JOURNAL OF MECHANICS AND MEMS : Vol. 10 (1), June 2018

Analysis of Steam Turbine Casing for Static Loading Condition

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Abstract: 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. Therefore This event can be numerically simulated using Finite element Analysis techniques.

In this work, the contact pressure analysis of steam turbine is validated by using the comparison of hand calculation and Finite element analysis results..The goal of this paper is to estimate the contact pressure so that there should not be any leak. Pretension in bolts are 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. Boundry Condition were given on the Finite element model using Hypermesh. Contact pressure analysis were performed using Radioss Software as solver.

During the last several years the primary changes to the design of steam turbines have focused on improving their efficiency, reliability and reducing operating costs. Siemens Power Generation, for example, has improved the overall efficiency and availability of its steam turbines by decreasing the steam flow energy losses in each of the steam turbines components. The steam turbine unit largely influences the efficiency and reliability of power stations. Any improvement in the design of steam turbine enables more efficient use of fuel and results in reduced cost. The high pressure steam at 5650 C and 156 bar pressure passes through the high pressure turbine. The exhaust steam from this section is returned to the boiler for reheating before being used. On leaving the boiler reheater, steam enters the intermediate pressure turbine at 5650 C and 40.2 bar pressure. From here the steam goes straight to the section of Low pressure Steam turbine expanding itself with increase in mass flow. From the intermediate pressure turbine, the steam continues its expansion in the three Low pressure turbines. The steam entering the turbine is at 3060 C and 6.32 bars. To get the most work out of the steam, the exhaust pressure is kept very low. The casing witness, energy of the steam turned into work in HP and IP-stages.

INTRODUCTION

The casing of a turbine is a pressure vessel where high temperature and high pressure steam from the boiler passes through nozzles which helps in rotation of turbine discs [1]. The casing withstands the steam pressure and supports internal components, i.e. turbine shaft with blades.

A turbine casing is a massive cast structure with a large wall thickness [2]. A casing is subjected to thermal stress across a wall, and to cyclic and sustained pressure/stress in service. Frequent start-ups and shutdowns generate cyclic compressive and tensile stresses in the casing walls [3].

Increased efficiency requires higher steam pressures and temperatures. It requires materials with improved thermal fatigue resistance, greater toughness and higher strength. Materials used for casings are usually low alloy Cr-Mo, and Cr-Mo-V [4] cast steels, with ferrite, ferrite-bainite, or tempered martensite microstructure. The strength of these steels at elevated temperature are obtained by solid solution strengthening and precipitation hardening.

High pressure turbine casings are liable to damages caused by distortion and cracking [5]. Distortion occurs due to thermal gradient, rapid start-ups and shutdowns cycles, or load shifts. Casing distortion can cause damage by allowing contact between stationary and rotating parts. [6].

Holmberg and Axelson [7] 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 [8].

Russian scientists P. Shlyakhin [9], A. Kostyuk and V.Frolov [10] 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 [11] has been extensively employed in analysis and design of bolted flanged connections. Waters and Taylor [12] 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.

Based on the theory of beam on elastic foundation, Timoshenko [12] 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.

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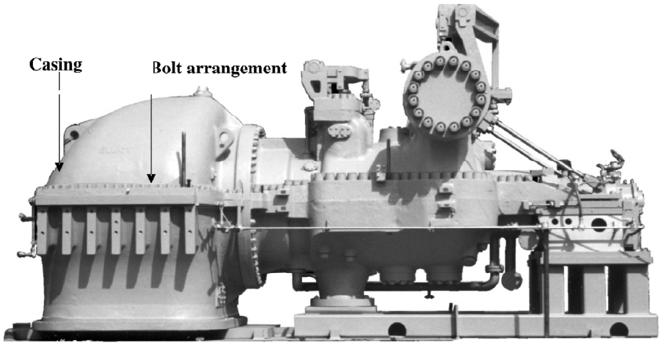

Figure 1: Typical Configuration for Steam Turbine Casing

Bolt Preloading: The minimum load applied on the bolts such that two parting surface establish contact between themselves firmly is said to be preload. Torque tightening of bolted joint places the bolt in tension and the clamped members in compression. [6].

Calculation of Pretension Load for Different Bolt Diameters: Standard bolt diameters are considered for the calculation of pretensionload.

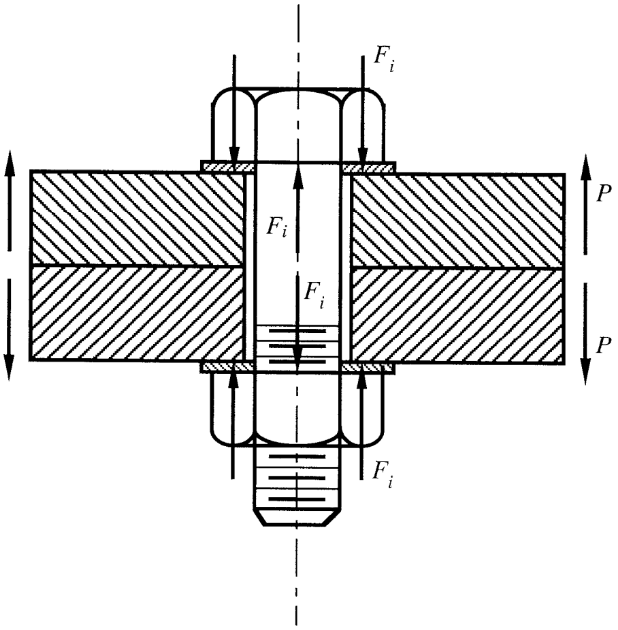

Figure 2: Forces Acting upon a Bolted Preloaded Connection

Stress = PretensionLoad/ Areaofbolt

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

For 42mm diameter bolt A = 1385mm^2

For 36mm diameter bolt A = 1017mm^2

For 30mm diameter bolt A = 706mm^2

Therefore, Pretension Load for bolt diameter 42mm = 321320 N. Pretension Load for bolt diameter 36mm = 235944N.

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.

GEOMETRIC CAD MODELLING

Because of the very complicated shape of the turbine cylinder the exact calculation of the wall thickness becomes very difficult.

$$t_c = \frac{PR}{SE - 0.6P} + 1.25$$

Where,P = Inner Pressure = 5Mpa
R = Radius of Casing=250mm
S = Allowable Stress = 77.5 Mpa

E = Joint Efficiency = 1

Allowable Stress considered in this case 77.5Mpa. i.e Factor of safety 2 is considered.

$$t_c = \frac{5 \times (500/2)}{(77.5 \times 1) - (0.6 \times 5)} + 15 = 31.78mm \approx 32mm$$

15mm is taken into account for casting deviations. 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.

The CAD model exists at the time the analysis is to be performed.

The solid modeling CAD systems use either a Boundary Representation (B-Rep) or Constructive Solid Geometry (CSG) method to represent a physical solid object .The B-Rep and CSG representations provide a complete mathematical definition of a solid object. In contrast, to traditional surface modeling software, solid modeling software has automated the process of creating solid model topology.

The modeling software UG was utilized to model the bolt and casing of steam turbine.UG introduces a comprehensive set of products for integration of product development processes for engineering and manufacturing industry organizations either large or small. It also provides a combination of tools to cater for varying levels of usage and required capability within an organization. UG provides advanced 3D Product Life cycle.

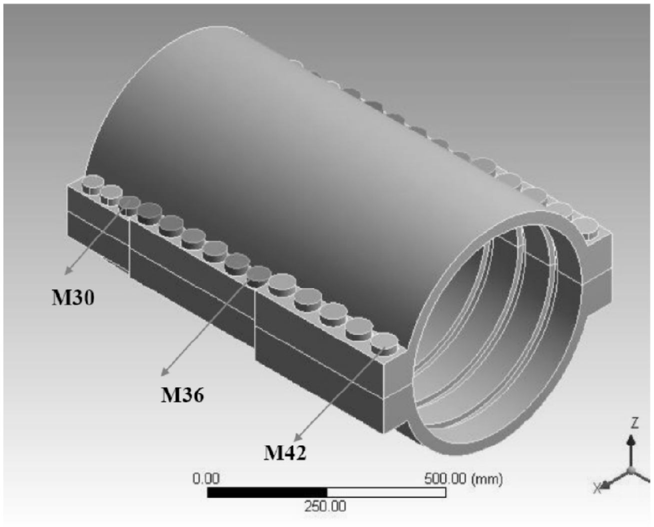

Figure 3: Cad Model of Casing and Bolts

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.

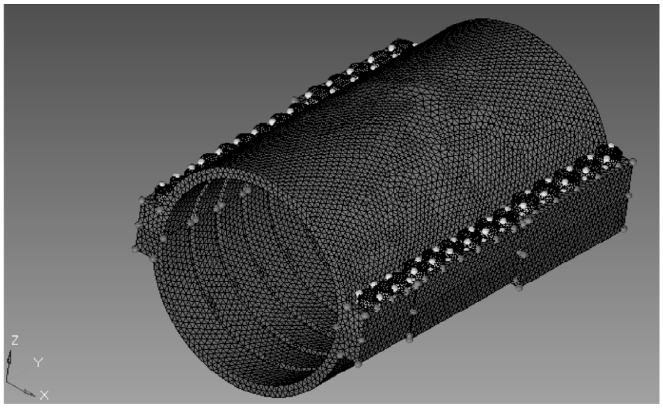

Figure 4: Meshed Model of Casing and Bolts

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 432916 nodes and 2012456 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

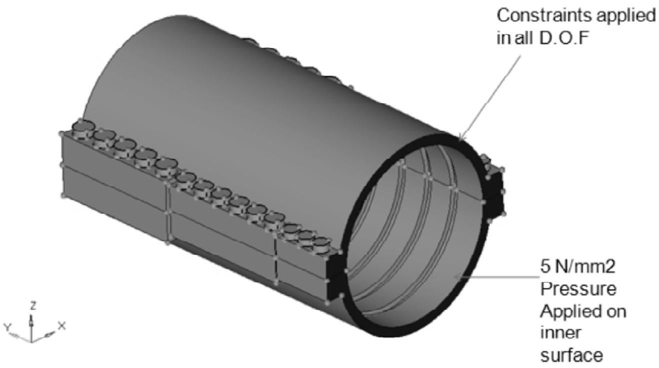

Figure 5: Meshed Model of Casing and Bolts

THEORITICAL CALCULATION

The theoritical calculation done in this work is compared with analysis 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 = 5 Mpa.

Therefore Contact Pressure = 15Mpa.

From the above calculation it is clear that contact pressure achieved in analysis should be greater than 15Mpa or else thedesign is unsafe.

RESULTS AND DISCUSSION

Figure 6 clearly shows that contact pressure achieved is 46Mpa (Green Band) which is greater than 3 times the inner pressure applied.

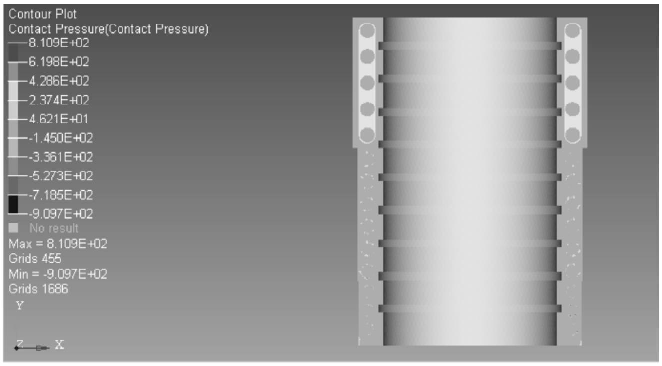

Figure 6: Contact Pressure at Parting Plane

Since contact pressure achieved 46Mpa is greater than 15Mpa i.e 3 times operating pressure, this ensures that there will be no leak and the casing is safe.

Stress and displacement contour are also shown below.

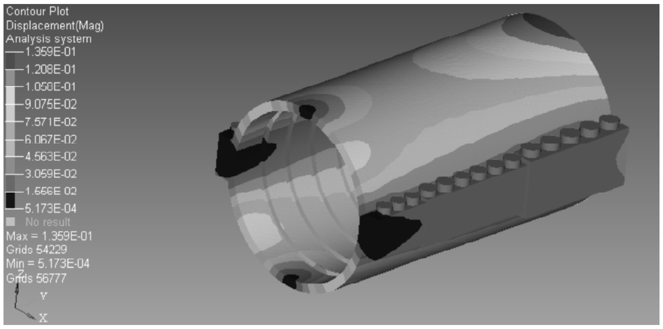

Figure 7: Displacement Contour

Displacement Contour Shown in Figure 7 shows that maximum displacement in the entire model is 0.13mm.

Von-mises Stress Contour shown in Figure 7 shows that maximum Von-mises stress in the entire model is 270Mpa, 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.

Von-mises Stress Contour shown in Figure 9 shows that maximum Von-mises stress in the Bolt is 253Mpa, which is less than yield stress 410 Mpa for Chromium steel. Hence it shows that all the bolts are safe

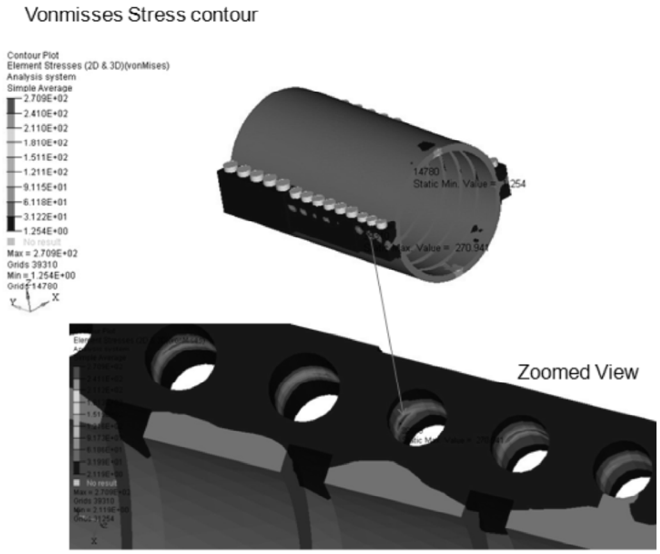

Figure 8: Von-mises Stress Contour

Figure 9: Von-mises Stress Contour on Bolts

COMPARISON OF RESULTS

Description	*Theoritical*	*Analysis (Altair)*
Contact Pressure	15Mpa	46 Mpa

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

CONCLUSION

To maintain High level of reliability and availability in a steam turbine plant contact pressure analysis should be carried out.

- The analysis results along with the results shown for validation of the 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 peak stresses are found at supports i.e. where boundary condition has been applied and at the bolt locations. These peak stresses are just surface stresses and do not pose any problems to the implemented design.
- 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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