Life Evaluation and Thermal Analysis of Steam Turbine Casing

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Abstract- *Steam turbine casings are the massive cast structure where high temperature and high pressure steam from boiler passes through nozzles. Casing withstands steam pressure & support internal components. Material used for casing is chromium steels. Casings often subjected to cyclic loads of pressure and temperatures in normal life span of casing.*

Fatigue, or metal fatigue, is the failure of a component as a result of cyclic stress over the span of time. The failure occurs in three phases: crack initiation, crack propagation, and catastrophic overload failure. Fatigue failure is the failure of a component subjected to cyclic stress over the period of time. Hence life evaluation of the component is important to predict the life of a component under operating conditions. High temperature causes thermal stresses across casing walls which is responsible for thermal failure if it crosses the yield limit of 535 MPa specified for chromium steel.

In the present studies, design of Casings is done using UG software. Fatigue analysis, steady state thermal Analysis for steam turbine is performed using ANSYS WORKBENCH 14.5. Life evaluation is done to know the life of the casing under cyclic stresses caused by combined cyclic loads. Here, thermal analysis is carried out to check the structural performance of the casing under static loads of pressure & temperature. However, the results show that the casing is safe under thermal loads which are under yield stresses of 535 MPa. Also the casing can withstand for low cycle fatigue life and has long life span 10, 00,000cycles.

Keywords**-** Casing, FEM, Bolt Pretension, Temperature, Fatigue life

I. INTRODUCTION

A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft and the turbine generates rotary motion. It is is a form of heat engine that derives much of its improvement in thermodynamic efficiency from the use of multiple stages in the expansion of the steam.

A turbine casing is a massive cast structure with a large wall thickness. A casing is subjected to thermal stresses across a wall, and to cyclic and sustained pressure/stress in service. Materials used for casings are usually low alloy Cr-Mo, and Cr-Mo-V cast steels, with ferrite, ferrite-bainite, or tempered martensite microstructure.

Finite Element Method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It uses subdivision of a whole problem domain into simpler parts, called finite elements. Thermal analysis play an important role in the design of many engineering applications, including internal combustion engines, turbines, heat exchangers, piping systems, and electronic components. In many cases, engineers follow a thermal analysis with a stress analysis to calculate thermal stresses (that is, stresses caused by thermal expansions or contractions) under design criteria specified. The finite element solution perform via ANSYS calculates nodal temperatures, and then uses the nodal temperatures to obtain other thermal quantities. Fatigue analysis is also available in the software to estimate the life of a component approximately.

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Here, Life evaluation is done to know the life of the casing under cyclic stresses caused by pressure & temperature. Fatigue failures are typically characterized as either low-cycle (<10,000 cycles) or high-cycle (>10,000 cycles). In summary, it can be considered that a failure at 10,000 cycle's very short life, the failure above 10,000cycle as long life span. Thermal analysis is carried out to check the structural performance of the casing under static loads of pressure and temperature & checked for yield stress of 535 MPa specified for chromium steels.

II. LITERATURE SURVEY

Malagowda patil et al.[1] has studied the problem of frequency of start-ups & load changes within the casing which is higher and can results in non-uniform stress-strain distribution. In this study, steady state thermal analysis was evaluated and results are compared versus analytical results. Results confirm more stresses developed in initial condition.

G Das [2] has studied the failure of a steam turbine casing due to improper welding in the casing. Various case studies like microstructure, composition, fractography, were studied to know the cause of failure. Results showed that crack originated around the weld region due to inefficient choice of electrodes, & in welding process.

Gordana M. BAKIet al. [3] has studied the results of residual life assessment of one high pressure steam turbine casing. The stress states of casing for stationary and non-stationary working regime were obtained. Residual life assessment of HP turbine casing was conducted considering the influence of thermal fatigue and creep.

Laxminarayan, K.et al. [4] has studied about Contact pressure analysis & static analysis of steam turbine which needs to be addressed for structural integrity. In this work, the contact pressure analysis of steam turbine is validated by using the comparison of hand calculation and Finite element analysis results.

Gayatri Choudhary et al. [5] has studied, the work involves in design consideration, design checks and sensitivity analysis to achieve the design criteria to fulfil the structural requirement for mechanical integrity. Large-capacity single-casing reheat steam turbines have been developed to meet the need for large-capacity single-shaft combined cycle plants and the market demand for reduced cost by using compact machines, enhanced flexibility of the operation, and high performance.

Through an exhaustive literature review it is observed that the literature is rich in study of the casing on different boundary conditions. The life of casing play a critical role between top & bottom casing, failure at short span can cause hazardous to the external environment as well as workers and loss to the company. According to Lakshmi narayan.k [4] paper the research is concentrated on structural performance of casings & contact pressure analysis. However, the research work to estimate life evaluation of casings is rare under combined loads. Thus, there is extensive scope to explore the life prediction of casing along with thermal analysis.

III. OBJECTIVES

The objectives of this present work are:

- Life evaluation of casing of a steam turbine.
- Steady state thermal analysis of casing of a steam turbine.

IV. METHODOLOGY

Fatigue failure is the failure of a component subjected to cyclic stress caused by pressure and temperature over the period of time. Casings are subjected to very high pressure & high temperature steam. High temperature causes thermal stresses across casing walls which is responsible for thermal failure if it crosses the yield limit of 535 MPa specified for chromium steel.

Thermal analysis is performed to overcome the problem of thermal failure. High temperature causes thermal stresses across casing walls which is responsible for thermal failure if it crosses the yield limit of 535 MPa specified for chromium steel. . Pretension load is calculated and applied according to theoretical calculations. The casing is subjected inner pressure of 5 MPa & temperature of 3060C[4] which causes stresses on casing walls. Analyst has to conclude whether the component is safe or fail by comparing maximum stress value with the yield stress. life evaluation work is performed to know the life span of a component. The life of the component is evaluated after thermal analysis using the software.

Chromium steel (G17CrMo55) is used for casing and bolts material with specific mechanical properties. The geometric model is generated using CAD package. The model of 40mm is generated with the help of UG-NX software. Initially 2-D model was created & converted to 3-D. The model is then imported to the ANSYS WORKBENCH 14.5 software. The analysis begins with pre-processor. Here material properties for the casing and bolt material, meshing, boundary conditions for the specified problem, application of pressure & temperatures, is defined. Based on the pre-processing stage the work path follows solution stage. Here the problem is evaluated according to required scenario. After the results are shown in post-processing stage, the behaviour of problem/model under various loads/boundary conditions is displayed. Post processing stage follows the conclusion part based on the results obtained.

V. THEORETICAL CALCULATIONS

Bolt preloading is the load applied for the bolts to ensure firm contact between the casings and calculated pretension load to be applied for the analysis. Bolt Preloading is the minimum load applied on the bolts such that two parting surface establish contact between themselves firmly is said to be preload. Calculated pretension value is applied for the bolts during pre-processing. Pretension load applied ensure that bolt is subjected to tension and the casing is subjected to compression.

Calculation of Pretension Load for Different Bolt Diameters

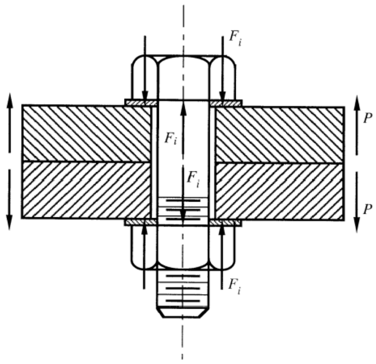

Fig1: Forces Acting upon a Bolted Preloaded Connection

Bolt size 40 mm**,** stress = 232Mpa**, [**4]
Stress = Pretension Load/Area of bolt, Area of bolt = $\pi d^2/4$
For 40mm diameter [4] bolt A = 1256.63mm^2.
Therefore, Pretension Load for bolt diameter 40mm = stress×area=**321320N**.
Inner pressure applied=5MPa. [4]
Temperature applied=3060C. [4]
Yield stress for chromium steel=535MPa.

VI. FEM ANALYSIS

The analysis is begins with the modelling stage. Once the model is generated it will be exported to ansys workbench 14.5 for the further analysis.

Modelling

The model of 40mm is generated with the help of UG-NX software. Initially 2-D model was created & converted to 3-D.

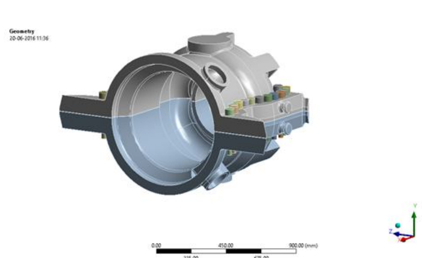

Fig. 2: Isometric View of Steam Turbine Casing

The element type used is 8 node 184, Tetra dominant method is used for meshing and size of each bolt is 40mm. The analysis has 3 basic steps: pre-processing stage, solution stage, post-processing stage.

i.Pre Processing Stage

Pre-processing stage is the fundamental stage of any engineering analysis. The material property, different boundary conditions, meshing, operating parameters, application of loads, etc. Need to be specified before entering into the solution stage.

Material property

Material property has to be defined for any engineering analysis to view the performance of the model/object under various boundary conditions. Materials used for casings are usually low alloy Cr-Mo, and Cr-Mo-v cast steels, ferrite-bainite, or tempered martensite microstructure. The strength of these steels at elevated temperature is obtained by solid solution strengthening and precipitation hardening.

Table 1: Material property

Description	Casing & bolt
Name	Chromium steel
Density (tonnes/mm3)	7.8E-9
Young’s modulas	2.1E-5
Poisson’s ratio	0.3

Table 1 describes the material property of both casing and bolt material. The material properties like density, young’s modulas, and poisson’s ratio are specified in pre-processor of software for the more approximate analysis of practical problem.

MESHING

For the sake of analysis the given model is divided into finite number of elements. The elements are so connected for the smooth analysis of problem. The connection of elements is called ‘**MESHING**’.

Fig 3: Meshing/Discretesiation of Steam Turbine Casing

Table 2 Statistics for Meshing

Statistics	
Nodes	81122
Elements	34045
Mesh Metric	None

Table 2 represents the statistics for meshing. The number of nodes generated is 81122 and number of elements generated is 34045.

A. Thermal Analysis(40mm bolts)

Casings are subjected to very high pressure high temperature steam. High temperature causes thermal stresses on casing walls which is responsible for thermal failure if it crosses the yield limit of 535 MPa specified for chromium steel. Themal analysis is performed to overcome the problem of thermal failure under the design criteria.

Analyst has to conclude whether the component is safe or fail by comparing maximum stress value with the yield or ultimate stress.

The model of 40mm is generated with the help of UG-NX software. initially 2-D model was created & converted to 3-D. The element type used is 8 node 184, Tetra dominant method is used for meshing And size of each bolt is 40mm.

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Young’s modulas	2.1E-5	2.1E-5
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Table 1 describes the material property of both casing and bolt material. The material properties like density, young’s modulas, and poisson’s ratio are specified in pre-processor of software for the more approximate analysis of practical problem.

Meshing

The generation of exact solution for the body with irregular shape is difficult and the formula for the particular is usually not available. Hence, for the sake of analysis the given model is divided into finite number of elements. The elements are so connected for the smooth analysis of problem. The connection of elements is called ‘**meshing**’.

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BOUNDARY CONDITION AND LOADS

The boundary condition need to be specified before solving any engineering problem. It specifies the specific boundary within which problem need to be solved. The minimum load applied on the bolts such that two parting surface establish contact between them firmly is said to be preload. Pretension load applied ensures that bolt is subjected to tension and the casing is subjected to compression. A Bolt pretention load of 321320N is applied for each bolt as per the calculations.

The boundary conditions may be fixing supports at one ends, or both ends etc. High temperature within turbine casings is responsible for damages such as thermal failure caused by thermal stresses. Therefore the pressure and temperature needs to be induced to check the performance of casing under pressure and temperature.

Fig.2: Boundary Condition for casing

Fig. 3: Application of 5 MPa Pressure

Figure 2 represents the bounary conditions applied for the static model. The top and bottom casings are fixed to analyze the model. Figure 3 represents the casing subjected to inner pressure of 5 MPa. The inner pressure developed due to the insertion of steam and combinational pressure developed due to the combined effect of blades, bolts, inner components by the insertion of steam which need to be analyzed.

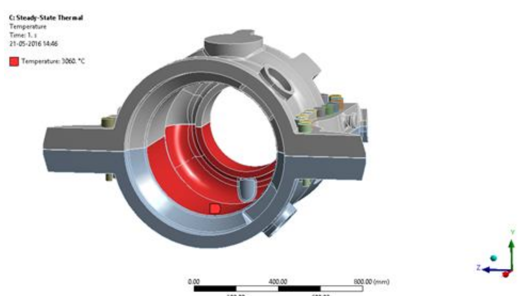

Fig. 4: Application of 3060c Temperature

Figure 4 represents application of temperature of 3060C inside the casing.

Solution Stage

After the model is built in the pre-processing phase, the solution of the analysis need to be obtained for the complete analysis of problem under different boundary conditions. Processing requires no user interaction.

The solution stage is completed for the given model under the pre-processing stage successfully. The solution is available and represented in the post-processing stage for the further analysis.

B. Life Evaluation of Casings

The same model is analysed to estimate the life of casings after thermal analysis. After successful completion of solution stage, the results are analysed in post-processing stage.

VII. RESULTS AND DISCUSSIONS

Post processing stage is the final stage of ANSYS analysis. The post processing of data includes presentation of result such component/assembly deformed shapes, strains and stress distribution etc.The major job of post-processor is to present results in an easy way with pictorial representation. The results are analyzed to get conclusion of the present work.

C. Thermal analysis

After this the design os casing with bolt diameter of 40mm it is allowed to solve in solution stage with the pre-processing work. the post-processing works are discussed with the help of results as below.

I. Von-Mises Stress & Maximum Principal Stress

Von Mises stress is the average stress developed for the casing under static load condition. principal stress is the maximum stress developed for the casing under static load condition of pressure & temperature.The stresses developed are displayed in various colour bands from red band to blue band. The red band shows the maximum stress and blue band shows the minimum stress. Remaining colour band shows intermediate stress zones.

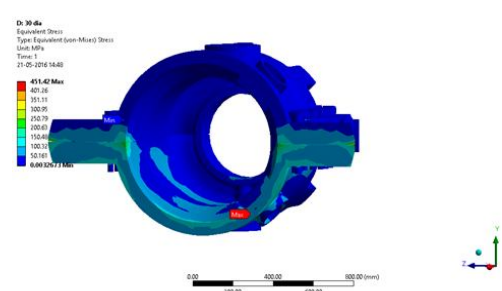

Fig. 3: Von Mises Stress is 451.42MPa

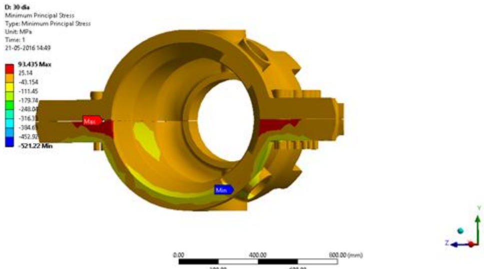

Fig 4**:** Principal Stress is 93.435MPa

The results in fig3 & 4 describes about von mises stress and principal stress developed in casing upon analysis. Since both the stresses are below the yield stress of chromium steel i.e. 535 MPa the design is safe under statical load conditions of 5MPa & temperature of 3060C.

II. Stresses in Bolts and deformation

stress are developed in casing under pressure and temperaturea considerable can also be observed in bolts due to the effect of stresses produced by thermal load & pressure. The casing can undergo deformation due to the massive pressure and temperature. The chances of deformation have to be evaluated to check safety of design. The stresses developed are displayed in various colour bands from red band to blue band. The red band shows the maximum stress and blue band shows the minimum stress. Remaining colour band shows intermediate stress zones.

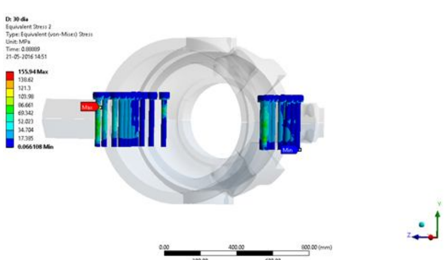

Fig.5: Stresses in Bolts is 155.91MPa

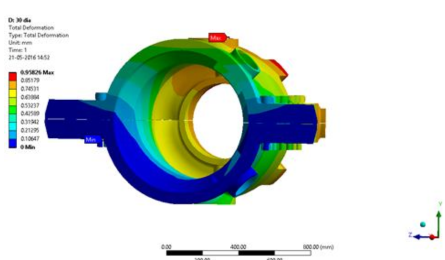

Fig 6: deformation is 0.95826

The results in fig 5 represents the stresses developed on bolts which are critical upon thermal analysis since stresses are below the yield stress of chromium steel i.e. 535 MPa the design is safe for pressure & thermal load conditions. Since deformation (0.95826) developed is within 1 the design is safe for deformation effects.

B. Life Evaluation of Casing

The life evaluation work is followed by thermal analysis. The life of the component is estimated successfully after solution stage using software.

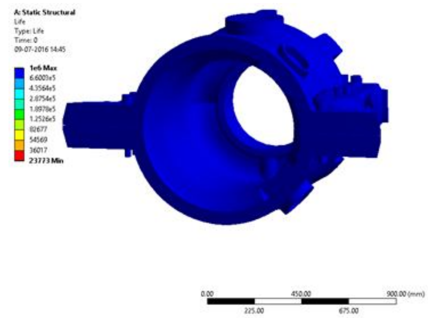

Fig7: life Evaluation of Casing

Figure 7 represents working cycle of steam turbine casings. The minimum work cycle is 23773 and maximum working cycle is 1oooooo is been observed. Since the casing sustains minimum life cycle of 23773 casings are safe for static & thermal load conditions. The maximum working cycle of 1000000 is been observed. It shows that the casing is said to have long life.

VIII. CONCLUSIONS

The objectives of this present work are to study the steady state thermal analysis, life evaluation of casing of a steam turbine. In this work, the 2-D model of was generated with the help of drawing provided by the **maxwatt** company. The 2-D modelling was generated with the help of **UG** software. The same model is converted into 3-D model with the same software. The work is then imported to the **ANSYS WORKBENCH 14.5** for the analysis process. High temperature within turbine casings is responsible for damages such as thermal failure caused by thermal stresses. Therefore, thermal analysis is performed by applying the pressure of 5MPa and temperature of 3060C. Fatigue failure is the failure of a component subjected to cyclic stress caused by pressure & temperature over the period of time. Hence life evaluation of the component is important to have long life span. The life evaluation is performed for the model with 40 mm diameter bolt under the pressure of 5 MPa, & temperature of 3060C.
From the study several conclusions can be drawn.

1. The Thermal Analysis showed that the design is safe for pressure of 5 MPa & thermal load of 3060C from the

evidence of von-mises stress, principal stresses, deformation developed as it is well within the yield stress (535 MPa) specified for chromium steel & also deformation is under limiting value of 1.

2. The Model is again analyzed for estimation of life the minimum work cycle is 23773 and maximum working cycle is 1oooooo is been observed. Since the design satisfies minimum life cycle of 23773 design is safe for static & thermal load conditions. The maximum working cycle of 1000000 is been observed. It shows that the design is said to have long life.

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