WEIGHT OPTIMIZATION OF STEAM TURBINE CASING USING OPTISTRUCT TOOL

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ABSTRACT

The Turbine Casing guides the steam from the last stage of the turbine to the condenser and it is designed to minimum pressure losses, which would increase the efficiency of the turbine. After the steam leaves the CASING section, it then enters the exhaust section of the turbine and then to a condenser where it is cooled to its liquid state in vacuum condition.

A Steam Turbine Casing was designed earlier for use with the 8MW-12MW impulse steam turbine (ST) newly developed by BHEL. This design of Turbine Casing is complicated in comparison to those used in industrial turbines of comparable ratings. Hence a need was felt by BHEL to optimize the Casing design to reduce its weight. This objective has been achieved in the present work.

The Casing is made in four parts, the lower left part, lower right part, upper right and upper left part. The casing has the assembly with a valve chest and exhaust hood from the lower parts.

The existing Casing is first analyzed for stresses and deformations and then optimization of the same is carried out.

Since the Casing is a large and complicated part it needs a lot of inputs to accurately define the complete geometry. The solid model is created in I-DEAS and finite element model for the casing is created with ten-node tetrahedral elements in HYPERMESH software. Optimization of the casing is done using HYPERMESH. This FE Model is then transferred to ANSYS.8.0 for analysis as it has better FE analysis capabilities. The type of analysis done in the present work is Stress analysis.

KEYWORDS: *Weight Optimization, Finite Element Mesh, Optistruct & Steam Turbine Casing*

Received: Jun 29, 2018; **Accepted:** Jul 20, 2018; **Published:** Aug 21, 2018; **Paper Id.:** IJMPERDAUG2018119

INTRODUCTION

Consistent development is necessary for almost every part of the steam turbine. Turbine Casing forms a vital part of a turbo machine since it houses rotating blades. The stiffness of the turbine is so important for the efficient performance of the steam turbine, also when the life of the turbine is concerned.

For a decrease of heat energy loss by means of shape modifications of the casing, it is necessary to understand the casing itself. The Steam Turbine Casing has relatively complicated shape. The flow of a wet steam has to be transmitted from axial direction behind the last blade stage to the radial direction and next into the condenser. Furthermore, the compressions of the wet steam at the pressure level in the condenser are required.

Due to the complicated inner shape of the Casing, which includes many kinds of brackets and stiffeners, there occurs a large heat energy loss. These losses could be decreased by better geometric shapes and by the position of these elements. With the aid of an experiment, it is possible to find the loss coefficient for the separately measured alternatives.

CASING DESCRIPTION

Turbine assembly consists of the casing, valve chest, nozzles, exhaust hood, blades etc. A casing is divided into four parts from the parting plane. Upper-right, upper-left, lower-right and lower-left. The parting plane divided the two sides (left and right side) symmetrically.

The steam present in the casing goes to the exhaust hood and from the exhaust hood to the condenser.

Due to the high pressure generated in the casing, there is a big chance of leakage of steam, which will affect the room temperature and thus is difficult for the operator to withstand the temperature. To prevent the steam losses and increase the room temperature, the bolt pressure should be more to the casing, i.e., the geometry of the casing should be in such a way that the number of bolts should be more, there should be an optimum distance (preferably less) between the bolts. This is based on the design criteria of the casing. This will help the bolts to generate more pressure (by a serial application), than the steam pressure and thus can avoid the steam leakage.

Hence the solid modeling of the casing should be done keeping in view this fact that the bolts to be made are more. The meshing of the component should be done very fine near the bolts so that the pressure applied is distributed uniformly along the bolts. Optimization is done to find out where can there be a shape and size change in the component. Contact analysis helps us to find out the stress distribution being done uniformly or not.

Maximum diameter of the casing: 1180mm.

Application: 6-12 MW Steam Turbine

Client: BHEL, R.C.PURAM, HYD.

Material: creep resistant alloy steel.

Salient Design features of Outer Casing

Provisions for mounting Valve chest

Layout to suit Blading plan

One extraction for 2.7 Kg/cm^2 , 5 Tons/hr.

Material: GS 22 Mo4

Weight: 2900 Kg.

Figure 1

Figure 2

This is the total assembly of the casing parts.

MODEL PREPARATION AND FORMULATION

Solid Modeling

For any 3D analysis and testing, solid modeling is the first step. It gives an excellent view of 3D structures, virtually for new products. FE models can easily be created from solid models by the process of meshing.

FE models can be made manually for simple cases only. One of the ways to prepare FE model is to mesh the solid and program it, if the model is of complex shape.

In the present work, the model is the Casing for Impulse Steam Turbine. Because of its large size casing is modeled into four parts i.e. upper part left, upper right part, lower left, and lower right parts. So it needs a lot of input data to accurately define the complete geometry. The first step in making finite element model is to make the CAD model of the Casing. This is done by drawing the parts, which are later assembled.

Figure 3

The Solid Model Assembly of a Turbine Casing.

With the help of the CAD model, a 3D finite element model can be obtained. The finite element mesh is generated in HYPERMESH software using 10 noded tetrahedral solid elements.

HYPERMESH

HYPERMESH is a pre- and post-processing system that enables engineers to create and manipulate finite-element models.

AUTOMESH

An element edge length is given then the AUTOMESH can automatically mesh specified surfaces of the element. It has the ability to select multiple surfaces and mesh. Before meshing, different parameters have to be specified such as increase biasing, density, change mesh and element types.

There are two options in the create mesh sub-panel. They are interactive and automatic. In interactive panel, auto mesh is used to mesh multiple surfaces or elements with user-controlled parameters. The automatic panel and the interactive panel have the same features. The only difference is without auto meshing modules, it creates elements on surfaces.

In the present work, the solid generation method is used for making FEM models.

Elements from the solid model method can be subdivided into two categories.

- Free meshing.
- Mapped meshing.

Figure 4

Figure 5

Finite Element Model of the Casing

Figure 6

Figure 7

The governing equation is:

$$[K]\{q\}=[F]$$

Where $[K]$ = structural stiffness.

$\{q\}$ = Nodal displacement.

$[F]$ = load matrix.

In the solution phase, we really end up with governing equations for each element. By solving these equations at each node, we obtain the degrees of freedom, which would give the approximate behavior of the complete model.

Material Properties

MATERIAL: G22Mo4

Specific Gravity: 7.85

Density: 0.28 lbs/in³

Electrical conductivity- 8-10% IACS

Co-efficient of linear expansion - 11×10^{-6} in/in/°C

Specific resistance- 18-25 micro lm/cm/cm²

Young's modulus 2.1×10^5

Poisson's ratio: 0.29

GENERAL METALLURGICAL CHARACTERISTICS

Molybdenum forms very stable carbides which are harder than, and formed in preference to iron carbides. Because of this, molybdenum steels have better creep strength, maintain hardness at the higher temperature and have increased harden ability over plain carbon steels. It also acts as the grain refiner, preventing excessive grain growth.

Molybdenum has many similar effects to tungsten, which is generally cheaper but requires large quantities to achieve the same purpose.

THERMAL TREATMENT

The low carbon steels are capable of accepting considerable cold-work but not as much as the plain carbon equivalent. Inter stage annealing is required between the stage of cold working and this requires a temperature of 840-900°C.

Reasons for using Alloying Steel

- Hardness is increased
- Strength is improved
- Mechanical properties are improved and all temperatures.
- Toughness is improved at any minimum hardness or strength.
- Wear resistance is Increased.
- Corrosion resistance is Increased.
- Magnetic properties are enhanced.

STRESS ANALYSIS

STRESS analysis is the analysis done to find out the stress limits especially when there is leakage in steam to the outer side of the casing. A pressure of 60 kg/cm² is applied in the internal surfaces of the casing. The pressure is applied internally from 2kg/cm² to 60kg/cm²

Figure 8

Figure 9

A model of the loads and boundary conditions applied on the casing. The model is an axis symmetric model.

Figure 10

Figure 11

OPTIMIZATION

From the days of Newton, Lagrange, and Cauchy, the existence of optimization methods can be traced. The development of differential calculus methods of optimization was possible because of the Newton and Leibnitz contribution to calculus.

The method of optimization for constrained problems by addition of un-known multipliers was invented by “Lagrange”. The steepest descent method to un-constrained minimization problems was the first application made by Cauchy.

Statement of an Optimization Problem

An optimization programming problem can be stated as follows:

Find $X = \{x_1, x_2, \dots, x_n\}$ which minimizes $f(X)$

Subject to the constraints

$g_j(X) \leq 0, j = 1, 2, \dots, m$

$i_j(X) = 0, j = 1, 2, \dots, p.$

Where X is an n -dimensional vector called DESIGN VECTOR, $f(X)$ is termed the objective function, and $g_j(X)$ and $i_j(X)$ are known as in-equality and equality constraints, respectively.

The problem stated above is called constrained optimization problem.

Constraints are not taken into consideration in some of the optimization problems which can be stated as:

Find $X = \{x_1, x_2, x_3, \dots, x_n\}$ which minimizes $f(X)$.

Design Vector

During the design process, some of the variables are defined as the set of quantities for any engineering system or component. These quantities are usually fixed at the outset and are called pre-assigned parameters. All other quantities are called design or decision variables and $x_i, i=1,2,\dots,n$. the design variables are collectively represented as a design vector $X = \{x_1, x_2, \dots, x_n\}$.

Design Constraints

To produce an acceptable design, the restrictions that must be satisfied are called design constraints. Constraints that represent limitations on behavior or performance of the system are called behavior or functional constraints. Constraints that represent physical limitations on design variables such as availability, fabrication ability, and transportability are known as geometric or side constraints

Constraint Surface

Consider an optimization problem with only inequality constraints $g_j(X) \leq 0$, the set of values of X that satisfy the equation $g_j(X) = 0$ forms a hyper surface in the design space and is called a constraint surface. Note that this is an $(n-1)$ dimensional subspace, where n is the number of design variables. The constraint surface divides the design space into two regions: one in which $g_j(X) < 0$ and the other in which $g_j(X) > 0$ are infeasible or un-acceptable. And the points lying in the region where $g_j(X) < 0$ are feasible or acceptable. The collection of all the constraint surfaces $g_j(X) = 0, j=1,2,\dots,m$, which separates the acceptable region called a composite constraint surface.

In the below figure, hatched lines in the infeasible region are indicated in hypothetical two-dimensional design space. A design point that lies on the surface which is constrained is called a bound point, and the associated constraint is called an active constraint. Design points that do not lie on any constraint surface are known as free points. Depending on whether a particular design point belongs to the acceptable or unacceptable region can be identified from the following four types:

- Free and acceptable point.
- Free and unacceptable point.
- Bound and acceptable point.
- Bound and unacceptable point.

All four types are shown in the figure below:

Figure 12

Objective Function

An acceptable or adequate design which merely satisfies the functional and other requirements of the problem can be obtained by the conventional design procedures. Thus a criterion has to be chosen from comparing the different alternative acceptable designs and for selecting the best one. The criterion, with respect to which the design is optimized, when expressed as a function of the design variables, is known as the criterion or merit or objective function. The choice of objective function is governed by the nature of the problem. The objective function for a minimization is generally taken as weight in aircraft and aerospace structural problems.

An optimization problem involving multiple objective functions is known as a multi-objective programming problem.

Optistruct

OptiStruct is a finite element-based structural optimization tool using topology optimization it generates design concepts or layouts. Unlike the traditional approach to size and shape, for optimization, OptiStruct does not require an initial design as input. Giving only a finite element model of the package space, load and boundary conditions, and a target mass, OptiStruct creates conceptual designs. When applied at the beginning of the design process, OptiStruct provides the optimal design.

OptiStruct enhances the design process:

- Introduce optimization during the concept design stage when the greatest improvements are possible
- Apply computer-aided engineering and design expertise early in the design cycle
- Use minimal input to create optimal designs that are often non-intuitive
- Reduce the number of design cycle iterations, decreasing development costs and time to market.

Optimization of Steam Turbine Casing

Firstly, the whole axis symmetric part of the casing is taken for optimization. The required design variables, objectives, design constraints are applied. Then, there must be a specification of designable space and non-designable space.

Following is the series of images showing the optimization over the casing.

Figure 13

Figure 14

Figure 15

The elements shown in white color is the material which can be considered for the removal but the problem now will arise about the removal as every area cannot be removed. There are crucial areas of the casing which do affect the stresses if they are removed. So, there must be a definition of the design space and non-design space of the casing. The following picture shows the design space (elements in yellow) and non-design space (elements in blue).

The reason behind taking on the rib area as the design space is a result of previous optimization problems of the casing. The discussion was done taking the examples of previous optimization problems of the casing and was hence decided that the rib area can be changed geometrically if the software shows an extra material, as part of design space. Thus, the partition is done.

Figure 16

Figure 17

Figure 18

Figure 19

Figure 20

Table 1: Stress Distribution Values

	Von Mises Stresses	X Dir	Y Dir	Z Dir
SMN	734E-03	27.381	-53.44	-85.055
SMX	201.961	55.807	80.427	107.262
DMX		0.19074	0.19074	0.19074

CONCLUSIONS

The material is suggested to be removed near the rib. Even a small change in the geometry can make a lot of difference in the weight, as the consideration of weight is the main criteria behind the project. The weight reduction of 9.7% is considered optimum. The total weight i.e. 281.3 kgs is the suggested removal

Figure 21

0th Iteration

Max displacement: 3.44e-02

Min displacement: 3.19e-05

Max stress: 5.52e+01

Min stress: 2.30e-04

100th Iteration

Max stress: 5.4e+01

Max displacement: 3.01e-02

ACKNOWLEDGMENT

Authors are grateful to BHEL R&D for providing facilities and technical assistance to carry out this research work.

REFERENCES

1. Rao.J.S; *Application Of Variatuional Principle To Shrouded Turbine Blades*, *Proceedings Of 19th Cong. Istam* P93-97 (1974).
2. Leissa.A.W, Macbain.J.C And Keilb.R.E, *Vibration Of Twisted Cantilever Plates Summary Of Provisions: Current Studies*, *Journal Of Sound And Vibration*, 1984, Vol-96 (20), P.No: 159-167.
3. Tsuneo Tsuiji, Teisuke Sueoka, *Vibrational Analysis Of Twisted Thin Cylindrical Panels By Using Raleigh-Ritz Method*, *Jsm International Journal*, Series Iii, 1990, Volume 33, Pages No: 501-505.
4. Le-Chung Shiau, Teng-Yuan Wu, *Free Vibration Of Buckled Laminated Plates By Finite Element Method*, *Transactions Of The Asme, Journal Of Vibrations And Accoustics*, October 1997, Volume 111, Page No: 635-644.
5. Hu, Xx And T.Tsuiji *Free Vibrartion Analysis Of Curved And Twisted Cylindrical Thin Panels*, *Journal Of Sound And Vibration*, Jan7, 1999,Vol-219 (1), Pageno: 63-68.
6. Yoo.H.H, J.Y.Kwak And J.Chung, *Vibrational Analysis Of Rotating Pre Twisted Blades With A Concentrated Mass*, *Journal Of Sound And Vibration*, Mar 2001, Vol 240(5), P.No:891-908
7. Park, Jung-Yong; Jung, Yong-Keun; Park, Jong-Jin; Kang, Yong-Ho, *Dynamic Analysis Method For Prevention Of Failure In The 1st Stage Low Pressure Turbine Blade With 2 Fingers Root*, *Proceedings Of Spie - The International Society For Optical Engineering* V 4537 2001. P 209-212
8. A.H.Shah, G.S.Ramsekhar And Y, M.Desai, *Natural Vibrations Of Laminated Composite Beams By Using Fixed Finite Element Modeling*, *Journal Of Sound And Vibration*, Vol: 257 Year: 2002, Page No: 635-651.
9. J.S.Rao, R.Bahree, A.M.Sharan, *The Design Of Rotor Blades Taking Into Account The Combined Effects Of Vibratory And Thermal Loads*, *Transactions Of The Asme, Journal Of Engineering Gas Turbines And Power*,Vol-111,Oct-1989,P.No.610-618.
10. Vyas.N.S, Rao.J.S, *Equations Of Motion Of A Blade Rotating With Variable Angular Velocity*, *Journal Of Sound And Vibration*, 1992, Volume 156(2), Page No: 327-336.
11. J.S.Rao, *Life Estimation Of Turbine Blades*, *B.H.E.L(R&D)*, Vol 14-16,Page No: 1-11, 1993.

12. Chen L.W & Pengwk, Dynamic Stability Of Rotary Blades With Geometric Non-Linearity, *Journal Of Sound & Vibration*, 1995, 187pp421-433.
13. Bhat.M.M, Ramamurthi.V, Sujatha. C, Natural Frequencies Of Industrial Studies On The Determination Of Turbine Blades. *Journal Of Sound1996 Vibration*, 196(5), Pp 681-703.
14. J.S.Rao, Y.D.Yu And T.N.Shiau, Transient Response Of Rotating Laminated Plates With Interfacial Friction Under Accelerating Conditions.,*Journal Of Sound & Vibrations (U.K)*; Vol-228 (1), 37-50;Nov-98.
15. Rao, J.S; Etal. The Effect Of Non-Linear Damping On The Resonant Stresses In Turbomchine Lp Rotor Blades. *Proceedings Of The Seventh International Conference On Vibrations In Rotating Machinery*, Nottingham, Uk, P 45,September, 2000.
16. J.S.Rao, A.Pathak, A.Chawala, Blade Life; A Comparision By Cumulative Damage Theories, *Transactions Of The Asme, Journal Of Engineering For Gas Turbines And Power*, Vol 123, Oct 2001, P.No. 886-892.
17. Vyas.N.S, Rao.J.S, Fatigue Life Estimation Procedure For A Turbine Blade Under Transient Loads, *Trans Of Asme, Journal Of Engineering Gas Turbines And Power*, 1994,Vol 116,P.No: 198-206.
18. Murari P Singh, Terry Mathews, Charles Ramsey, Fatigue Damage Of Steam Turbine Caused By Frequency Shift Due To Solid Builtup –A Case Study, 23rd Turbomachine Symposium, 1994,Page No: 33-41.
19. Chynoweth. J.M, Gerzen. G.S, Tomala. R.W, Root Cause Analysis Of Low-Pressure Turbine Blade Failure. *Proceedings Of The American Power Conference*, 1996, Vol.2, P.1230-1236 .
20. D.P.Walls, R.E.Delaneuville, S.E.Cunningham, Damage Tolerance Based Life Prediction In Gas Turbine Engine Blades Under Vibratory High Cycle Fatigue, *Transactions Of The Asme. Journal Of Engineering For Gas Turbines And Power*,Jan 1997, Voi 119, P.No: 143-152.
21. Bohra.S.A,Dealing With Turbine Blade Failures In India, *Nuclear Engineering International V 44 N 543*, 3 Pp, 1999.
22. Rao.J.S, K.Gupta, N.Vyas, Blade Damping Mesurements In A Spin Rig With Nozzle Passing Excitation Simulated By Electromagnets, *Shock And Vibration Digest*, Vol 56, P.No 109-116,Aug 1986.
23. Kadambi, J.R.; Quinn, R.D.; Adams, M.L, Turbomachinery Blade Vibration And Dynamic Stress Measurements Utilizing Nonintrusive Techniques, *Transactions Of The Asme. The Journal Of Turbomachinery Vol.111, No.4 P.468-74, Oct. 1989*
24. B.L.Jaiswal, S.K.Bhave, Experimental Evaluation Of Damping In A Bladed Disk Model, *Journal Of Sound And Vibration*, Vol-177 (1), 1994,Pp.No.111-120.
25. E.M.Curtis, H.M.Hodson, M.R.Baneighbal, J.D.Denton, R.J.Howell, N.W.Harvey, Development Of Blade Profiles For Low-Pressure Turbine Applications,*Transactions Of The Asme. Journal Of Turbomachinery*, And P.No: 531-543, July 1997, Volume 119.
26. Sharma, A., & MA, M. (2016). Modeling and Finite Element Analysis of Vertical Axis Wind Turbine Rotor Configurations..
27. Rossi, G.L.; Santolini, C.; Tomasini, E.P.; Nava, P.; Pinzauti, M, Experimental Tuning Of Resonance Frequencies Of A Turbine Blade By A Laser Scanning Vibrometer, *Proceedings Of The International Modal Analysis Conference - Imac V 2* 1998. Sem, Bethel, Ct, Usa. P 1758-1762 , 1998.
28. B.R.Al-Bedoor, Blade Vibration Measurement In Turbo-Machinery: Current Status, *The Shock And Vibration Digest*, Vol-34, No-6p.No: 455-461,Nov 2002.
29. *Engineering Optimization Theory And Practice* By Singaresu. S. Rao.
30. *Metallic Metals* By Robert B Ross, Chapman And Hall Ltd.

31. *Introduction To Physical Metallurgy* By Sydney H Anver
32. *Metallurgy Of Basic Weld Metals* By G.M Evans And N.Bailey
33. *Engg Metals For Advanced Friction And Wear Applications* Abington Publications