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Thermal Analysis of Steam Turbine Rotor Using FEA

Kotha Srinu
Department of Mechanical Engineering,
Avanthi Institute of Engineering and Technology,
Vizianagaram, Andhra Pradesh 531162, India.

Lenka Manikanta
Department of Mechanical Engineering,
Avanthi Institute of Engineering and Technology,
Vizianagaram, Andhra Pradesh 531162, India.

Mathala Shyam Kumar
Department of Mechanical Engineering,
Avanthi Institute of Engineering and Technology,
Vizianagaram, Andhra Pradesh 531162, India.

Patna Ramana
Department of Mechanical Engineering,
Avanthi Institute of Engineering and Technology,
Vizianagaram, Andhra Pradesh 531162, India.

ABSTRACT:

In this project an effort has been made to estimate the effects of the transient thermal in the turbine rotor using Finite Element Analysis. A typical turbine rotor is considered for transient thermal analysis using the modeling software i.e. CAD software and ANSYS software. The turbine rotor of a steam turbine is subjected to temperature variations in short periods of time due to the start and stop cycles of the turbine. This causes sudden changes in the temperature with transient thermal stresses being induced into the turbine rotor. The transient effects are due to the changes in the material properties like - Density, Specific heat and Young's Modulus. The estimate of the thermal stresses induced in the turbine rotor due to change in temperature is important. The rotor material is 30Cr and the properties of the material are updated to the model. The appropriate boundary conditions depicting the actual environment in which the turbine rotor works in steam turbine are also updated. The thermal stresses due to large temperature gradients are higher than the steady state stresses. The large thermal stresses occur before reaching the steady state value. By varying materials properties of rotors.

***Key Points:** Steam Turbine Rotor, Catia, Ansys*

INTRODUCTION

When we consider many start and stop cycles, then the Transient thermal analysis is the thermal analysis wherein boundary conditions and properties change with time. This is to say that the constraints such as ambient temperature, thermal coefficient and material properties etc. are time dependent. Transient thermal analysis is important in analyzing models that are subjected to boundary conditions and material properties that vary with time and temperature. Turbine rotors used in steam turbines are subjected to high temperature rise as they are subjected to large temperature variation, the material properties such as Specific heat, Enthalpy and Young's modulus undergo variation with time. In such conditions there is the probability of failure of the turbine rotor if the turbine rotor is not designed taking into consideration the transient effects. There are many finite element analysis, packages available for conducting the transient thermal analysis. We used the packages for modeling CATIA, and for analysis we used ANSYS 11.

From an analysis using these packages, temperature distribution and instantaneous thermal stresses induced under transient conditions can be estimated. These packages allow the designer to vary the temperature with time, vary the convective thermal coefficients with time . A typical turbine rotor has been analyzed for transient thermal using ANSYS 11. One degree section of a model of the turbine rotor, is considered for the analysis. From the analysis the temperature distribution is obtained. Although the analysis is straight forward using these package, the boundary conditions need to be applied judiciously in order to realistically model the

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actual situation. Moreover the choice of number of elements for modeling, time interval for calculation, type of elements and the locations at which boundary conditions are updated are essential for the accurate estimation of transient temperature and stress distribution.

Turbine is a rotary engine that converts the energy of a moving stream of water, steam, or gas into mechanical energy. The basic element in a turbine is a wheel or rotor with addles, propellers, blades, or buckets arranged on its circumference in such a fashion that the moving fluid exerts a tangential force that turns the wheel and imparts energy to it.
This mechanical energy is then transferred through a drive shaft to operate a machine, compressor, electric generator, or propeller.
Turbines are classified as hydraulic, or water, turbines, steam turbines, or gas turbines. Today turbine-powered generators produce most of the world's electrical energy. Windmills that generate electricity are known as wind turbines.

The difficulty in analysis of stress and strain in structural engineering depends on the structure involved. As the structure grows in complexity, so does the analysis. Many of the more commonly used structures in engineering have simplified calculations to approximate stress and strain. However, these calculations often provide solutions only for the maximum stress and strain at certain points in the structure. Furthermore, these calculations are usually only applicable given specific conditions applied to the structure.

A rotor of a modern steam turbine, used in a power plant

Operation Principles

The steam turbine unlike the reciprocating steam engine (which operates due to the pressure energy of system) operates due to dynamic action of the steam.

The acceleration, which may be a change in either magnitude or direction of a stream of fluid, produces a turning moment on a rotating shaft. In a steam turbine, the velocity of steam is increased at the expense of pressure by passing the steam through a set of nozzles and this high velocity steam when allowed to impinge on a series of moving blades fixed to a common shaft, produces the shaft work.

The velocity of steam may be partly increased in the passage between the moving blades themselves.
There are two principles through which turbine operate. They are

- Impulse principle
- Reaction principle.

Impulse principle

For a turbine to be purely impulse there should be no pressure drop in moving blade ring. In principle the impulse steam turbine consists of a casing containing stationary steam nozzles and a rotor with moving or rotating buckets.

The steam passes through the stationary nozzles and is directed at high velocity againstthe rotor buckets causing the rotor to rotate at high speed. If steam at high pressure is allowed to expand through a stationary nozzle, the result will be a drop in the steam pressure and an increase in steam velocity.

In fact, the steam will issue from the nozzle in the form of a high-speed jet. If this high velocity steam is applied to a properly shaped turbine blade, the steam will change in direction due to the shape of the blade.

The effect of this change in direction of the steam flow will be to produce an impulse force on the blade causing

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it to move. If the blade is attached to the rotor of a turbine, then the rotor will revolve.

The force applied to the blade is developed by causing the steam to change direction of flow (Newton's 2nd Law - change of momentum). The change of momentum produces the impulse force.

In an actual impulse turbine there are a number of stationary nozzles and the moving blades are arranged completely around the rotor periphery. Note that the pressure drops and the velocity increases as the steam passes through the nozzles.

Then as the steam passes through the moving blades the velocity drops but the pressure remains the same. The fact that the pressure does not drop across the moving blades is the Distinguishing feature of the impulse turbine. The pressure at the inlet to the moving blades is the same as the pressure at the outlet from the moving blades.

Reaction principle:

If the moving blades of a turbine are shaped in such a way that the steam expands and drops in pressure as it passes through them, then a reaction will be produced which gives a force to the blades.

If there is no escape opening or nozzle for the steam, then the pressure will be the same on all walls of the container and the container will remain at rest. If, however, the container has an escape opening or nozzle, then steam will expand through the opening and drop in pressure.

Therefore there will be an unbalanced pressure on the wall opposite to the opening and a reaction force will be produced causing the container to move due to reaction effect. A reaction turbine has rows of fixed blades alternating with rows of moving blades.

The steam expands first in the stationary or fixed blades where it gains some velocity as it drops in pressure. It then enters the moving blades where its direction of flow is changed thus producing an impulse force on the moving blades.

In addition, however, the steam upon passing through the moving blades, again expands and further drops in pressure giving a reaction force to the blades. This sequence is repeated as the steam passes through additional rows of fixed and moving blades.

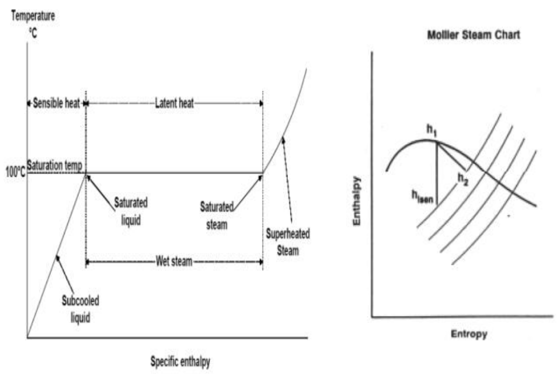
Note that the steam pressure drops across both the fixed and the moving blades while the absolute velocity rises in the fixed blades and drops in the moving blades.

The distinguishing feature of the reaction turbine is the fact that the pressure does drop across the moving blades. In other words there is a pressure difference between the inlet to the moving blades and the outlet from the moving blades.

Special Aspects of Reaction Turbines

There is a difference in pressure across the moving blades. The steam will therefore tend to leak around the periphery of the blades instead of passing through them. Blade clearances therefore must be kept to a minimum.

Also, due to pressure drop across the moving blades, an unbalanced thrust will be developed upon the rotor and some arrangement must be made to balance.



Enthalpy (*H*) kJ/kg Internal energy (*u*) kJ/kg
Entropy *s*) kJ/kg Specific volume *v*) m3/kg
Density (□) kg/m3 Isobaric heat capacity (*cp*) kJ/kg-K

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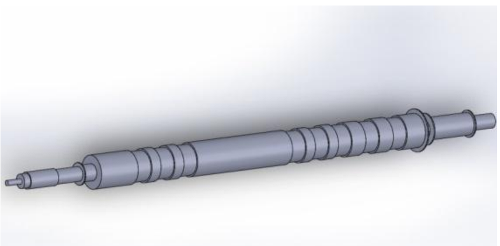
Turbine Designation

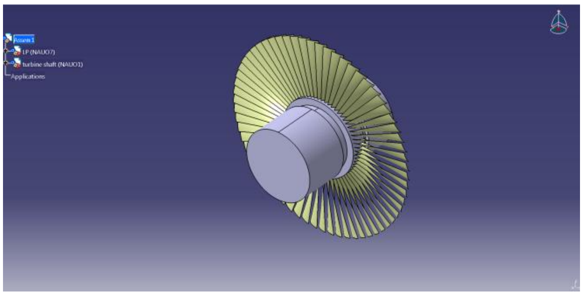
H- Single Flow HP Turbine K - HP/IP Opposite flow
E - HP/LP Opposite flow N - Double flow LP Turbine
M - Double flow IP Turbine

METHODOLOGY

To replace the existing hollow rotor shaft with a solid shaft & find out the advantage/ disadvantage of doing so. We have to perform various calculations on centrifugal loads, torsional loads Thermal loads &core defects for the comparison. When a Steam turbine rotor rotates at 3000 rpm the blades exert a centrifugal pull on the rotor discs. If the discs are integrated to the shaft of rotor then there is a reduction in length of the rotor & expansion in the rotor discs. Now the turbine is a very sophisticated machine in which the clearances between the blades & casing is very low to avoid steam leakage & efficiency loss. In order to properly design such fine clearances the mechanical as well as thermal expansion of the blades & rotor must be calculated accurately. Theoritical calculations can give a value for expansion/contraction, We have to verify this value by FEM analysis in which all the real constraints are defined. The result of the analysis must give the results within acceptable range of theoretical result. Since the rotor is symmetric about its rotational axis we use axisymmetric modelling technique to create the model. After modelling meshing has to be done with proper element shapes &size to get the desired results. The FE model of IP Rotor of Steam turbine is shown in Fig. 1.



The purpose of turbine technology are to extract the maximum quantity of energy from the working fluid to convert it into useful work with maximum efficiency by means of a plant having maximum reliability, minimum cost, minimum supervision and minimum starting time. The gas turbine obtains its power by utilizing the energy of burnt gases and the air which is at high temperature and pressure by expanding through the several rings of fixed and moving blades. To get a high pressure of order 4 to 10 bar of working fluid, which is essential for expansion a compressor, is required. The quantity of ten working fluid and speed required are more so generally a centrifugal or axial compressor is required. The turbine drives the compressor so it is coupled to the turbine shaft. If after compression the working fluid were to be expanded in a turbine, then assuming that there were no losses in either component, the power developed by the turbine can be increased by increasing the volume of working fluid at constant pressure or alternatively increasing the pressure at constant volume. Either of these may be done by adding heat so that the temperature of the working fluid is increased after compression. To get a higher temperature of the working fluid a combustion chamber is required where combustion of air and fuel takes place giving temperature rise to the working fluid.



Steady-State Analysis

The ANSYS/ Multi physics, ANSYS/Mechanical, ANSYS/FLOTRAN, and ANSYS/Thermal products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis, performed after all transient effects have diminished.

You can use steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. Such loads include the following:

- Convections
- Radiation
- Heat flow rates
- Heat fluxes (heat flow per unit area)
- Heat generation rates (heat flow per unit volume)
- Constant temperature boundaries.

The amount of heat transfer is directly proportional to the size of the temperature gradient and the thermal resistance of the material(s) involved

In engineering applications, there are three basic mechanisms:

- Conduction
- Convection
- Radiation

Conduction

For a thermally orthotropic material*, the heat transfer per unit volume per unit time can be stated (in SI units of Joules per cu. meter per second, or simply Watts per cu. meter)
All the terms on the LHS of (1) represent conduction of heat through material (usually solid bodies)
The physical mechanism of this conduction is usually molecular (or electronic) vibration.

For steady-state problems with no heat generation in one-dimension

Convection

Convection is a mechanism of heat transfer that occurs due to the observable (and measurable) motion of fluids As fluid moves, it carries heat with it. In engineering applications, this phenomenon

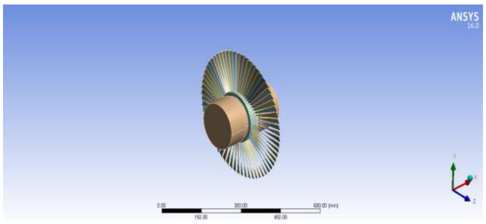
Radiation

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter
Two different bodies at different temperatures separated by some neutral medium (space or air) will exchange heat through this mechanism

ANSYS Workbench is a new-generation solution from ANSYS that provides powerful methods for interacting with the ANSYS solver functionality. This environment provides a unique integration with CAD systems, and your design process, enabling the best CAE results.

RESULTS

MODEL IMPORTED TO ANSYS



Ansys Model fig1.0

MESHING OF IMPORTED MODEL

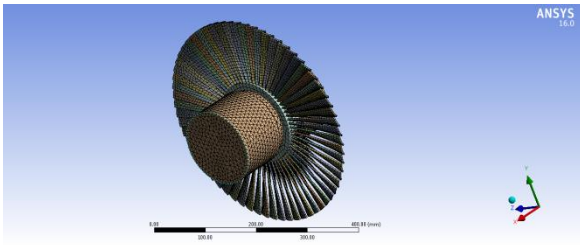
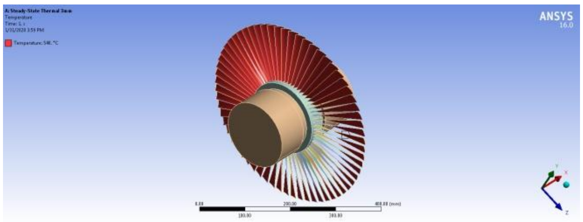


Fig2.0MESH MODEL

BOUNDARY CONDITIONS OF MODEL:



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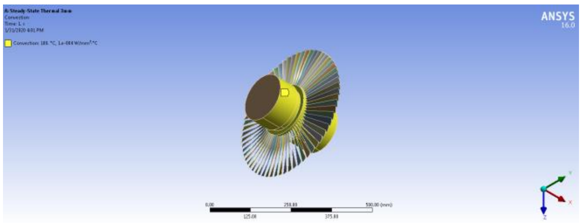
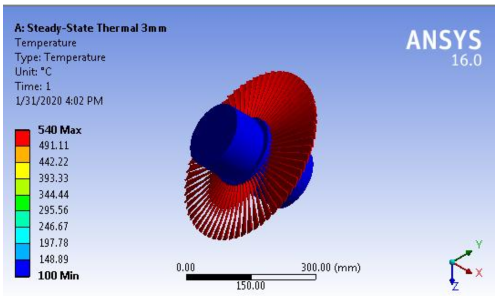
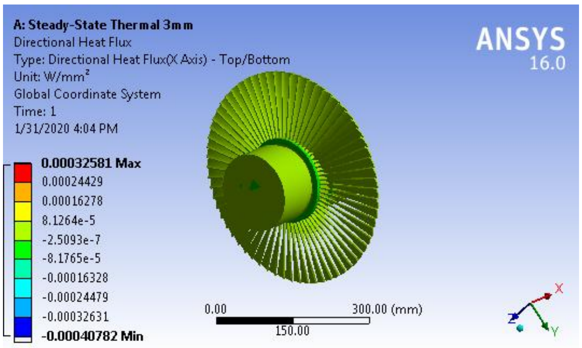
TEMRATURE ON THE BLADE



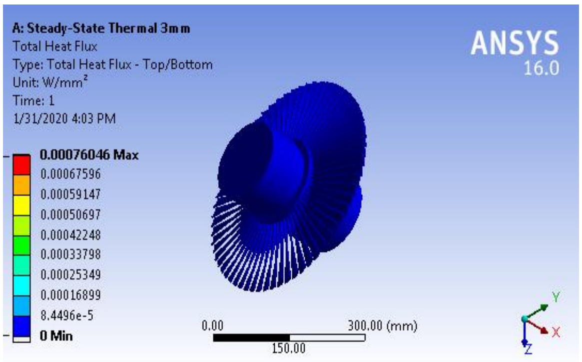
CONVENTION OF THE SHAFT
STEADY STATE THERMAL ANALYSIS
THREMAL PROPERTIE MATERIAL: TITANIUM AT 540°c



Temperature

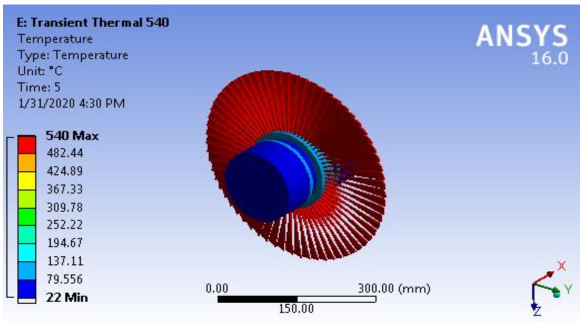


Directional heat flux

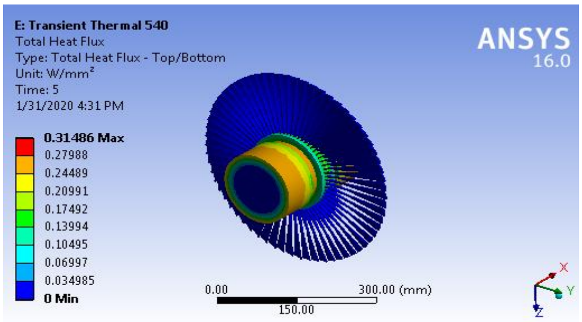


Total heat flux

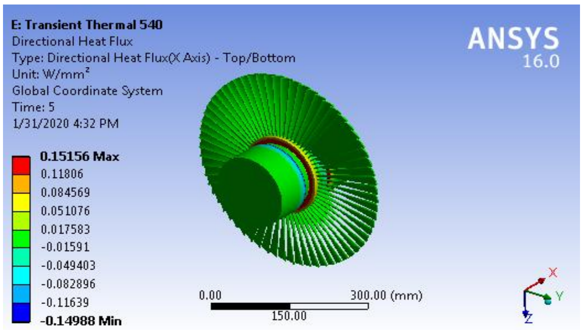
TRANSIENT ANALYSIS
THREMAL PROPERTIE MATERIAL: TITANIUM AT 540°c



TEMPERATURE



TOTAL HEAT FLUX



DIRECTIONAL HEAT FLUX
TITANUM MATERIAL:

TYPE OF ANALASIS	TEMPRETURES AT BLADE	TEMPRETURE VALUES	TOTAL HEAT FLUX	DIRECTIONAL HEAT FLUX
STEADY STATE THERMAL ANALYSIS	540	491.11	0.00076046	0.00032581
	440	402.22	5.52E-12	4.42E-12
	340	313.33	4.90E-12	3.49E-12
TRANSIENT ANALYSIS	540	482.44	0.31486	0.15156
	440	393.56	0.30143	0.14084
	340	304.67	0.43024	0.4004

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MATERIAL: Structural steel

TYPE OF ANALASIS	TEMPRETURES AT BLADE	TEMPRETURE VALUES	TOTAL HEAT FLUX	DIRECTIONAL HEAT FLUX
STEADY STATE THERMAL ANALYSIS	540	518.08	0.40455	0.32992
	440	402.22	5.9506e-11	5.0192e-11
	340	313.33	0.036549	0.011905
TRANSIENT ANALYSIS	540	482.44	0.29291	0.13363
	440	393.56	0.29291	0.13363
	340	304.66	0.29291	0.13364

CONCLUSION

CONCLUSION The transient thermal analysis is carried out. The initial temperature of the rotor is at 1000C. The ambient temperature for the blade rises from 1000C to 5400C in 560 seconds and then remains at 540 0C.

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