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Identification of Critical Speeds of Turbine Blade Along with Stress Stiffing and Spin Softening Effects

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Abstract: ***Turbo machinery blades pass through several natural frequencies during start up and shut down operations. That will cause the resonance and cumulative damage to the turbine blades. Hence it is important to identify critical speeds.***

Critical speed is theoretical angular velocity which extends natural frequency of a rotating object, such as shaft, propeller, lead screw or gear. As of the speed of the rotation approaches the objects natural frequency, the object begins to resonate which dramatically increases systematic vibration. The resulting resonance occurs regardless of orientation.

In this project the natural frequencies of turbine blade are identified using FINITE ELEMENT modal analysis at different speeds with spin softening and stress stiffening effects. Then the critical speeds are obtained by plotting Campbell diagram.

I. INTRODUCTION TO TURBO MACHINES

The word turbo implies a spinning action is involved. Turbo machinery, in mechanical engineering, describes machines that transfer energy between a rotor and a fluid, including both turbines and compressors. While a turbine transfers energy from a fluid to a rotor, a compressor transfers energy from a rotor to a fluid. The two types of machines are governed by the same basic relationships including Newton's second Law of Motion and Euler's energy equation for compressible fluids. Centrifugal pumps are also turbo machines that transfer energy from a rotor to a fluid, usually a liquid, while turbines and compressors usually work with a gas. Turbo machines can be classified according to: Direction of energy transfer, either from mechanical to thermal/pressure or vice versa. Type of fluid medium handled, either compressible or incompressible, and Direction of flow through the rotating impeller-it can be in axial, radial, or mixed with respect to the rotational axis.

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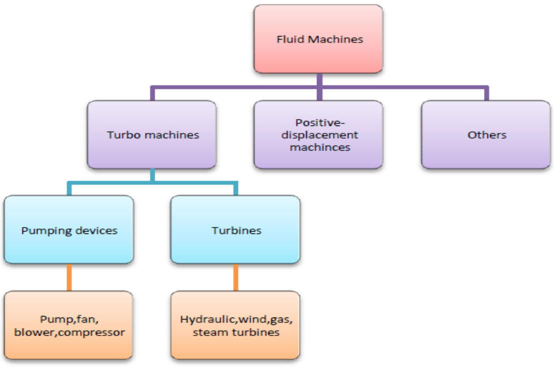


II. TURBINE BLADING

The commonly used materials for turbine blades are 12% chromium steels. Turbine blade alloys are chosen for their ability to provide properties particular to mechanical and environmental service which they must endure.

III. PROBLEM DESCRIPTION TO IDENTIFY CRITICAL SPEEDS:

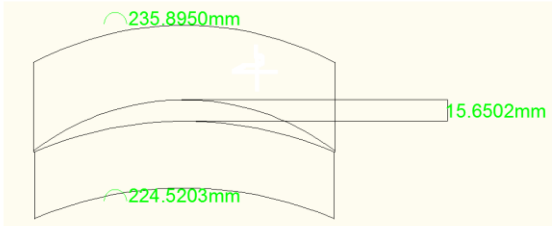
During the working of a turbine, blade will come across many critical speeds. At these critical speeds resonance will occur which will decrease the life of the turbine blade. So now we are finding critical speeds of a last stage double flow low pressure turbine blade by considering stress stiffening spin softening effects.

IV. DIMENSIONS OF LOW PRESSURE TURBINE BLADE:

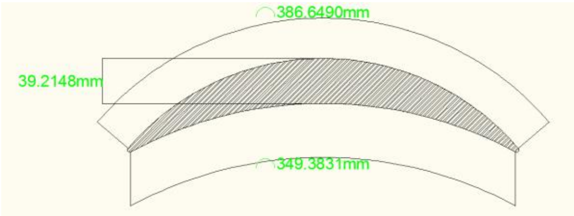
The dimensions are taken from the "NTPC" Ramagundam (2600 MW) .THE below dimensions is the last stage of the "LOW PRESSURE TURBINE BLADE" of 500 MW.

1) Dimensions at the top of the low pressure turbine blade:
Horizontal Length of the blade= 200mm
Vertical length of the blade=7mm

2) Dimensions at the middle of the blade:
Length of the arc at the front =224.5mm
Length of the arc at the rear =235.89mm
Angle =47
Thickness of the arc=294.4mm
Radius of the arc=268.13mm



3) Dimensions at the bottom of the blade:
Length of the arc at the front=349.31mm
Length of the arc at the rear side=386.3mm
Angle=60
Thickness of the arc=39.214mm
Radius of the arc 294.443mm



4) Diameter of shaft: 0.8m to 1m

V. SPECIFICATIONS OF STEAM TURBINE:

MAKE: BHEL.KWU
TYPE: 3-CYLINDER, RE-HEAT CONDENSING REACTION TURBINE
NO OF STAGES: HP Turbine: 18(single flow, double casing)
IP Turbine: 2*14(double flow, double casing)
LP Turbine: 2*6(double flow, triple casing)
Normal rating: 500mw
Throttle pressure: 170 ata
1st stage pressure: 151.79 ata
Ms /HRH TEMP: 537/537°C
Peak loading: 545mw
Rated Speed: 3000RPM
Max/min speed (no Time limitation): 3090/2850 RPM
Speed exclusion range: 400 to 2850 RPM
Moment of inertia of LP CYLINDER: 22981 kg-m^2

VI. VIBRATION (ABSOLUTE VIBRATION):

	Bearing housing	Shaft
Nominal value for alarm		30 microns above normal level
Max value for the alarm	35 microns	120 microns
Tripping(manual)	45 microns	200 microns

VII. DIFFERENTIAL EXPANSIONS:

TURBINE	EXPANSIONRANGE
HP TURBINE	+5MM TO -3MM
IP TURBINE	+8MM TO -2MM
LP TURBINE	+30MM TO -3MM

VIII. MATERIALS USED FOR TURBINE:

	Hp Turbine	Ip Turbine	Lp Turbine
SHAFTS	28Cr Mo Ni 59	30Cr Mo Ni V511	26 Ni Cr Mo V145
Moving Blades	X 20Cr Mo V 121	X 20 Cr Mo	X 20 Cr 13
Fixed Blades	X22Cr Mo V 121/x 20 Cr Mo 13	X 20 Cr 13/x20 Cr Mo 13/20 Mn 5/x	X 20 Cr13/x 20Cr Mo 13/20 Mn 5/x7 Cr Mo 13

Bearing pedestal vibration: HIGH: 35 microns
High-high: 45 microns (Turbine to be tripped)
Shaft vibration: high: 120 mic
High-high: 200 microns (turbine to be tripped).

IX. MATERIAL PROPERTIES:

Mechanical Properties:

Quantity	Value	Unit
Young's modulus	200000-200000	MPa
Tensile strength	650-880	MPa
Elongation	8-25	%
Fatigue	275-275	MPa
Impact strength	90-95	J/cm
Yield strength	350-550	MPa

Physical Properties:

Quantity	Value	Unit
Thermal expansion	10-10	e-6/K
Thermal conductivity	25-25	W/m.K
Specific heat	460-460	J/kg.K
Melting temperature	1450-1510	°C
Density	7700-7700	kg/m3
Resistivity	0.55-0.55	Ohm.mm^2/m

X. PREPROCESSING:

Blade Modeling:
Model of the low pressure last stage steam turbine blade is drawn in ***CATIA*** by using part modeling module. Various commands used are:

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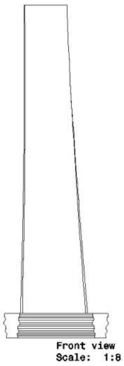
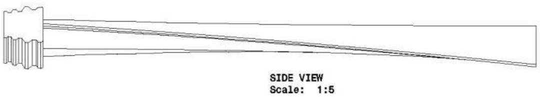
1) Shaft: The base part of the blade is drawn by using shaft command. The profile is drawn in ZX plane in sketcher and revolved. This results in the base part of the blade.
2) Datum plane: Two datum planes are created at positions where different cross sections are to be drawn.
Multi section solid: Various sections were drawn on datum planes by using the command 'ratio method' and then these sections are combined to obtain blade.
3) Face-face fillet: Fillet is given between the blade face and top surface of root.
Views of the blade model:

XI. SOLID MODEL OF CATIA

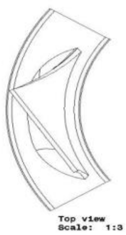
XII. FRONT VIEW OF BLADE



XIII. SIDE VIEW OF BLADE



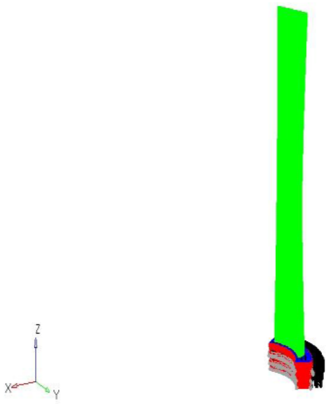
XIV. TOP VIEW OF BLADE



XV. MESHING OF BLADE MODEL IN HYPERMESH

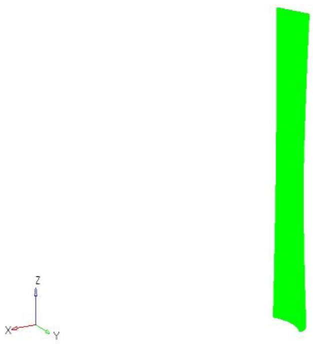
1) Set the user profile for 'ANSYS' as we are meshing it to solve it in 'ANSYS' software, this will load 'ANSYS' features.
2) Import the geometry from the 'CATIA' file whose format is '.cat part'.
3) Clean the geometry which will remove unnecessary points and edges and get model ready for meshing.
4) Create element type **solid185** and update component collector with element type.
5) Create the material collector.
6) Create the property collector.
7) Update the component collector with property and material.
8) Assign the property to the component.
9) Create the solids.
10) Divide the solids into two.
11) Mesh each solid.
12) Create entity sets for slave and master nodes (for contact) and also for constrained nodes.
13) Create the .cdb file.
14) Open the cdb in 'ANSYS' and create contact using and also constrain the nodes.
15) Save .cdb file.
16) Run the input file.
17) This gives us fem file.

XVI. FEM MODEL IN HYPERMESH



1) Change the order of element from first order to second order.
2) Export it for 'ANSYS' from 'HYPERMESH' in the format '.cdb' file. This will write everything into 'ANSYS' understandable format.
3) After all the meshing looks like this:

FINAL FEM MODEL EXPORTED TO ANSYS FROM HYPERMESH



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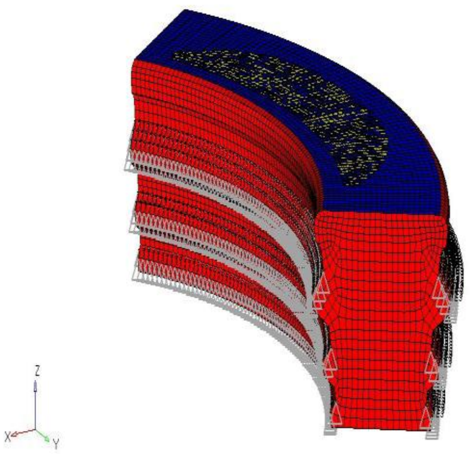


XVII. POST PROCESSING

Modal Analysis:

Modal analysis is used to determine the natural frequencies and mode shapes of a structure. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions.

You can do modal analysis on a pre-stressed structure, such as a spinning turbine blade. Another useful feature is modal cyclic symmetry, which allows you to review the mode shapes of a cyclically symmetric structure by modeling just a sector of it.

Process Involved in a Modal Analysis:

The procedure for a modal analysis consists of four main steps:

1. Build the model.
2. Apply loads and obtain the solution.
3. Expand the modes.
4. Review the results.

XVIII. SOLVING IN ANSYS

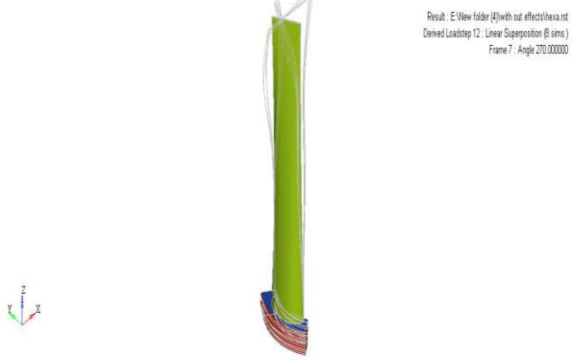
1. Start ANSYS and click on open and select '.CDB' file and click open and enter 'EPLOT' command in command box which will import fem file.

ANSYS '.CDB' IMPORTED FEM MODAL

Now go to solution and select analysis type as 'MODAL' and set analysis options as required.

1. Now go to apply loads and fix the root faces.
2. Add stress stiffening effect by giving the command **'sstif,on'**.
3. Apply spin softening effectby giving the command **'omega, angular velocity along X, Y, Z, kspin'**.
4. Now solve the current LOAD STEP.
5. Repeat the above steps for different inertia loads in increasing order from 0 to 3500 with load difference of 500 RPM.

XIX. MODE SHAPES:



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Modal analysis without any effects:

LOAD STEP	ANGULAR VELOCITY	FREQ 1	FREQ 2	FREQ 3	FREQ 4	FREQ 5
1	0	43.82	128.79	203.81	281.81	290.2
2	500	43.82	128.79	203.81	281.81	290.2
3	1000	43.82	128.79	203.81	281.81	290.2
4	1500	43.82	128.79	203.81	281.81	290.2
5	2000	43.82	128.79	203.81	281.81	290.2
6	2500	43.82	128.79	203.81	281.81	290.2
7	3000	43.82	128.79	203.81	281.81	290.2
8	3500	43.82	128.79	203.81	281.81	290.2

Modal analysis with spin softening:

LOAD STEP	ANGULAR VELOCITY	FREQ 1	FREQ 2	FREQ 3	FREQ 4	FREQ 5
1	0	43.82	128.79	203.81	281.81	290.2
2	500	41.308	122.61	191.06	279.97	288.79
3	1000	88.835	158.96	274.14	284.54	499.85
4	1500	57.709	132.53	264.14	277.59	493.26
5	2000	51.636	104.71	249.39	268.03	482.77
6	2500	13.551	59.724	228.85	256.14	466.48
7	3000	51.232	200.60	242.58	440.75	485.11

Modal analysis using stress stiffening & spin softening effects:

LOAD STEP	ANGULAR VELOCITY	FREQ 1	FREQ 2	FREQ 3	FREQ 4	FREQ 5
1	0	43.82	128.84	204.01	282.83	291.16
2	500	41.33	122.77	191.48	281.00	289.95
3	1000	89.06	159.32	275.13	285.70	505.78
4	1500	57.81	132.79	265.02	278.68	499.05
5	2000	51.72	104.96	250.11	269.02	488.40
6	2500	15.18	59.877	229.42	257.05	471.90
7	3000	51.28	201.01	243.40	445.81	489.98
8	3500	48.44	160.64	228.64	404.91	478.94

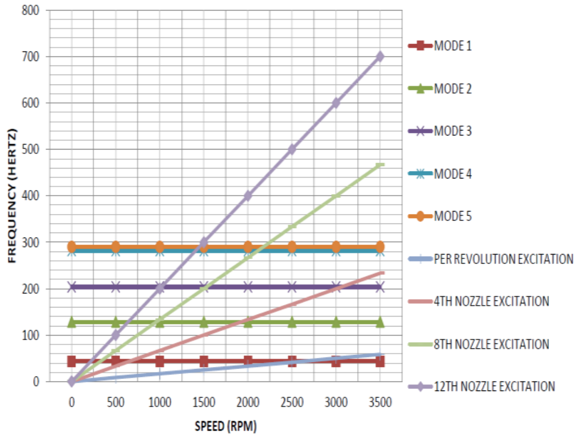
XX. CAMPBELL DIAGRAM:

A **Campbell diagram** plot represents a system's response spectrum as a function of its oscillation regime. It is named for Wilfred Campbell, who has introduced the concept,

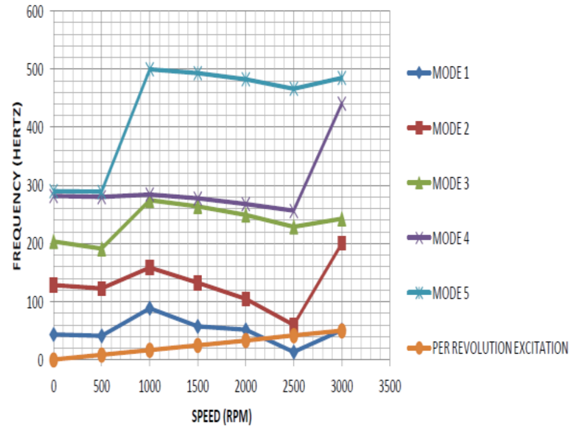
A mathematically constructed diagram used to check for coincidence of vibration sources with natural resonances. The form of the diagram is like a spectral map, but the amplitude is represented by a circular or rectangular plot, the larger the amplitude the larger the circle or rectangle.

Because the critical speeds are determined graphically, their accuracy depends upon the quality of the Campbell diagram.

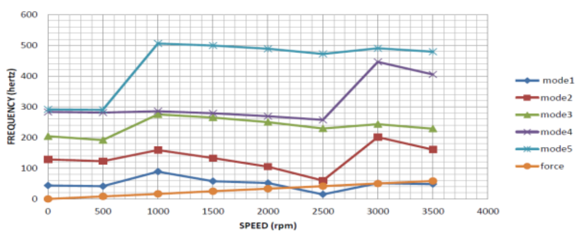
XXI. CAMPBELL DIAGRAM WITHOUT ANY EFFECTS



XXII. CAMPBELL DIAGRAM WITH SPIN SOFTENING EFFECTS



XXIII. CAMPBELL DIAGRAM WITH STRESS STIFFENING & SPIN SOFTENING EFFECTS:



XXIV. CRITICAL SPEEDS RESULTS:

WITHOUT EFFECTS:

S.NO	EXCITATION FORCE	MODE NUMBER	CRITICAL SPEED
1	Per revolution excitation	1	2000
2	9^{TH} Nozzle excitation	5	1730
3	10^{TH} Nozzle excitation	5	1590

WITH SPIN SOFTENING EFFECTS:

S.NO	EXCITATION FORCE	MODE NUMBER	CRITICAL SPEED
1	Per revolution excitation	1	2200
2	Per revolution excitation	1	3000
3	9^{TH} Nozzle excitation	5	2880
4	10^{TH} Nozzle excitation	5	2550

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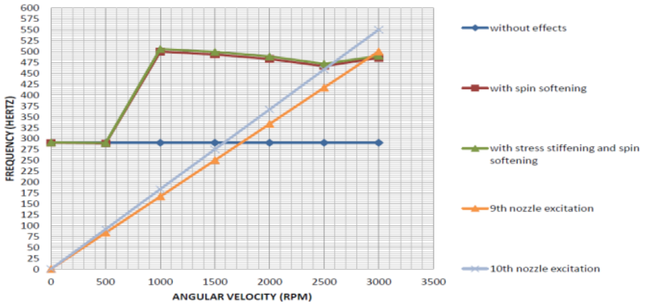
XXV. WITH STRESS STIFFENING & SPIN SOFTENING EFFECTS:

S.NO	EXCITATION FORCE	MODE NUMBER	CRITICAL SPEED
1	Per revolution excitation	1	2200
2	Per revolution excitation	1	3000
3	9^{TH} Nozzle excitation	5	2910
4	10^{TH} Nozzle excitation	5	2600

XXVI. CONCLUSION:

We have known the different critical speeds of the turbine blade in our project and the critical speeds of the blade without considering any other effects is at 1730 RPM for the 9th nozzle excitation and by considering only spin softening effect the critical speed changes to 2880 RPM at the same excitation whereas this critical speed changes to 2910 RPM by considering stress stiffening and spin softening effects. The operating speeds are minimum of 2850 RPM and maximum of 3090 RPM so at the 9th nozzle excitation we must reduce the amplitude by various methods so that damage may not occur. Hence we need to consider stress stiffening and spin softening effects.

Varying natural frequency with respect to angular velocity due to the stress stiffening and spin softening effects:



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