Static and Modal Analysis of Jeffcott Rotor Under Low Volume Conditions

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***Abstract -** A thermal power station is a power plant in which the prime mover is steam driven. Here the work is focused on the study of behavior of steam turbine rotor in low volume flow condition with the rotor dynamics concept using ansys. The Jeffcott rotor is modeled by pro-e modeler, meshed and analyzed by ansys workbench. In this paper we described the design and analysis of single stage Jeffcott rotor and multistage Jeffcott rotor. Further comparison of standard single stage rotor with modified single stage rotor of equivalent stresses, maximum principal stresses and total deformation again comparison of standard multistage rotor with modified multistage rotor's stresses and total deformation. The analysis results are tabulated and found that during normal operation the stresses are within the allowable limit but in low volume flow condition the stresses are exceeding the allowable limit. Reduction in weight of rotor without affecting the functionality and efficiency of turbine will help to reduction in material cost, weight etc.*

Key Words: Steam turbine, Jeffcott Rotor, Static and modal analysis, Equivalent stresses.

1. INTRODUCTION

The majority of the conventional power generation is associated with the consumption of natural resource and are not sustainable.This has led to a growth in renewable and localised production of power, which is expected to address all these problems.This diversification of power generation method has enhanced the requirement for operational flexibility of steam turbines in power production. Renewable energy sources cannot provide uninterrupted and reliable power production as their output is often difficult for predicting and storage capacity is also not available in the required quantities.These results in large variations of the power demand from conventional power production.steam turbines are increasingly expected to be operated in regions without sufficient water-cooling such as desert regions. A steam turbine is a heat engine in which the energy of the steam is transformed into work. First, the energy in the steam expands through a nozzle and is converted into kinetic energy. Then, that kinetic energy is converted into work on rotating blades.The turbine is divided into different modules with the different pressure levels. The critical components in terms of flexible operation are those enduring highertemperature and higher pressure such as the inlet valves or the rotor of the high andintermediate turbine, which can suffer from low cycle fatigue under high thermal transients.

Causes of Failures in Industrial Turbine

Following are the major causes of failure of industrial turbines.

1. Weight Unbalance
2. Bearing misalignment
3. Resonance (Critical Speed)
4. Centrifugal forces
5. Uneven loads on rotor.

LITERATURE SURVEY

Dilip Kumar Garg, Shrinivas Chambalwar, Jayant Sarode and Ajay Dhanopia et.al., [1] presented the rotating instability flow phenomenon numerically in the last stage of low pressure steam turbine operated at very low mass flow rate. This kind of instability imposes a major risk to the mechanical stability of last stage moving blades in low pressure steam turbines. Goal is to predict the unsteady flow phenomena and their effects.

Nagaraju Tenali1 and Srinivas Kadivendi1et. al., [2]worked on analysis of steam turbine rotor using Rotor dynamics principles. . Rotor dynamics Mainly deals with studies of lateral and torsional vibrations of rotating shafts or structures with the main objective of predicting rotor vibrations and limiting the vibration level under an acceptable limit. The generalized Jeffcott rotor consists of long flexible mass less shaft with flexiblebearings on both the ends. The different analysis carried out to the rotor dynamic integrity of the steam turbine rotor such as Modal analysis, Harmonic analysis and Transient analysis in Ansys.

Chenchu Deepa, B.Jayachandraiahet. al., [3] conducted an analysis to estimate the Efficiency of Low Pressure Steam Turbine. The steam turbine blade performance is related to many factors. One of the important factors is the change and degradation in turbine blade profile after many operations. This leads to increased in flow losses and hence reduction in overall efficiency of turbine. The performance of turbine blade can be predicted and improved by using Computational Fluid Dynamics (CFD).

PROBLEM DESCRIPTION AND OBJECTIVE

The objective of this study is to study the behavior of steam turbine rotor in low volume flow state in LP stage by applying rotor dynamics concepts.

Following stages are followed by

1. Initially simple Jeffcott rotor will be studied in order to understand the dynamic behavior of such simple rotors before dealing with large industrial rotors.
2. The study will include predicting critical speeds calculation for Jeffcott rotor.
3. After the study on the Jeffcott rotor model, a finite element model of a Jeffcott rotor will be meshed and formulated in ANSYS software.
4. Critical speedis calculated mathematically for single stage rotor.
5. Static structural analysis module is used to calculate displacements, strains, stresses and reaction forces under the effect of applied loads.
6. By plotting Campbell diagram with the results from Modal analysis, critical speed is verified and compared with the calculated values.

METHODOLOGY

1. Involves behavior of single stage rotor (Jeffcott Single Mass Rotor) and analyze the results by mathematically and also by analytical method by using Ansys.
2. Study of change in frequency of the rotor as the mass & speed of rotor varies.
3. Study of behavior of single stage rotor in various operating speeds and frequencies.
4. Study of critical speed and resonance of single stage rotor and plotting Campbell diagram.

Finite Element Approach

The process of data analysis proceeds in two stages:

a. Identifying the appropriate type of model (with viscous or structural damping). This choice is often in practice limited by software used for the modal analysis. Most of software packages work with one type of damping and give no choice to the user.

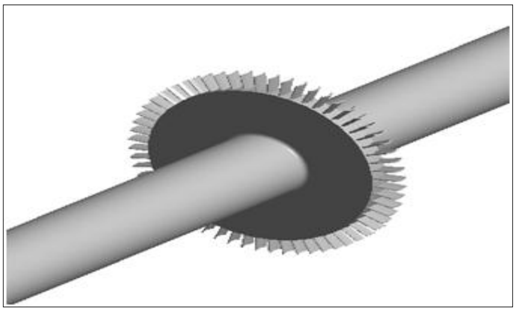
b. Determining appropriate parameters of the chosen model. This stage, also called modal parameters extraction, is done by curve-fitting of the measured frequency response functions to the theoretical expressions.

Material Selection

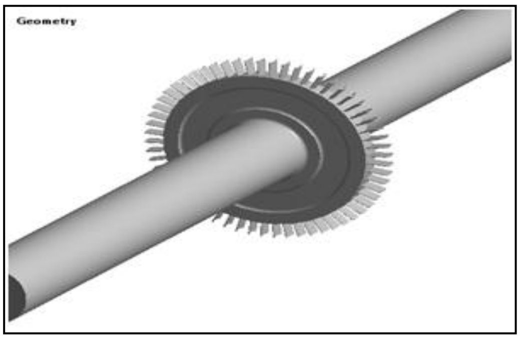
Material	ChromeSteel(X28CrMoNiV49)
Density	7.7×10^{-9}Kg/mm^3
Young's modulus	2.1×10^5 MPa

Yield strength at room temperature	550 MPa
Yield strength at 100^0 temperature	540 MPa
Poisson's ratio	0.3
FOS at 100% operating Speed	1.68
FOS at 121% operating Speed	1.15
Allowable stress at 100% operating Speed	321MPa
FOS at 121% operating Speed	469MPa

Geometric Modeling



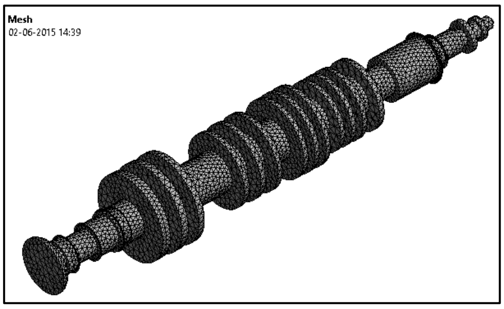
3D model of Jeffcott's Rotor



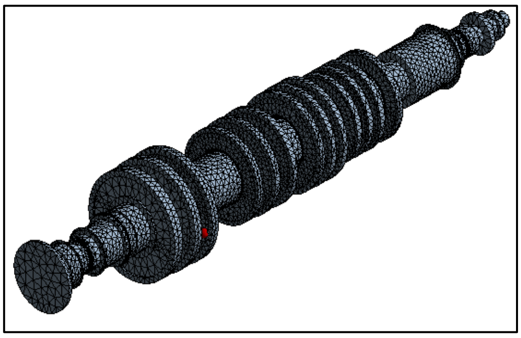
3D model of Modified Jeffcott's Rotor

Description	Jeffcott Rotor	Modified Jeffcott Rotor
Length of Rotor Shaft	1.5 m	1.5 m
Dia. Of Shaft	0.2 m	0.2 m
Dia. Of Rotor Disk	0.5 m	0.5 m
Thickness of Rotor Disk	0.05 m	0.05 m
OD of Cutout in Disk	0.50m	0.425m
ID of Cutout in Disk	0.30m	0.275m
Thickness of Cutout in Disk	0.007m	0.005m(Both Sides)

Meshing

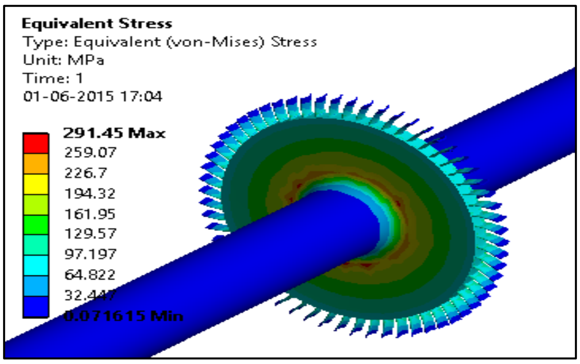


Meshed model of the Multi Stage Rotor

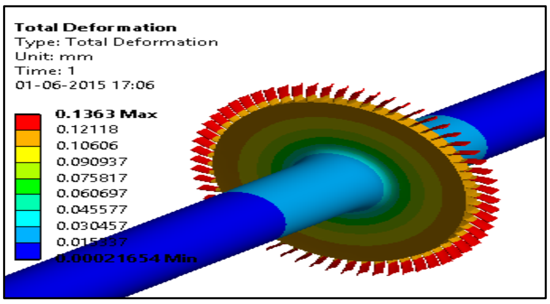


Meshed model of the Modified Multi Stage Rotor

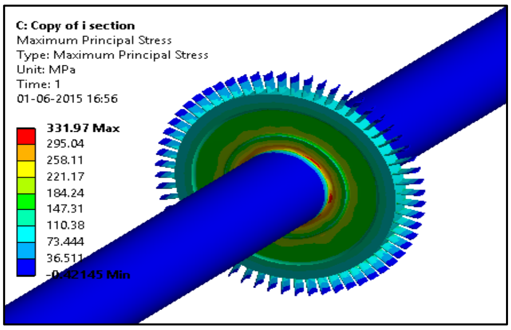
RESULTS AND DISCUTION



The figure 6.1shows Equivalent stress of 291.45MPa for the singe stage rotor with rotational velocity of 6500rpm and displacement.



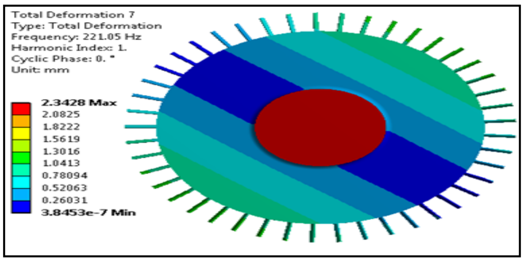
The figure 6.2 shows total deformation of 0.150 mm for the rotor with the rotational velocity of 6500rpm and displacement.



The figure shows Maximum Principal Stress of 0.1363 mm for the rotor with the rotational velocity of 6500rpm and displacement.

Description	Singe Stage Rotor	Modified Singe Stage Rotor
Equivalent Stress(Von Mises) in Mpa	291.45	265.05
Maximum Principal Stress in Mpa	364.7	331.97
Total deformation in mm	0.1363	0.1506

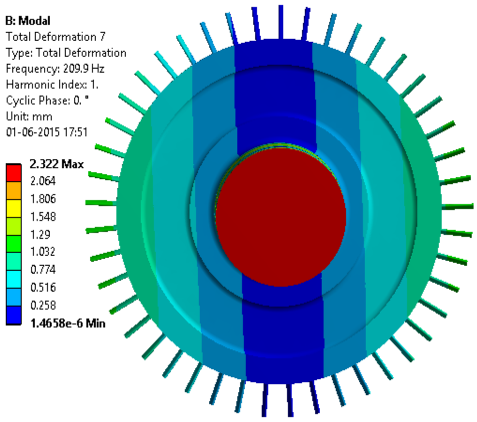
Mode 1



The figure shows total deformation of 2.3428 mm in first mode with the frequency of 221.05 Hz for the given boundary conditions

Frequency and Deformation of Standard Jeffcott's Rotor

Mode	Frequency in Hz	Deformation in mm
1	221	2.34
2	784	3.5933
3	1490	12.364
4	1680	7.37
5	2301.5	15.043
6	4965	25.291



The figure shows total deformation of 2.3428 mm in sixth mode with the frequency of 4965 Hz for the given boundary conditions.

Frequency and Deformation of Modified Jeffcott's Rotor

Mode	Frequency in Hz	Deformation in mm
1	209.9	2.322
2	758.98	3.83
3	1341.9	12.995
4	1627	7.466
5	2008.3	18.558
6	4430.7	31.243

Comparison of Stresses and deformation

	Standard Multi Stage Rotor	Modified Multi Stage Rotor
Equivalent Stress in Mpa	224.76	253.59
Maximum Principal Stress in Mpa	340.57	407.5
Total deformation in mm	0.4245	0.34485

CONCLUSIONS

The main objective of the work is focused on the study of behaviors of steam turbine rotor in low volume flow condition with the Rotor Dynamics concepts using Ansys. Here the basic work involved is study of single stage (Jeffcott's) rotor and the results are compared with multi stage steam turbine rotor. Here we mainly concentrated on Low Pressure stage turbine experiences stresses due to low volume flow.

The Multi stage steam turbine rotor is modeled in Pro-e and meshed in ANSYS 14.5 Workbench. A methodology to determine dynamic stresses of low pressure stage steam turbine rotor under low volumetric flows of steam is illustrated. Stresses are tabulated and mode shapes with deformation at certain speed is plotted and are evaluated from centrifugal load or speed from a static structural analysis module and the results tabulated in table 6.4 shows the deformation and stresses generated in the Multi stage steam turbine rotor and are within the acceptable limit.

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