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MODELING AND ANALYSIS OF SINGLE STAGE STEAM TURBINE ROTOR

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Abstract: The low pressure impulse steam turbine blade rows have a history of stress failure. They suffer from tensile and bending stresses partly due to the centrifugal force as a result of high rotational speeds and partly due to high pressure, temperature and speed steam loading. The behavior of the steam turbine in its duty can be easily analyzed with the assistance of high-end CAE software packages, followed by part modeling by application of CAD. The designer always aims at reducing the stresses. One way to do so is by the analysis of blade. That is to make the variable of blade cross section stead in of straight. This paper presents the modeling of low pressure single stage impulse steam turbine. Analysis (static) of such turbine is also done as applied to the steam turbine blade

Keywords: Impulse steam turbine, CAD, CAE, Steam turbine blade

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INTRODUCTION

The steam turbine is a prime mover in which the potential energy of the steam is transformed in to kinetic energy and latter in its turn is transform in to mechanical energy of rotation of the turbine shaft. The turbine shaft, directly or with the help of reduction gearing is connected with the driven mechanism. Depending on the type of the driven mechanism a steam turbine may be utilized in most diverse fields of industries, for power generation and for transport. Transformation of the potential energy of steam in to the mechanical energy of rotation of the shaft is brought about by different means.

A steam turbine may be defined as a form of heat engine in which the energy of the steam is transformed into kinetic energy by expansion through nozzles, and the kinetic energy of resulting jet is in turn converted into force doing work on rings of blades mounted on a rotating disc. The majority of steam turbines have, therefore two important elements:

i) The Nozzle (stator), in which the steam expands from a high pressure and a state of comparative rest to a lower pressure and a state of comparatively rapid motion.

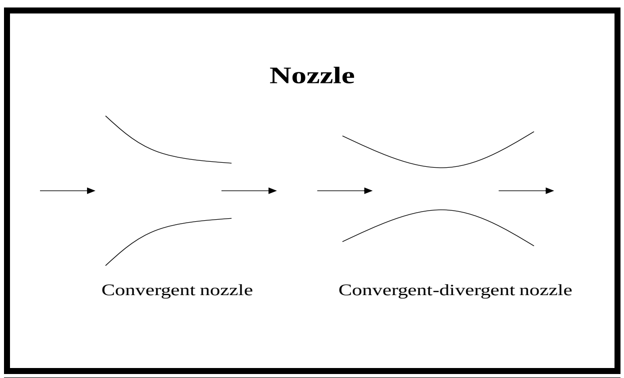


Fig.01 Nozzle

ii) The Blade (rotor), in which the stream of steam particles has its direction and hence its momentum changed. A blade force results the difference between the momentum entering and the momentum exiting the rotor blade row. The blades are attached to the rotating element of the machine or rotor shaft. The resultant of blade forces is then converted into shaft power to drive the load. On another hand, the nozzles are attached to the stationary part of the turbine (casing), as shown in Fig. The rotor blades facing the steam will carry most of the flow loading. Hence to design these blades, the flow has to be studied first, flow forces to be estimated and blade stresses to be evaluated.

Fig. 02 Turbine Rotor

1.1 Simple Impulse Steam Turbine:

The top portion of the fig. exhibits a longitudinal section through the upper half of the turbine , the middle portion shows one set of nozzles which is followed by a ring of moving blades , while lower part of dig. Indicates approximate changes in pressure and velocity during the flow of steam through the turbine. This turbine is called simple impulse turbine since the expansion of steam takes place in one set of the nozzles.

As the steam flows through the nozzle its pressure falls steam chest pressure to condenser pressure. Due to this relatively higher ratio of expansion of steam in the nozzles the steam leaves the nozzle with a very high velocity. It is evident that the velocity of the steam leaving the moving blades is a large portion of the maximum velocity of the steam when leaving the nozzle.

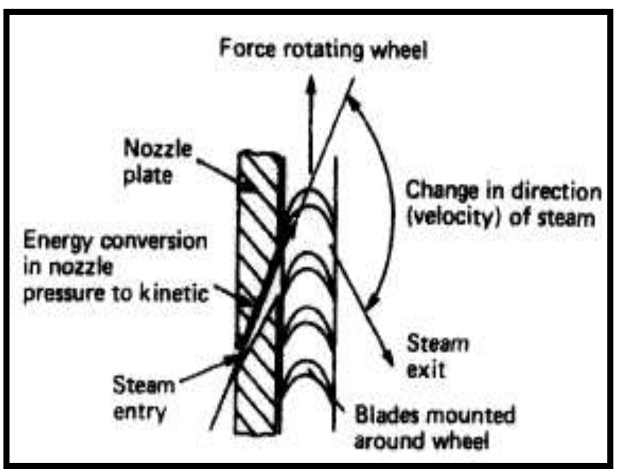


Fig.03 Simple Impulse Turbine

Fig.04 Measurements of Steam Turbine at Sugar Mill.

Fig.05 Measurements of Steam Turbine at Sugar Mill.

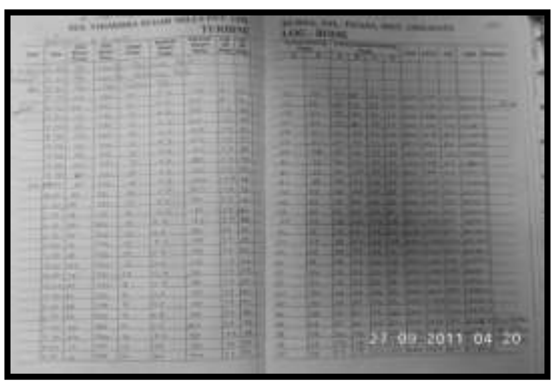


Fig.06 Temp. & Pressure conditions at Vidarbha Sugar Mill, Kurha

Fig.07 Temp. & Pressure conditions at Navalsingh Sahakari Shakar Karkhana Maryadit, Navalnagar

1. Material Properties:

- Table 01 Blade Stainless Steel Material Property for Analysis

Structural	
Young's Modulus	1.93e+005 MPa
Poisson's Ratio	0.31
Density	7.75e-006 kg/mm³
Thermal Expansion	1.7e-005 1/°C
Tensile Yield Strength	207. MPa
Compressive Yield Strength	207. MPa
Tensile Ultimate Strength	586. MPa
Compressive Ultimate Strength	0. MPa
Thermal	
Thermal Conductivity	1.51e-002 W/mm·°C
Specific Heat	480. J/kg·°C
Electromagnetics	
Relative Permeability	10000
Resistivity	7.7e-004 Ohm·mm

2. CAD Modeling:

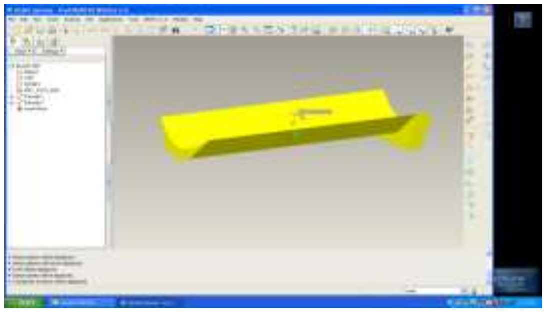


Fig.08 Single Blade

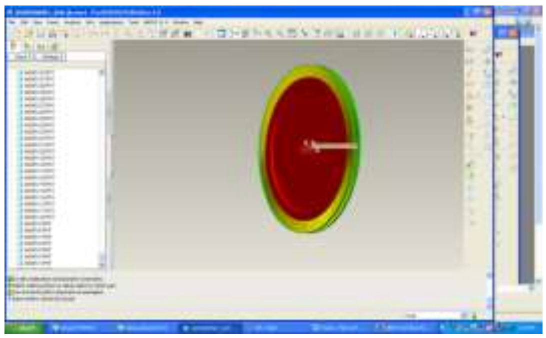


Fig.09 Assembly of Single Stage Steam Turbine Rotor

3. Analysis Result by ANSYS 11.0

4.1Analysis Results of Single Blade:

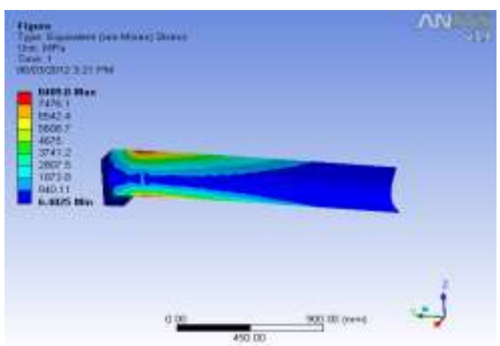


Fig.10 Equivalent (Von-Mises)Stress

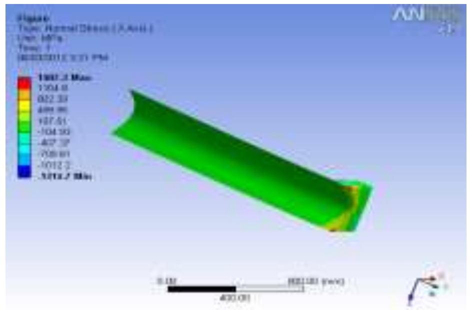


Fig.11 Normal Stress

3.2 Analysis Results of Turbine Rotor:

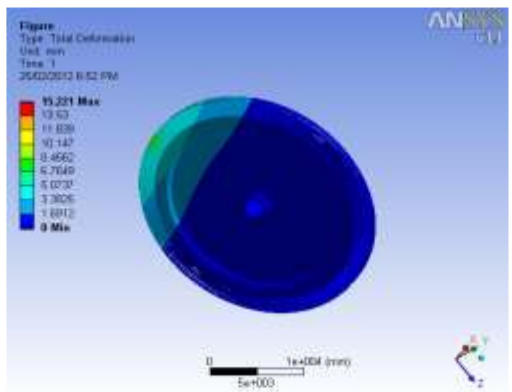


Fig.12 Total Deformation

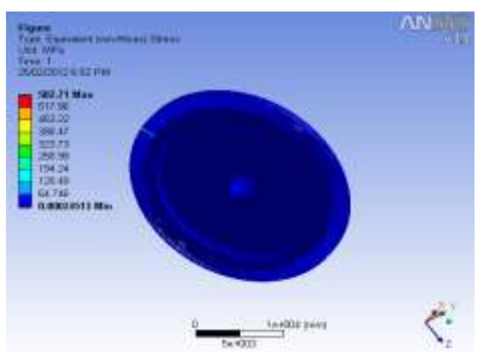


Fig.13 Equivalent (Von-Mises)Stress

4. Mathematical Analysis

5.1 Geometrical Calculations

5.1.1. Calculation of blade c/s area

Dividing the C/s. area of blade into various geometrical shapes as Trapezium, circular arc

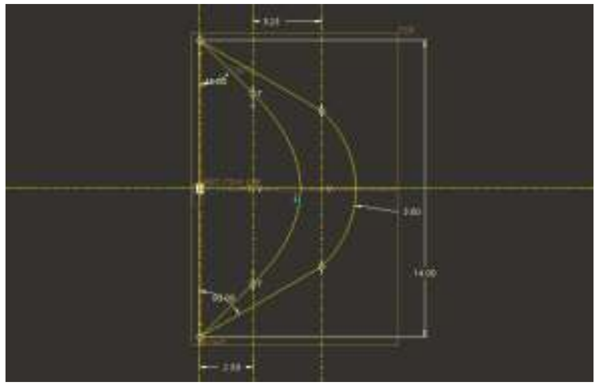


Fig.14 Cross sectional area for single blade

(a) Area of Internal Arc:

$=\frac{2}{3}\times h1\times L=(\frac{2}{3})\times 2.25\times 9=\mathbf{13.5}\,\boldsymbol{mm^2}$

(b) Area of External Circular Arc**:**

$=\frac{2}{3}\times h2\times L=(\frac{2}{3})\times 1.62\times 9=\mathbf{9.72}\,\boldsymbol{mm^2}$

Area of Trapezium:

$=(\frac{a+b}{2})\times h$

$=((\frac{9+7.36}{2})\times 3.25$

$=\mathbf{26.585}\,\boldsymbol{mm^2}$

Area

= A trapz. –A arc =26.585-13.5

$=\mathbf{13.085}\,\boldsymbol{mm^2}$

Required Area 1

= AREA + Area (b)

=13.085 +9.72

=$\mathbf{22.805\ mm^2}$ ....(AREA 1)

Full Trapezium Area

=(($\frac{a+b}{2}$) ×h)

=(($\frac{14+9}{2}$) ×5.75 =**66.125**$\boldsymbol{mm^2}$

Required Area 2

= (Full Trapezium Area)-(Area)

= (Full Trapezium Area)-((A.inttrapz) + (A extr trapz))

= (66.125) – [(28.75) + (26.585)]

=**10.79** $\boldsymbol{mm^2}$ ....(AREA 2)

Now,

Total Area

= AREA 1 + AREA 2

= (22.805) + (10.79)

= **33.595** $\boldsymbol{mm^2}$

Total Horizontal C/S. Area Is 33.595 mm^2

5.1.2. Calculation of Surface Area of Internal Arc

1) Perimeter of arc

= π×(a+b)

=π×(2.25+4.5)

=**21.2057 mm**

2) Internal edge length of blade

=2×L

=2×3.53

=7.06 mm

AREA = (Perimeter of arc) + (Internal edge length of blade)

= (21.2057) + (7.06)

= **28.2657 mm**

5.1.3. Total Surface Area

= AREA×HEIGHT OF BLADE

= (28.2657) × (73)

= **2063.3961** $\boldsymbol{mm^2}$

5.1.4 Nozzel Area

= space in nozzle and blade × height of blade

= 4.85 ×68

=329.8 mm^2

=3.298 × $\boldsymbol{10^{-4} m^2}$

5. Design Calculation

1. Inlet Velocity
2. Specific Volume of Steam
3. Density of Steam
4. Force
5. Working Stress
6. Factor of Safety

6.1 Inlet Velocity (Vi)

GIVEN:

Rotor mean dia. = 0.981 m

N = 6000 rpm

α = 30 degree

Cbl = blade velocity

Cbl $=\frac{\pi DN}{60}$

$=\frac{\pi \times 0.981 \times 6000}{60}$

Cbl=308.1902 m/s

Now, Cbl$=\frac{\cos\alpha}{2}$×V1

Vi=841.8347 m/s

6.2 Specific Volume of Steam

At inlet pressure P= 30 bar

Temperature = 380 degree Celsius

At certain condition, data obtained from steam table is,

∀= sp. Volume

∀=0.09931 m^3/kg

6.3 Density of Steam

ρ=$\frac{1}{\forall}$

ρ =$\frac{1}{0.09931}$=10.0694 kg/m^3

6.4 Force

F=2 ρ a$V1^2$cos∝

=407.660 KN

6.7Normal Stress

Stress=$\frac{force}{areaof\ blade}$

=$\frac{407660}{2063.3961}$

=198.0546 N/mm^2

Normal Stress=198.0546 MPa

6.8 Factor of Safety

Yeild stress = 207 MPa….(given for material)

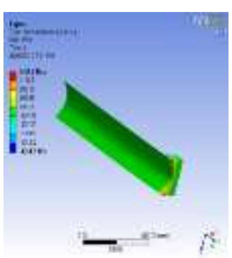
F.S.=$\frac{yeild\ stress}{working/normal\ \ stress}$

=$\frac{207}{198.0546}$

F.S.=1.0480

7. Result comparison

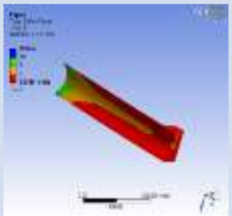
From ANSYS Report:



Mathematically:

Normal Stress=198.0546MPa

From ANSYS Report:



Mathematically:

Factor of Safety=1.0480

Result by Mathematical analysis And Software analysis Are At Approximately Same Value.

8. CONCLUSION:

The results obtained by the modeling and static Analysis of steam turbine rotor shows that stress at points on the steam turbine rotor are within safe limits under operating conditions. Also, it is found that it is safe under given position in model and testing.

The stresses obtained from the analysis are well applicable to the turbine material (blade stainless steel). Higher values of stresses are noted at the point of application; however these values can be neglected.

Also, the mathematical designing has done and the Result in mathematical and software analysis is at approximately to the same value.

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