Frequency (Hz)
Straight	14.4	87.3	493
20	47.2	143	407

Table 5: Comparison of Actual Problem for Stability.

6. CONCLUSION

Structural analysis of casing and disc has been carried out to find the effect of ribs on the structural strength of the members under rotation load. From the above analysis we can conclude the following statement.

- Finally actual problems are analysed for the rotational loads. The results show similar trends to the previous conclusions. Both deformations and stresses are high with inclined ribs and natural frequencies are reducing. So simplified methods can be applied before going for actual problems which will reduce the solution time along with memory requirements. Also it reduces the modelling times. All the results are represented with necessary results pictures.
- The results shows almost zero effect with high volume geometries as the rib volume is considerably less compared to the remaining structure. But as the removed volume is considerable, the rib has effect on the stress generation in the problem. It is slightly increasing deformation as well as stress. So, straight ribs are better compared to the inclined ribs. This can be attributed mainly to concentration of large mass at the end which creates higher stress under rotation (mass is directly proportional to increase of centrifugal force).

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