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Study & Redesign of a Gas Turbine Casing Considering Bolt Pre-Tension

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Abstract-As **gas turbine operates under harsh environments, the body of the gas turbine casing is subjected to various kinds of loads, forces, pressures and thermal stresses and has to yet stay strong for a long working life span. The casing is very prone to crack in locations where there is a sudden change in cross section, such as holes and sharp edges. As stress concentration is much greater at these critical points as the casing experiences both thermal and structural cyclic loads inside it. The failure that occurs due to crack generation and propagation is termed as fatigue failure. Most of the work done in the field of research with respect to gas turbine casing is been mostly related to thermal or structural loads that act on the casing. None of the studies have included the effect of bolt pre-tension that is provided to the casing during manufacture, in order to bolt the two halves tightly together. This project mainly concentrates with the effect of pre-tension with the inside pressure and to study how the casing behaves in different conditions and how does the pre-tension effect its life and strength.**

Keywords — Gas turbine casing, finite element analysis, Bolt pretension, Flange, Fatigue. Design of casing

1. INTRODUCTION

One of the most concerning factor in a gas turbine industry is its unstable states arising during start-ups, shutdowns, and load changes which gives rise to a variable temperature distribution in the steam turbine components. Rapid increase in temperature result in higher thermal stresses acting on the component which in turn makes the component more susceptible to failure further reducing its operating life. In such power plants large steel-cast casings enclose the internal stationary and rotating components. Thermo mechanical fatigue (LCF) act majorly at the nozzle fit corner radius, and other stress concentration shapes such as sharp corners, sudden changes in cross sections, and these are one of the major factors that result in cracking of such pressure casings, as shown in Fig. 1.1. Cracking of a gas turbine casing may result in steam leaks or even explosion of the casing itself in some extreme cases.In case of a turbine casing failure considerable amount of time is required for its repair and replacement. Hence with the right knowledge of stresses and strains acting on the component such unexpected failures can be prevented with scheduled inspections. Such frequent inspections can help in optimizing inspection, integrity evaluation and life assessment of these components. However predicting the exact time of failure or even the life of component has not been possible as seen with few of the previous studies and hence is very limited when operating conditions is taken into account.Objective of the present study is to study the fatigue life of a gas turbine casing considering the bolt pre-tension in the component.

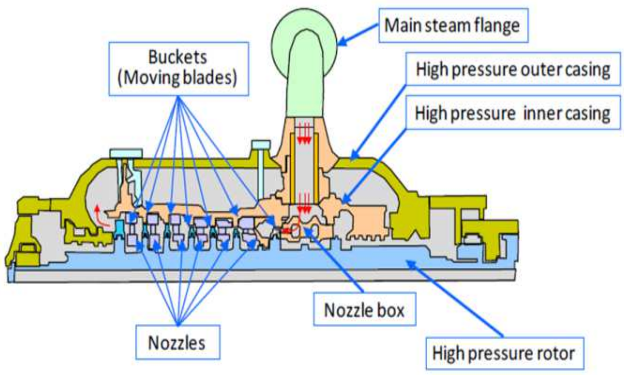

Fig 1.1.Section view of a high pressure turbine assembly

1.2 Turbine casing

Major component of a steam turbine is its casing which has stationary blades fixed to it from the inside and a rotor carrying moving blades on the periphery. The rotor is fitted within the casing such that on operation the rows of moving blades penetrate between those of fixed blades. Thus steam flowing through the turbine has to alternatively pass through fixed and the moving blades such that the fixed blades guide the steam at an appropriate angle for entry into the moving blades. The design of the casing and rotor has to be such that the thermal stresses are minimized, and the moving blades should be securely fitted with the rotor to withstand themassive centrifugal forces generated during operation.The shaft of the rotor is supported by bearings and is further linked to the electrical generator for its operation. Hence the bearing has to be appropriately aligned in order to accommodate the natural bending of the shaft under gravitation.

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2. TURBINE CASING CONFIGURATION

Cylinders of turbine have to withstand extreme conditions during operation. The pressure of steam acting on the cylinder is very high, hence to prevent the cylinder from failure the design has to be robust. Thick walled cylinders are not preferred as the temperature of steam can be extremely high and may result in thermal expansion of cylinder due to temperature gradient. These temperature gradients within components can set up high stresses in the material, which when combined with mechanical stress due to pressure, can cause failure of the material.

During the course of operation of the gas turbine it goes through varying temperatures and hence rapid heating and cooling of the components may take place. This demands the design to have a section of uniform thickness and also provision for flow of steam within the casing as shown in Figure 2.1 to promote uniform temperature changes, particularly during start-up of the unit. As the incoming steam is at a much higher temperature than that within the cylinder, proper provisions are required to take care of the thermal stresses and differential expansions in these areas.

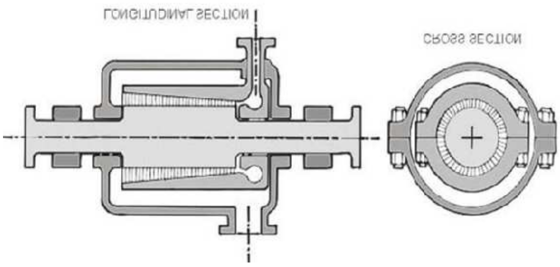

Fig 2.1.Diagrammatic sections of turbine cylinder

For maintenance and repair purpose if the turbine is to be removed the casing will have to be split opened somehow. For such occasions the casing is designed in two halves namely upper and lower. These two halves are held together by means of bolts and nuts across its length horizontally so as to facilitate easy removal of the upper casing on disassembly leaving the lower casing in its position with the other components such as rotor and rotating blades. This joint should be strong enough to withstand all the forces acting on it and hence the flanges is made thick and is provided with a pretension for the joints to be held in position strongly with the two half of the casing.

3. OBJECTIVE

The objective is to study the behaviour of a gas turbine casing under the effect of pre tension and hence calculating its fatigue life. Casing has two halves, one being the upper half and other the lower half. Both these halves are bolted together tightly, hence the casing structure is pre stressed. With the fatigue loads already acting on the casing during the operation of gas turbine, this pre stressed effect further adds to the stresses on the casing, resulting in reduction of the life of the casing. So the objective is to mainly study the effect of bolt pre tension on the simplified casing and suggest appropriate design so as to strengthen the casing against such failure.

4. METHODOLOGY

Initially the problem identification is done with the help of literature surveys and other related research studies obtained from various sources. Next important step is to understand the operation of a gas turbine with its complete working cycle. This will help in the understanding of different loads that arise during its operation. This is followed by the study of the material of casing and its fabrication method.

As the two half of the casing are to be assembled by tightening them together with the help of bolts, the casing is provided with a bolt pre-tension, the magnitude of this pre-tension is to be studied which is the basis of this study.

The casing is then created in a 3D modelling software followed by its analysis in Ansys software which gives the behaviour of the casing under load, pressure and the bolt pre-tension. A modified design of the casing is then created with the purpose to improve its strength, which is analysed for the same boundary conditions. A design which satisfactorily gives improved results is then finalized and considered as the better design for the casing against bolt pre-tension.

5. MATERIAL PROPERTIES

The material generally used for the casing is A395 Ductile cast iron. As the casing of a gas turbine operates under extreme working conditions such as high pressure and temperatures, the material of the casing should be such that it should be able to handle such high pressure and temperatures and not deform or fail.

5.1 Chemical composition

Element	C	Si	Mn	Al	Cu	Ni	V	Cr	Mg	Ti	Co	Fe
W%	3.344	2.7	0.136	0.016	0.351	0.082	0.044	0.12	0.057	0.038	0.033	Balance

5.2 Mechanical properties

Hardness (Brinel)	Tensile strength Ultimate (MPa)	Tensle strength Yield (MPa)	Modulus of elasticity (GPa)	Poisson’s ratio
167	461	329	165	0.29

Table 5.2. Mechanical properties

6. MODELLING OF THE TURBINE CASING

Below is a detailed figure of a gas turbine casing with the dimensions. The model of the casing is made using these dimensions in a modelling software.

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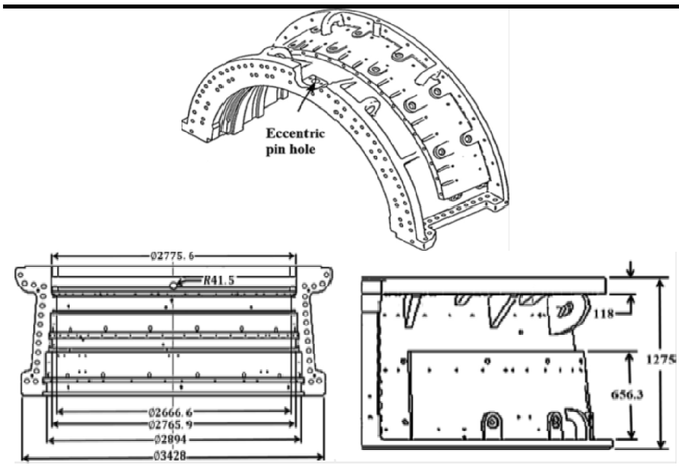
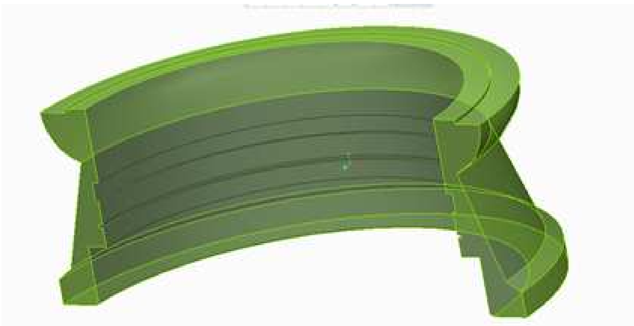


Fig 6.1. Dimension of a gas turbine casing in various views

The model can be created using any 3D modelling software, in this studyProEcreo version and even UG NX8 for modelling.



7. ANALYSIS OF THE TURBINE CASING

The real size of the casing is simplified further by the advantage of symmetry in order to reduce the computation time in Ansys. Only the portion near the flange with the bolt and nut assembly alone is taken for the analysis.

This simplified design is then imported in Ansys14.5 software for its analysis with the application of pressure and boundary conditions.

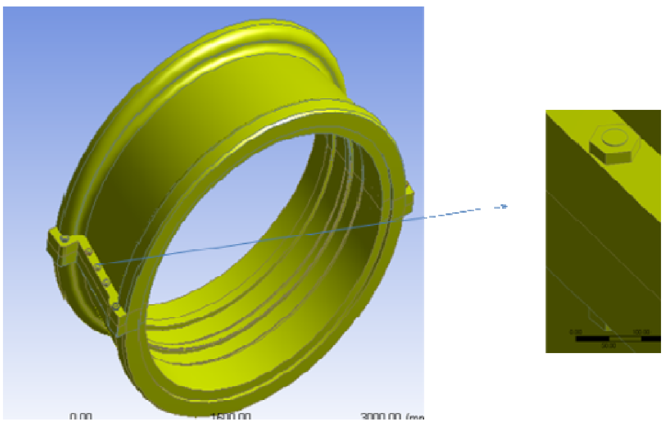


Fig 7.1. Assemble view of the casing

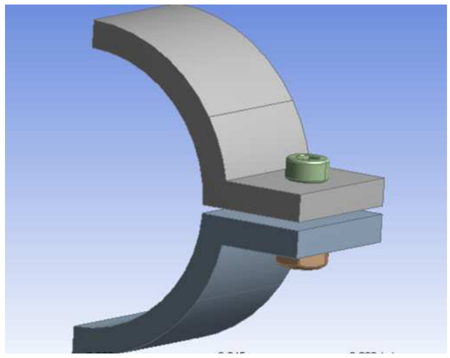


Fig 7.2. Simplified Casing Model to reduce computation time

Boundary conditions and the loads are applied. Fixed support is provided at the end of the flange. Pressure acts at the inside surface of the casing. Bolt tension the main feature acts on the bolt region as shown.

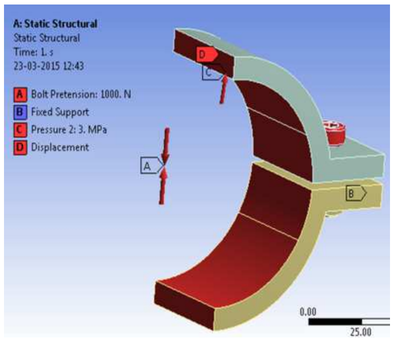


Fig 7.3.Boundary condition

A bolt tension of 1000 N is provided and the pressure acting inside the casing is 3MPa. The stress acting on the casing for these forces is then computed and following result is obtained.

As it can be seen in the figure below a maximum stress of 271.3MPa is induced when bolt tension & pressure is considered.

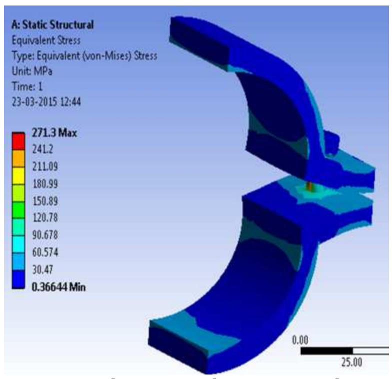


Fig 7.4. Equivalent Stress shown in complete view

International Journal of Ethics in Engineering & Management Education
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7.1Fatigue Analysis

Fatigue analysis is carried out for the existing casing for the same boundary conditions and then solving for fatigue life and fatigue stress.

7.1.1 Fatigue Life

Fatigue life for the existing casing was found out as shown in fig 7.5. It shows that a minimum fatigue life of 12536 cycles.

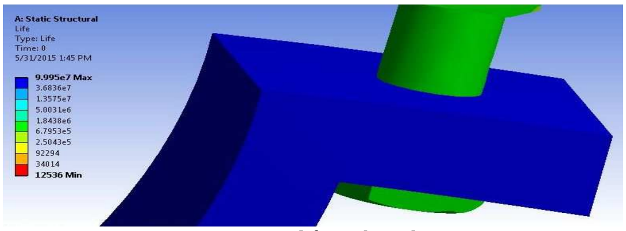

Fig 7.5. Fatigue life- Enlarged view

7.1.2 Fatigue Stress

Fatigue stress for the existing casing was found out as shown in fig 7.6. It shows that a maximum fatigue stress of 544MPa is induced.

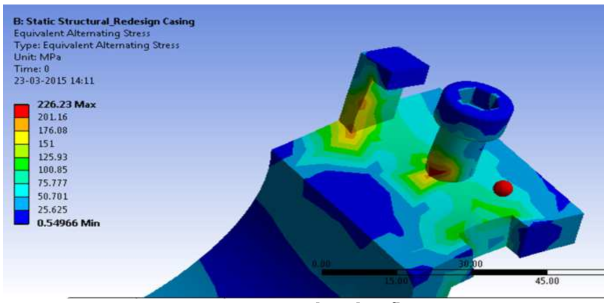

Fig 7.6. Fatigue stress induced in flange region

8. REDESIGN OF THE CASING

In order to improve the strength of the casing, the existing design of the casing is redesigned as shown in the figure. The conceptual idea is reinforcement of ribs to the structure and reducing the surface area of contact between the flange interfaces.

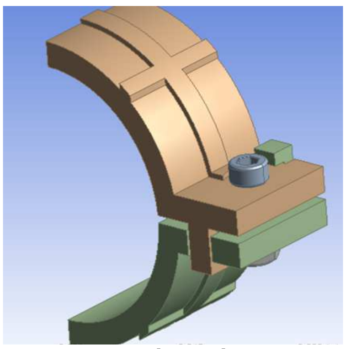

Fig 8.1. Redesigned casing

9. ANALYSIS OF REDESIGNED CASING

Analysis of the new redesigned casing is done similar to the existing casingThe material properties are entered in the static structural data, followed by assigning the properties to the casing components and then meshing the assembly. The loads are then applied just as actual design in previous chapter and then the required results were found out.

As it can be seen in fig 9.1, a maximum stress of 113.12MPa is induced under combined loading for the redesigned casing.

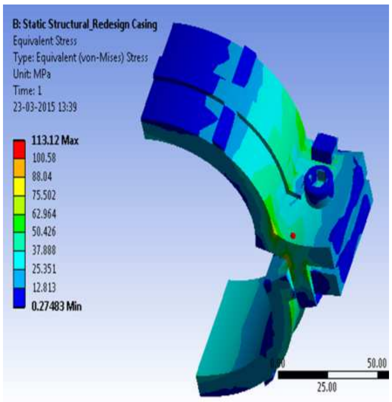

Fig 9.1.Equivalent Stress- outer surface view

It is evident from the results of the static analysis that the portion of the casing flange near the bolt are subjected to minimum stress without pretension and the same is subjected to higher stress when pretension is applied along with the pressure. Though the difference in the stress magnitude is marginally small, it makes a big difference if analysis is carried out for high pretension and pressure values.

In the redesigned casing the stress in the flange of the casing is less than the existing casing model subjected to static loads.

9.1Fatigue Analysis

Fatigue analysis is carried out for the redesigned casing for the same boundary conditions and then solving for fatigue life and fatigue stress.

9.1.1 Fatigue Life

Fatigue life for the redesigned casing was found out as shown in fig 9.2. It shows that a minimum fatigue life of 16533 cycles is achieved which clearly indicates that the redesigned casing has an improved design compared to the existing design.

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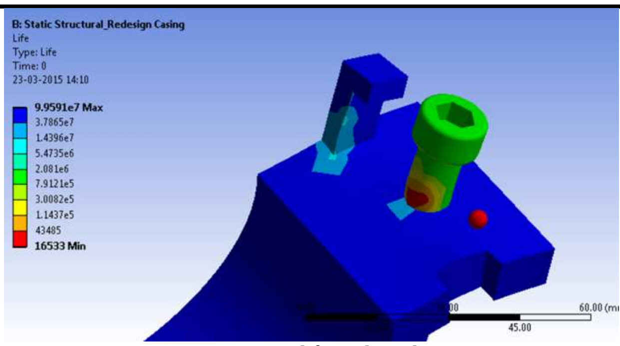

Fig 9.2. Fatigue life- Enlarged view

9.1.1 Fatigue Stress

Fatigue stress for the redesigned casing was found out as shown in fig 9.3. It shows that a maximum fatigue stress of 226.23MPa is induced which clearly indicates that the redesigned casing has an improved design compared to the existing design.

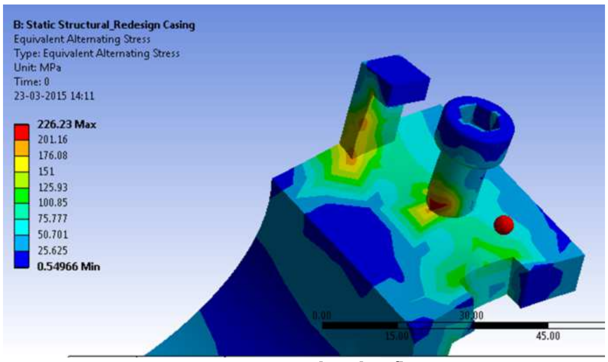

Fig 9.3. Fatigue stress induced in flange region

RESULTS

On analysis of the existing and the redesigned casing under the same loading conditions following results were obtained:-

(i) The redesigned model experiences less stress under the same loading condition. 271MPa of stress is induced in the existing model whereas only 113MPa of stress is induced in the redesigned model.

(ii) The fatigue life of the redesigned casing is improved compared to the existing casing. The existing casing fails too early, whereas the redesigned casing survives for a minimum of 16533 cycles.

(iii) The fatigue stress of the redesigned casing is improved compared to the existing casing. A fatigue stress of 544MPa is induced in the existing casing, whereas a stress of only 226.23MPa is induced in the redesigned casing.

CONCLUSION

The stress distribution was calculated by performing analysis in Ansys software for the existing and the redesigned casing. As per the results obtained and on comparison following conclusion was drawn:-

(i) It is concluded from the results that the redesigned casing offers high strength than the existing one under all the three loading cases.

(ii) Also by performing fatigue analysis, fatigue life of the existing and the redesigned casing was found out and the results show that the fatigue life of the redesigned casing is improved under the same loading conditions.

(iii) Fatigue stress was also obtained for both existing and redesigned casing, and the results clearly show that less stress is induced in the redesigned casing than the existing casing.

It shall be summarized that a good correlation is observed and methodology adopted has promised the confidence in design.

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