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Contact Pressure Validation of Steam Turbine Casing for Static Loading Condition

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ABSTRACT: *Steam Turbines are devices used to convert thermal energy of steam into mechanical energy, which may be used to produce Electrical Energy. Steam turbine generator units are being used extensively all over the world for generation of electric power and for co-generation of steam and power. Contact pressure and pretension in bolts-analysis has been made easier in recent years due to the availability of high computational capabilities and flexibility in the computational methods using finite element analysis.*

In the present work, one such analysis is carried out to evaluate the contact pressure in a high pressure steam turbine casing. The shape and design of a steam turbine casing depends on key sensitivity parameters like bolt pre-tensions, contact pressure and thickness of casing which determine the structural integrity of the casing. The preset work reviews a recent structural integrity assessment carried out on a high-pressure turbine inner casing that had suffered from temper embrittlement Conventional design of a steam turbine casing is considered. Experimental work is carried out at Maxwatt to verify the contact pressure. The assessment will be carried out to demonstrate that the casing can be safely returned to service based on custom made revised operating conditions. The experimental results will be verified through finite element Analysis results.

The project which is presented in this paper has paid special attention to employ a standard methodology to perform static analysis and experimental condition. For this purpose a new methodology called "Contact pressure" has been developed. This enables accurate and complete leak proof condition. More over due to evolution of computer software and hardware large size boundary element models can now be solved with reasonable computing time.

The goal of this paper is to estimate the contact pressure so that there should not be any leak. Pretension in bolts is considered to achieve a firm contact between the casings. The three dimensional model of steam turbine casing were created using Hypermesh Software. The cad model created was meshed using Hypermesh Software by utilizing standard quality parameters. Boundary Condition were given on the Finite element model using Hypermesh. Contact pressure analyses were performed using Radioss solver.

Contact pressure analysis of turbine casing is very important in steam turbine which needs to be addressed for structural integrity. During operating condition steam turbine casings are subjected to very high pressure and temperature which results in stress and strain distribution. If the contact pressure is not achieved as per the standards then it leads to leakage of steam which causes explosion of casing. These effects are difficult to validate experimentally, since the setup is very costly.

I. INTRODUCTION

All turbines manufactured by Maxwatt use multiple piece casings consisting of two or more pieces that are split at the horizontal centerline to facilitate inspection or removal of the turbine rotor. The casings are either cast, fabricated, or a combination of both depending on operating conditions. The casing can be of iron, carbon steel, carbon moly steel, or chrome moly steel [1].

LP casing and for redesigning it to suit the new efficient modern design of rotor. This paper presents the numerical stress analysis of the turbine casing of an aero-engine. High thermal stress gradients were found at the region of casing where fatigue cracks were detected during engine operation [2].

Has analyzing the failure of a weld repaired turbine casing after 30 years of total service including 5 years after weld repair. The casing was weld repaired by a high Cr–Ni weld metal (24Cr–32Ni–4Mn–Fe). The base metal low alloy ferritic steel (1Cr–0.5 Mo steel) with ferrite–pearlite structure did not show any abnormality to indicate significant degradation [3].

Has studied about designing of complex steam turbine low pressure casing the ever growing competition in capital intensive power sector is pressing turbine manufacturer's world over to develop new efficient steam turbine designs and to update/retrofit the old steam turbine which are in service. BHEL is also putting up major design development efforts to meet the present market challenges [4].

Holmberg and Axelson [5] presented an analysis of stresses in circular plates and rings, with applications to rigidly attached flat plates and flanges, considering the loading at bolt force point as well as gasket compression.

The ASME Code contains extensive rules for the design of pressure vessel components, including rules for non-circular pressure vessels of unreinforced and reinforced construction. These rules cover the sides, reinforcing ribs, and end plates of such vessels [6].

Russian scientists P.Shlyakhin [7], A.Kostyuk and V.Frolov [8] had proposed methods to design flanges and bolts of a steam turbine casing. The method proposed by Shlyakhin stands out since it incorporates the bolt design along with flange design.

The theory of elasticity [8] has been extensively employed in analysis and design of bolted flanged connections. Waters and Taylor [9] developed an analytical method, based on the theory of elasticity, for ring and hub flanges with straight hubs. The deflection results calculated were compared with test results to demonstrate good agreement.

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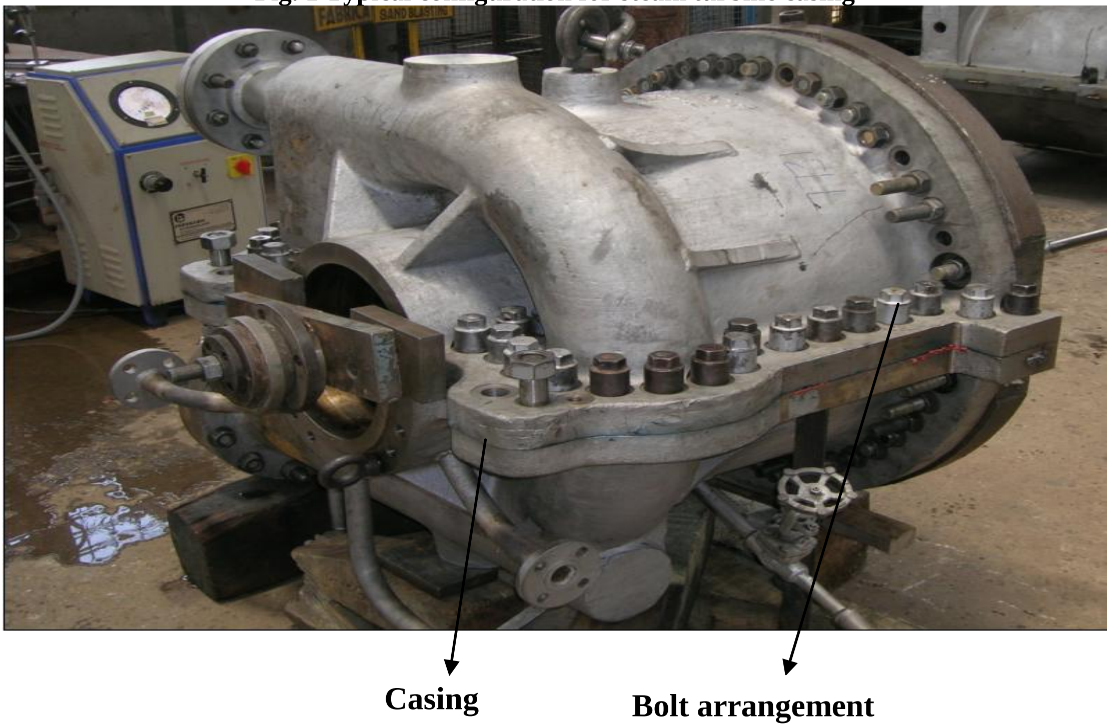
Based on the theory of beam on elastic foundation, Timoshenko [10] proposed a simplified method for the analysis of bending of circular rings. The maximum circumferential stresses for ring flanges and longitudinal stresses for hub flanges can be calculated by using this method.

Development of Life Prediction System for Thermal Power Plant Based on Viscoplastic Analysis, Final report, KERPI [11].

Fig. 1 Typical configuration for steam turbine casing



II. BOLT PRELOADING

Due to high loads, bolted connections can separate. To minimize this effect, a pretension is applied to the bolt. Pretension insures that the connection will not separate, provided the applied load remains less than the pretension. Torque tightening of bolted joint places the bolt in tension and the clamped members in compression. [6].

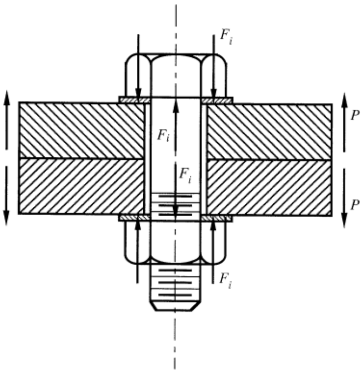


Fig.2 Forces acting upon a bolted preloaded connection

III. CALCULATIONOF PRETENSION LOAD BOLT DIAMETER.

Standard bolt diameters are considered for the calculation of pretensionload. ***Stress=PretensionLoad/Areaofbolt***

Area of bolt =$\pi d^2/4$, *stress = 232Mpa*

For 27mm diameter bolt A=572mm^2

Therefore, Pretension Load for bolt diameter 27mm = 120236.6 N. Pretension Load for bolt diameter 30mm = 163792N.

Calculated pretension value is applied

For the bolts during preprocessing.

Pretension load applied ensures that bolt is subjected to tension and the casing is subjected to compression.

IV. GEOMETRIC CAD MODELLING

Inner Diameter of Casing = 500mm

Casing Diameter thickness = 35mm

Flange thickness = 50mm

Length of Turbine = 600mm
Bolt Diameter = 27mm diameter
Bolt Length = 90mm
Capnut height = 55mm

Dimensions of the above are measured at Maxwatt to perform the FEA analysis.

It is very difficult to exactly model the steamturbine casing, in which there are still researches going on to find out the behavior of casing during operating condition at high temperature. There is always a need of some assumptions to model any complex geometry. These assumptions are made keeping in mind the difficulties involved in theoretical calculation and the importance of the parameters that are taken and those which are ignored. In modeling we always ignore the things that are of less importance and have little impact on the analysis. The assumptions are always made depending upon the details and accuracy required in the modeling. The assumptions made which are made while modeling the process are 1. Casing material is considered as homogeneous and isotropic. 2. Inertia and body force effects are negligible during the analysis.3. Structural analysis is carried out to find out the contact pressure 4. Thus stress level below yield stress is considered. 5. The analysis does not determine the life of the casing.

In an ideal scenario, CAD and FEA activities are coordinated to minimize the duplication of effort as analysis is made an integral part of the design process. The geometry built by the design team will ideally be usable FEA and all downstream applications. It is the responsibility of both the analyst and the designer, or geometry provider, to plan projects such that the optimal level of coordination between CAD and FEA is achieved. Before attempting to consider the merits of using the design model as the analysis model, the conditions listed below must be met. Design models are built in 3D solids or surfaces that fully enclosed volumes. The part can and should be meshed with tetrahedrons, or is simple enough to provide the foundation for solid mapped brick meshing or mid-plane surface extraction for building shell models.

Hydro Test Procedure as per ASTM

Component should be cleaned properly to remove machined burrs, sand, extra projections and any other foreign particles. Retapp all the tapped holes.

Close all openings by using proper flanges with gaskets/O rings.

Make provision for air release in appropriate place by fixing a valve.Hydrotest pressure will be 1.5 times the working pressure. Hold the pressure for half an hour.Take one 500gm weighing hammer and gently hammer the outer surface of the component. Ensure that there is no leakage found (by observation).offer the hydro tested component to Quality department for there approval.

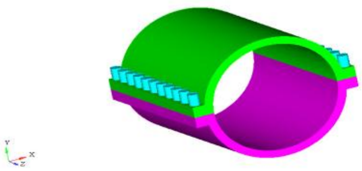


Fig.3 Cad Model of Casing and Bolts

Fig.4 Section view of actual casing and bolts during Hydro test

V. FINITE ELEMENT MODELLING AND ANALYSIS

In this part, the modeled casing is taken up for contact pressure and structural analysis. By carrying out the contact pressure analysis it will be taken care that required contact pressure is maintained at the parting plane and thus no steam leaks out of the casing [11].

By carrying out the structural analysis the stresses and deflections in the casing can be determined. Finite element analysis is a numerical technique by which the solution of a set of differential equations may be performed. The finite element method is probably the most widely used form of computer-based engineering analysis. The method can be used for analysis of a broad range of engineering problems.

Finite element methods are predominantly used to perform analysis of structural, thermal, and fluid flow situations. They are used mainly when hand calculations cannot provide accurate results. Finite element modeling involves the processes of feature suppression, model idealization and meshing of the solid model. The bottleneck of the whole process is model idealization, which is the process of generating a geometric model into an analysis model of suitable quality and reduced size so that it may be analyzed efficiently using FEA. The purpose of a finite element analysis is to re-create mathematically the behavior of an actual engineering system. In other words, the analysis must be an accurate mathematical model of a physical prototype. In the broadest sense, this model comprises all the nodes, elements, material properties, real constants, boundary conditions, and other features that are used to represent the physical system.

In FEA General Purpose programming terminology, the term model generation/finite element modeling usually takes on the narrower meaning of generating the nodes and elements that represent the spatial volume and connectivity of the actual physical prototype. ALTAIR HYPERWORKS used for the present work offers the following approaches for model generation/finite element modeling.

Default mesh control in ALTAIR HYPERMESH produces an adequate mesh for any analysis, however several mesh controls have been provided in order to achieve mesh of desired quality depending upon the requirement.

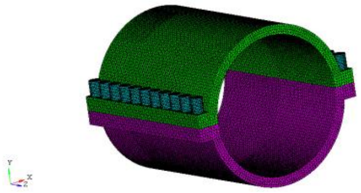


Fig.4. Meshed Model of Casing and Bolts

The meshed model of steam turbine casing is shown in Figure 4. Initially UG part file is imported to ALTAIR HYPERMESH, then meshing is carried out. In the present work we have used higher order tetra mesh for the accuracy of the results. The total mesh consists of 83999 nodes and 346571 elements. Chromium steel material is used since this material is anti corrosive and has good resistance to high temperature and pressure. Given Below are the material properties defined for the analysis.

Description	Casing	Bolt
Name	Chromium steel	Chromium steel
Density (Tonnes/mm^3)	7.8E-9	7.8E-9
Young's Modulous (MPa)	2.1E5	2.1E5
Poisson's ratio	0.3	0.3

Table 1: Material Properties

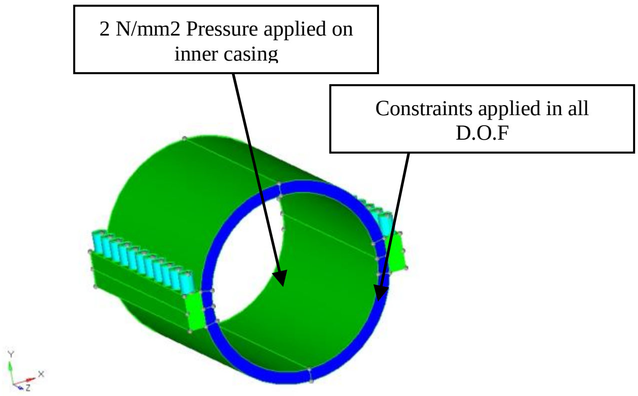


Fig.5. Boundary Conditions

VI. THEORITICAL CALCULATION

The Theoritical calculation done in this work is compared with analysis results and experimental results. i.e for the design and the casing to work on safe condition the contact pressure achieved in analysis should be greater than the calculated value. If the contact pressure achieved in the analysis is lesser than the theoretical value calculated then the design is unsafe.

For safe condition

Contact Pressure = 3 * Inner Pressure

Inner pressure applied = 2 Mpa.

Therefore Contact Pressure = 6 Mpa.

From the above calculation it is clear that contact pressure achieved in analysis should be greater than 6 Mpa or else the design is unsafe.

VII. RESULTS AND DISCUSSION

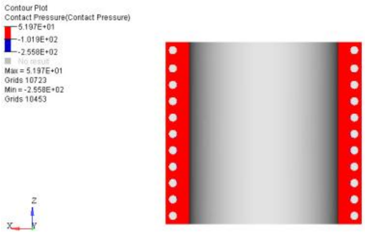


Fig.6. Contact pressure at parting plane

Figure 6 clearly shows that contact pressure achieved is 51Mpa (Red Band) which is greater than 3 times the inner pressure applied.
Since contact pressure achieved 51Mpa is greater than 6 Mpa i.e 3 times operating pressure, this ensures that there will be no leak and the casing is safe.
The same model was experimentally tested by doing Hydrotest at Maxwatt.
The test clearly showed there was no leak in the experiment and the casing is safe.

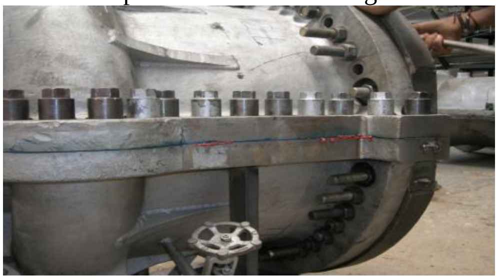


Fig.7. Contact pressure without Leak

Stress and displacement contour are also shown below.

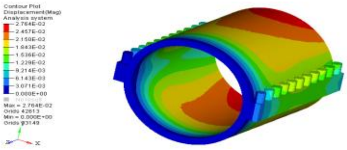


Fig.8. Displacement Contour

Displacement Contour Shown in Figure 8 shows that maximum displacement in the entire model is 0.027mm.

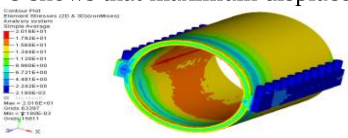


Fig.9. Von-mises Stress Contour

Von-mises Stress Contour shown in Figure9 shows that maximum Von-mises stress in the entire model is 20.16Mpa, which is less than yield stress 410 Mpa for Chromium steel. Hence the component is safe. Chromium steel is a good anti corrosive material for high temperature and pressure.

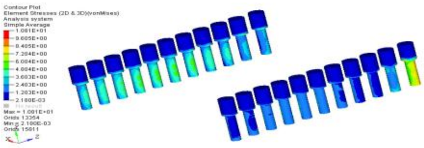


Fig.10. Von-mises Stress Contour on Bolts

Von-mises Stress Contour shown in Figure 10 shows that maximum Von-mises stress in the Bolt is 10.81Mpa, which is less than yield stress 410 Mpa for Chromium steel. Hence it shows that all the bolts are safe

VIII. COMPARISON OF RESULTS

Description	Theoritical	Analysis (Altair)
Contact Pressure	6 Mpa	51 Mpa

Table 1: Validation Table

From Table 1 result it is clear that contact pressure achieved in analysis is greater than calculated value and hence the design is safe.

IX. CONCLUSION

Validation of steam turbine casing is successfully proved theoretically, Analytically and experimental method.

- Theoretical, Analytical and experimental procedure show that this design procedure has been successful in generating an optimum design solution and thus can be easily implemented.
- The required contact pressure (wiz 3 times the pressure at respective stage) is achieved in the high pressure as well as in the intermediate pressure stages.
- It is clear from the results that the stress in the casing is well within the allowable stress of 210 MPa.
- The finite element analysis gives a complete picture of mechanical behavior of the flange structures, and design guidelines without costly experiments. The analysis results show that this design procedure has been successful in generating an optimum design solution and thus can be easily implemented.

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