Static and Modal Analysis of Base Frame for Steam Turbine

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Abstract

The main objective of the project is to determine the deflections, stiffness and natural frequencies of base frame due to static loads of turbine assembly, gear box and due to self weight of the base frame. Base frame is a rigid structure comprises of I beams and plates, where the bearing pedestal assembly is fixed at left most side of the base frame through four anchoring bolts and the rear bearing pedestal assembly is fixed at rear end by bolts, and gear box is fixed at right side of the base frame. The forces coming on the base frame are due to the weights of turbine sub assemblies, gearbox etc. The base frame is modeled using CAD software Pro-E. Base frame is then analyzed for its rigidity doing static analysis by using FEA tools Hyper mesh & Ansys. Modal analysis is performed to evaluate its natural frequencies. Campbell diagram is also drawn for checking resonance.

Keywords: *Base frame, Steam Turbine, Deflections, Modal analysis, Boundary conditions, Campbell diagram, stiffness etc.*

1.0 Introduction:

Turbo machines form the heart of any power plant. Thus for any developed or developing nation, capacity of supplying unhindered energy not only ensures a steady industrial growth, but also goes into improve the quality of life in long way. The main source of this energy is obviously electricity and this is what the turbo machines generate. The steam turbine is one of the most important and complicated system in design, manufacturing and testing. The steam turbine assembly and its auxiliaries have a huge weight usually ranging from 8000 kg to several tones. Steam turbines are widely used in various industries like steel, sugar, cement, paper, textile, chemical, bio-mass based application. The American Petroleum Institute (API) establishes standards for steam turbine manufacturers and provides guidelines for the maximum allowable deflection, stiffness, frequencies and stress levels for various components. However, for industrial applications compliance API 612 is mandatory. Most of the high speed industrial turbines are mounted on base frames. Which is rigid fabricated structure is generally made up of I beams and standard plates, I beams are mainly used at major load acting locations where as plates are mounted for supporting the structure. Steam turbines are mounted on the base frame to carry its weight, to maintain its alignment and to assist in carrying the dynamic loads which every turbine generates. Steam turbine base frame needs an effective design technology to ensure that the base frame as designed performs the required functions, and maintains its integrity. There is also a need to maximize the life of the turbine base frame under the loads to which it is exposed.

2.0 The scope of work:

Find out the structure deflection, stiffness and natural frequencies. Campbell diagram is also drawn for checking resonance.

Approach: i. Modeling and assembly of base frame, which comprises I beams and plates is done using Pro – E Tool.

ii. Modeled structure is imported to hyper mesh, where meshing is performed. All loads are applied here.

iii. Meshed model is imported to ANSYS for solving and post processing.

3.0 Material Properties:

Material used for base frame construction is **Carbon Steel IS 2062**. The material properties are listed.

Table 1. Material Properties

S. No	Material Properties	Units	
1	Density	kg/mm^3	$7.850x10^{-6}$
2	Poisons ratio		0.3
3	Ultimate tensile strength	N/mm^2	410
4	Yield strength	N/mm^2	230
5	Young‘s modulus	N/mm^2	$2.1x10^{11}$

4.0 Modeling:

Base frame comprises of different types of parts known as I-beams and plates which are in standard sizes. Modeling of base frame is done by using Pro-E tool. Assembly of base frame is done using Bottom-Up approach.

Bottom-Up Design: In this approach, components are modeled individually and then started to construct assemblies.

Modeling & assembly is done by using the following features.

Extrude: is used to add or removal of material normal to a section or along a reference plane.

Pattern: Pattern is used to replicate a feature or group of features multiple times in a repetitive manner.

Hole: This feature is used to make holes on the component at different alignment locations

Align: An Align takes two surfaces and points their normals in the same direction and lines up both surfaces.

Mate: A mate takes two surfaces and points their normals towards each other and lines up both surfaces.

4.1 Different parts of base frame:

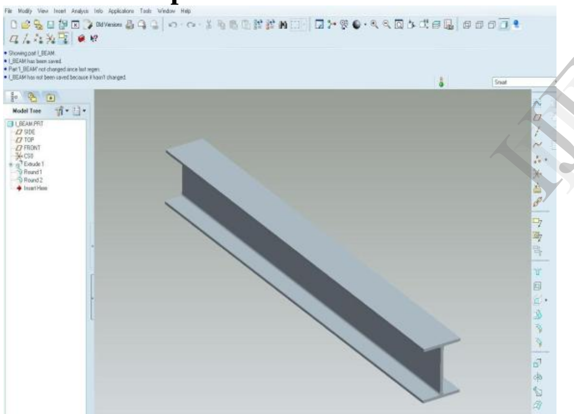

Figure 1. I Beam

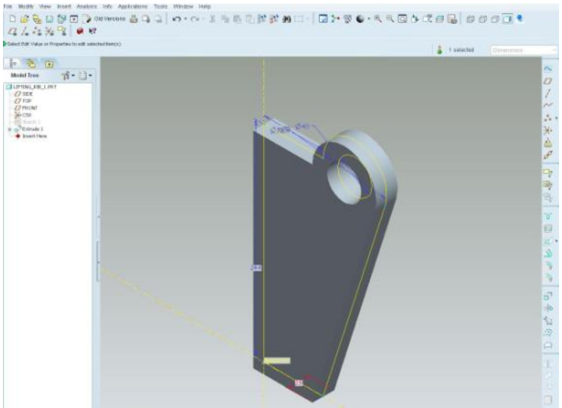

Figure 2. Lifting rib

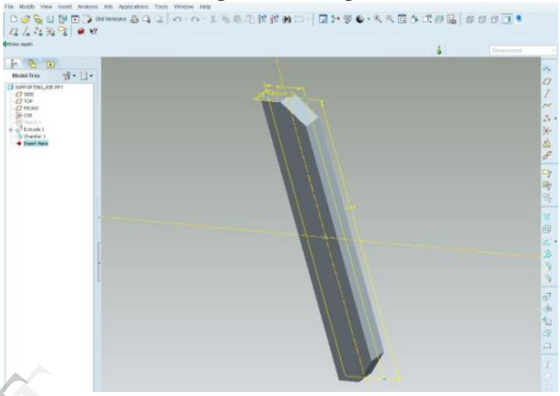

Figure 3. Supporting rib

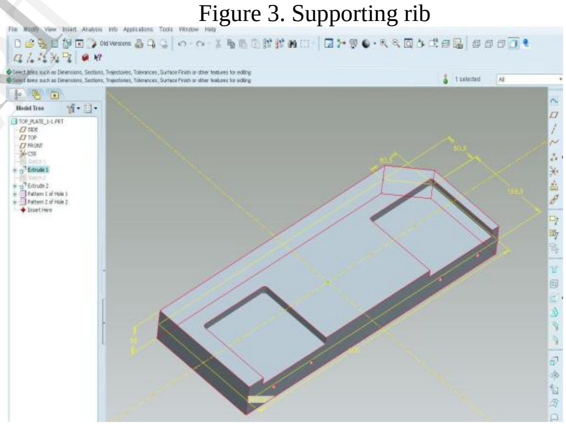

Figure 4. Resting plate

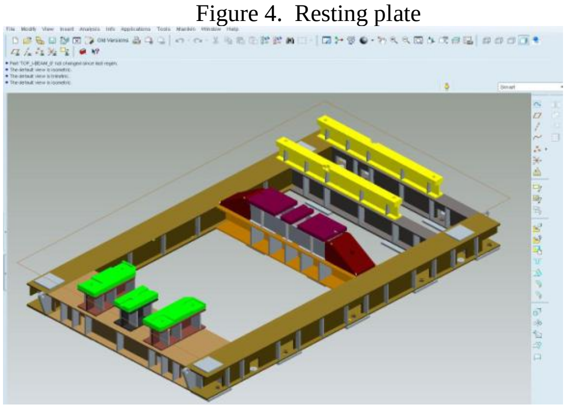

Figure 5. 3D model of base frame

5.0 Meshing:

Using hyper mesh, the base frame meshed into hexa and penta elements. The quality of the elements was maintained with all required quality parameters throughout the structure.

Element Type	:	SOLID 45
Warpage	:	6-12
Aspect Ratio	:	5-8
Skew	:	60-70 Deg.
Min. Length	:	65% of Element Size
Jacobian	:	0.5-1.0

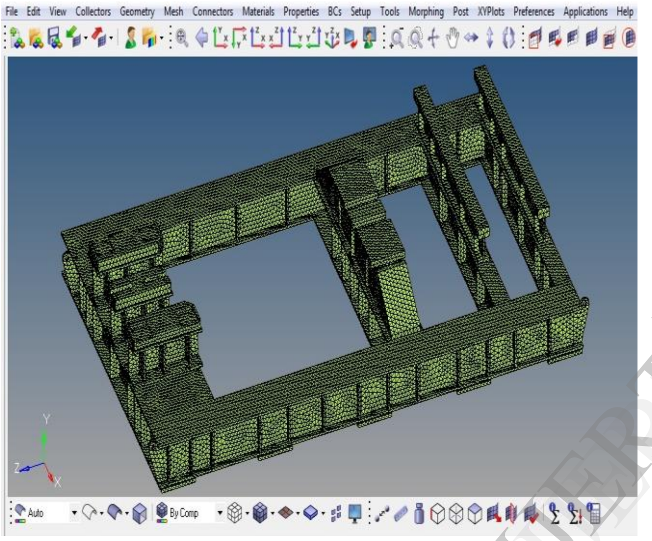

Figure 6. Meshed model of base frame

5.1 Loads & Boundary conditions:

The base frame is constrained in all degrees of freedoms at all foundation bolt locations. The component weights are distributed uniformly at respective interface locations using MASS 21 element.

Table 2. Load details

Description	Units	Weight
Weight on front side	kg	3877
Weight on rear side	kg	2634
Weight of gearbox	kg	3775
Total weight acting on base frame	kg	10286

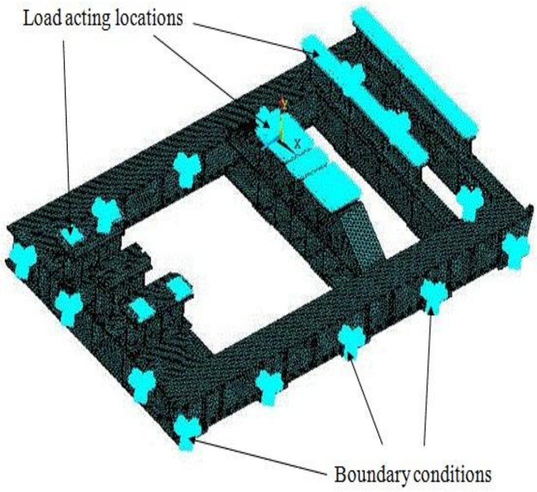

Figure 7. Loads & Boundary Conditions

6.0 Analysis:

Base frame is analyzed for the deflection, stiffness and natural frequencies due to static loads of the turbine assembly, gearbox and due to self-weight of the base Frame.

6.1 Case I: Static analysis: Static analysis is performed to determine the deflection, stiffness and stresses due to component weights and self weight of the base frame. The obtained values are within acceptable limits of the material used. So the results are tabulated below.

6.1.1 Results & Plots:

Table 3. Stress and deflection values

S.No	Type	Value
1	Maximum Deflection (USUM)	53.7 microns
2	Vonmises Stress (max)	21.8 Mpa
3	Stress in X direction	23.2 Mpa
4	Stress in Y direction	11.1 Mpa
5	Stress in Z direction	21 Mpa
6	1st Principal Stress	28.5 Mpa
7	2nd Principal Stress	12.8 Mpa
8	3rd Principal Stress	82.7 Mpa
9	Shear Stress in XY plane	11.7 Mpa
10	Shear Stress in YZ plane	75.1 Mpa
11	Shear Stress in XZ plane	73.4 Mpa

Among all the stress some of the plots were shown below.

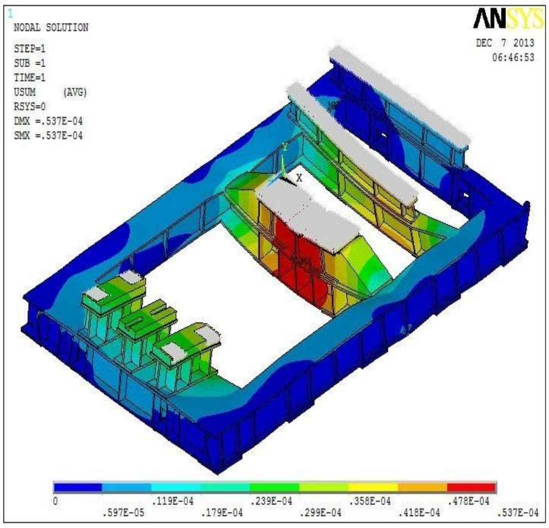

Figure 8. USUM plot (maximum deflection)

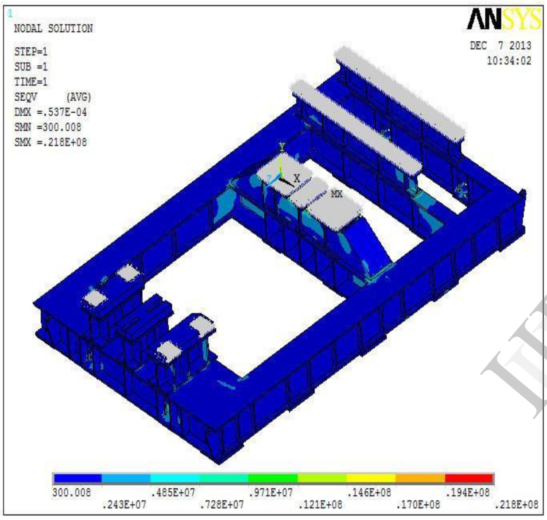

Figure 9. Vonmises Stress plot (maximum stress)

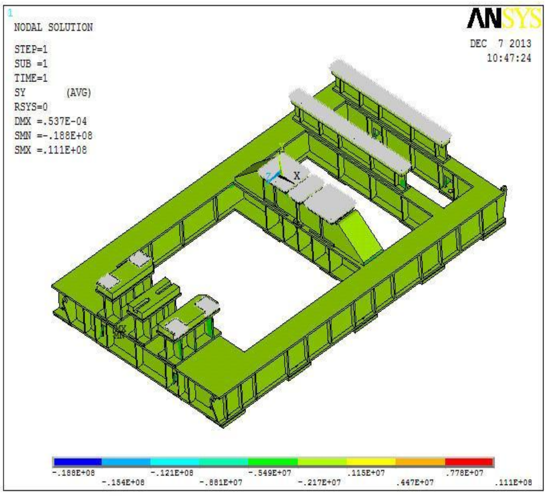

Figure 10. Stress plot (Y- component)

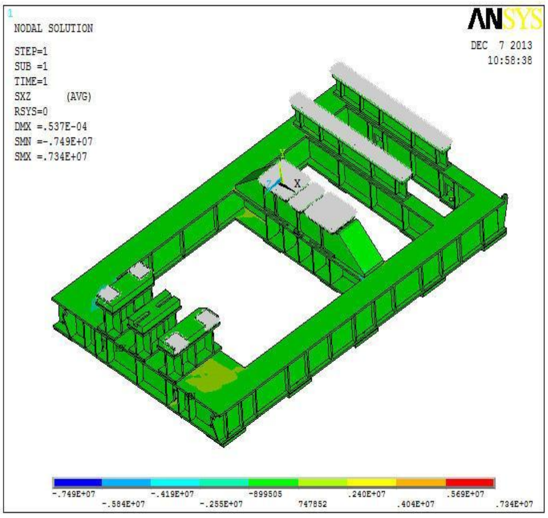

Figure 11. Shear Stress in XZ plane

Figure 12. Shear Stress in YZ plane

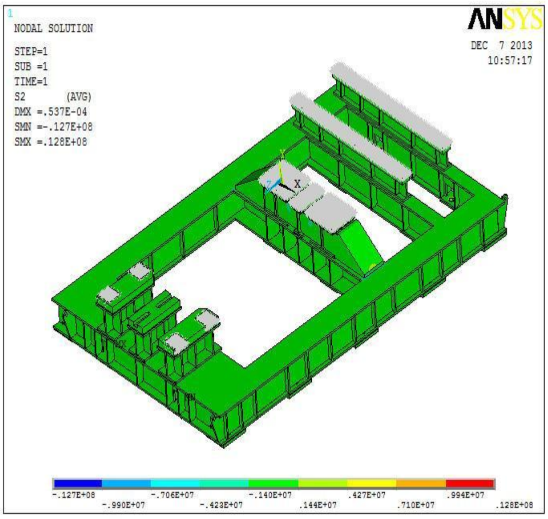

Figure 13. 2nd Principal Stress

6.2 Case II: Modal analysis: Modal analysis is performed to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. When natural frequency of the structure matches with the operating frequency of the system then resonance will occur. Hence the structure needs to be analyzed to ensure the natural frequencies are away (with 15% safety margin) from the operating frequency.
The obtained frequencies are tabulated and mode shapes are also plotted.

6.2.1 Results & Plots:

Table 4. Mode number and frequency values

Mode No.	Frequency (Hz)	Mode No.	Frequency (Hz)
1	20.293	13	78.433
2	24.593	14	78.656
3	33.485	15	81.566
4	47.278	16	88.447
5	51.305	17	134.65
6	51.95	18	135.82
7	67.831	19	137.32
8	70.339	20	139.24
9	71.708	21	140.47
10	72.581	22	150.76
11	74.054	23	154.3
12	77.156	24	171.88

Among all the frequencies some of the frequency plots were shown below.

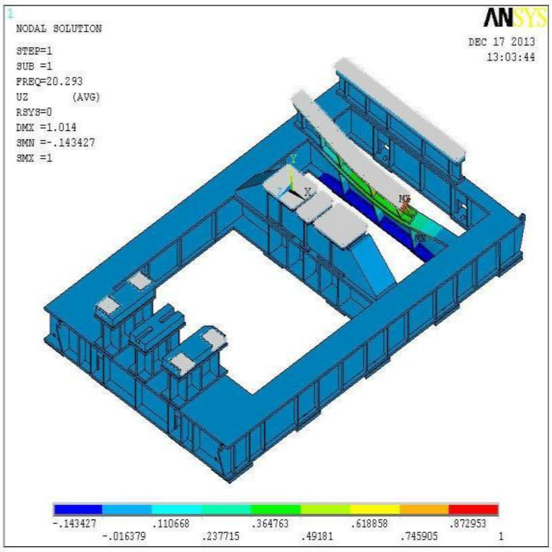

Figure 14. 1st mode of Modal Analysis

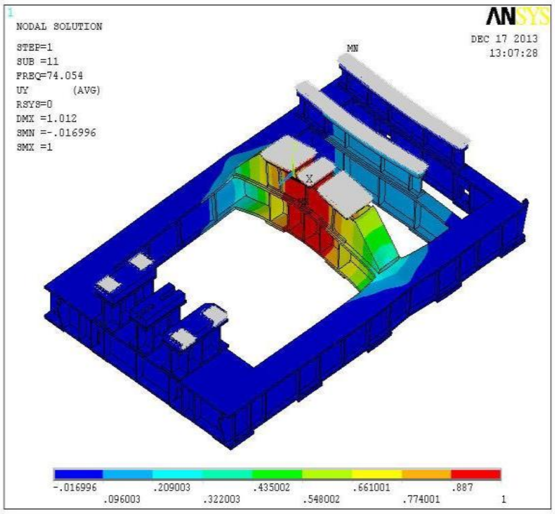

Figure 15. 11th mode of Modal Analysis

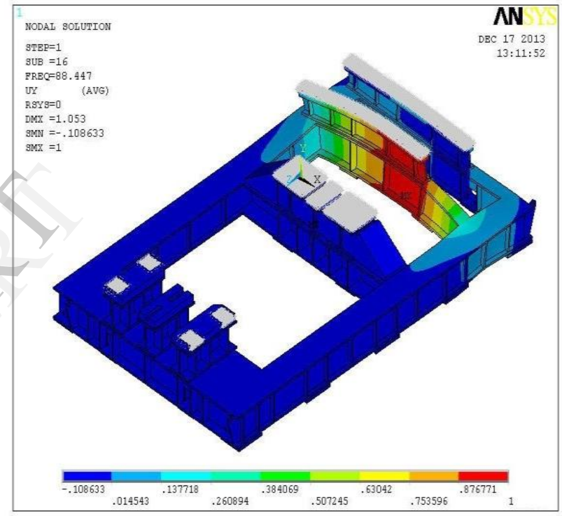

Figure 16. 16th mode of Modal Analysis

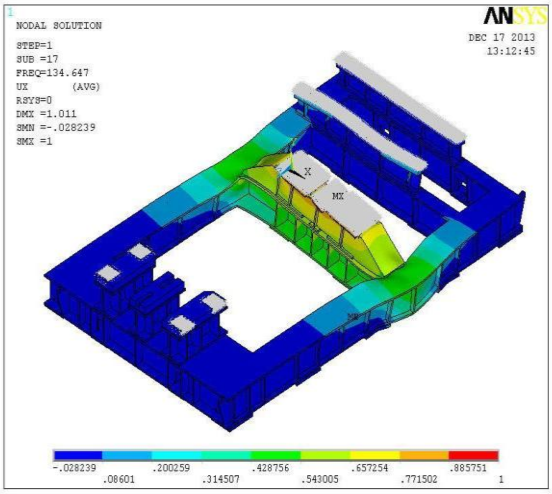

Figure 17. 17th mode of Modal Analysis

6.3 Campbell diagram:

Campbell diagram is drawn for checking resonance. So the base frame is analyzed for resonance criteria for the obtained natural frequencies to the operating speed. In the present case 16th and 17th mode of natural frequencies are considered for plotting Campbell diagram.

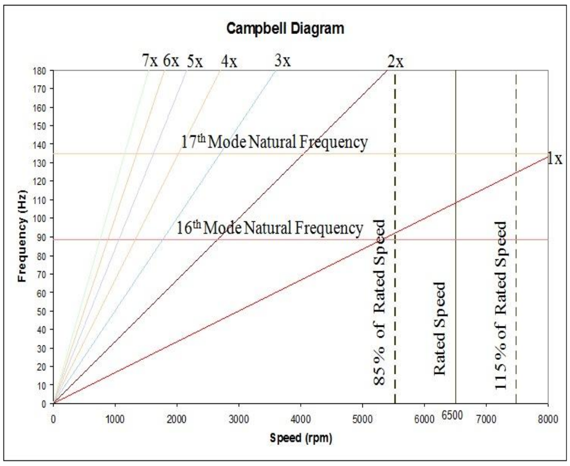

Figure 18. Campbell diagram

7.0 Conclusions:

1. The maximum deflection at steady state condition is 53.7 microns.
2. Stiffness value obtained is 0.019×10^6 N/mm, for the maximum deflection. As per API standard the value of stiffness should not exceed 0.875×10^6 N/mm. Hence the structure is safe from stiffness point.
3. The natural frequency at mode 16 is 88.447 Hz. Which is 18% away from the operating frequency on lower side, and the natural frequency at mode 17 is 134.65 Hz, which is 24% away from the operating frequency on higher side. As per API, these Natural Frequencies are ± 15% away from the rated operating frequency. (108.3 Hz)
4. The Vonmises stresses, principal stresses at peak frequencies are within acceptable limits of the material.
5. Hence, the base frame is safe from the deflection point of view and from the resonance conditions.

8.0 References:

1. API standard 612, 5th edition April 2003, " Petroleum, Petrochemical and Natural Gas Industries – Steam Turbines-Special–purpose Applications", American Petroleum Institute, Washington D.C
2. Design and Standardization of Base Frame & Ant Vibration Mounts for Balanced Opposed Piston Air Compressor. Kishor D. Jadhav & Maneet.R.Dhanvijay. ISSN: 2231 –5950, Vol-2, Iss-2, 2012
3. Finite Element Dynamic Study on Large Framed Foundation of Steam Turbine Generator, by Ahmed Mounir Ibrahim Abou Elsaoud., Department of Construction and Architectural Engineering, The American University in Cairo.
4. Experimental and Finite Element Analysis of Base Frame for Rigidity. Amit V. Chavan, S.S Gawade, PG Student, Associate Professor, Mechanical Engineering Department, R.I.T, Sakharale.
5. T.R.Chandrupatla and A.D. Belegundu, 2004, "Introduction to Finite Elements in Engineering," Prentice Hall of India, 3rd edition.
6. J.N. Reddy, "An Introduction to the Finite Element Method", Tata Mcgraw Hill, 2nd edition-2003.