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Dynamic Analysis of Turbo Generator Frame Foundation

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Abstract:
Machine with greater speed such as Turbo-Generators are mounted on a frame type foundation by using steam as source the electricity is generated. Supporting the equipment, the foundation should have sufficient bearing capacity. The frame foundation consists of a heavy foundation slab at the bottom which is supported by soil and series of columns connected to the longitudinal beams and transverse beam forming a deck slab on which the equipment is placed. Turbo generator foundation is modeled and analysis is done by using ANSYS 15.0, APDL application. Analysis of the foundation which is expose to the vibrations are very sensitive. Analysis is done by two methods free vibration analysis and forced vibration analysis. Free vibration analysis is done to know the natural frequency and mode shape whereas forced vibration analysis is done to know the amplitude of the structure and the amplitude limit should be within 30 microns for the operating speed 3000 rpm as per IS 2974- part-3.

Keywords: Turbo-Generator, Natural Frequency, Mode shape, Amplitude, Mass participation, Damping, Mode Superposition.

1. INTRODUCTION

Growth of electricity in the whole world is developing gradually with environment necessities .industrial provision like fertilizer plant, steel plant and chemical plants are made up of number of various types of machines which plays a main role in the operation .in the situation of the rotating machineries for example Turbo-Generator very carefully construction and analysis is done because if any small vibrations generated during rotation, operating torque, or due to dynamic loads when the machine is operating. It may develop the cracks in the structure which will be a very big disadvantage and it may reduce the operation capacity. In the early stages of development, turbo generators were mounted on the “wall type foundations” which consist of two pair of wall in which the equipment was mounted. Increase in size and output of the machine the foundation has to be devised for the functional reasons. For supporting the high-speed machinery framed foundation are now popular, the advantages of the framed foundation, saving in materials, saving in space, easy accessibility to all the machine parts for inspection for maintenance and installation and less liability to cracking due to settlement and temperature changes. For the construction of these type of foundation the material used are reinforced concrete and steel. In India Reinforced concrete is used for the turbine and generator foundation. The analysis and design of the foundation which is exposed to vibration loads are very sensitive to deal with because the loads coming on the deck on which the machine is mounted should be transferred to the foundation and then to the soil for which the geometrical engineering, structural engineering and vibration theory plays a most important role. In various countries they use main source has turbo Generator for the electricity generation. Selection of foundation mainly dependent on the type of machine capacity of the machine and its geometry. For the safe and continuous operation quality of machine should be good, the machine should operate smoothly without any problem and the foundation which is used to support the equipment should be capable of withstanding the loads which is transferred from the equipment to the foundation. Analysis is done by using the software ANSYS 15.0, APDL application.

2 METHODOLOGY

2.1 SYSTEM DESCRIPTION

The Turbine and Generator foundation is of reinforced concrete construction and consists of Top deck, Columns and the Foundation mat. Turbine and generator are supported by the top deck slab at bearing locations. The columns of the TG pedestal, columns of internal platform and condenser pedestals rest on the mat. In figure 2.1 shows the general arrangement of the equipment and the bearing locations at the top of the deck. Equipment layout is represented in the figure 2.2.

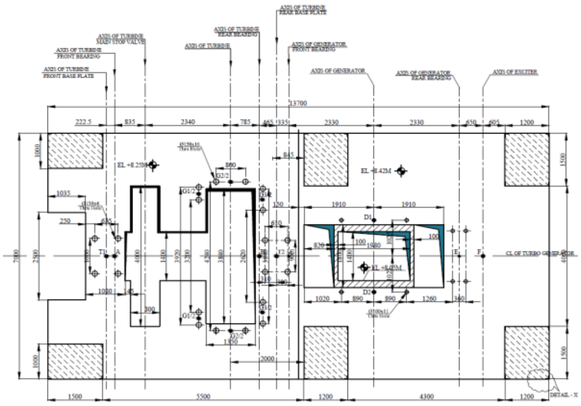

Figure.2.1. deck plan view

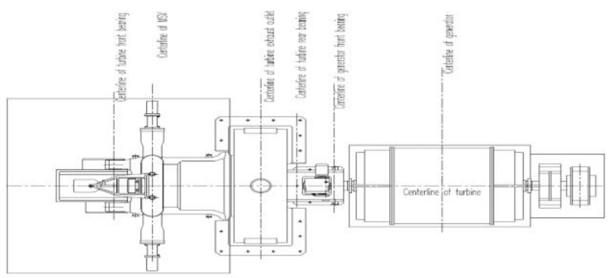

Figure.2.2. Equipment layout plan view

2.2 PARAMETERS ADOPTED IN THE ANALYSIS:

- Grade of concrete for TG deck and main columns is M25
- Grade of concrete for columns is M25
- Modulus elasticity of reinforced concrete 31250 N/mm^2 for deck and columns (For dynamic analysis – as per IS:2974 (Part-3))
- Poisson's ratio is 0.15
- Weight density of concrete 25 kN/m^3
- Mass density of concrete $2.55x10^{-9}$ $N\text{-}sec^2/mm^4$
- Machine speed is 3000 rpm

2.3 MODELLING:

2.3.1 GENERAL:

A 3-D finite element (FE) model of the structure consisting of TG deck and the supporting columns is developed using ANSYS Finite Element package (Version 15.0). as the base mat is rigid, columns are considered fixed at their bottom ends, i.e., at the top of the mat at EL (-) 1.900m. the geometry of the TG foundation considered is based on drawings.. The model has 119041 nodes and 101630 elements. The masses are given in the Table 2.2 & 2.3 are lumped in all three directions at their CGs using MASS21 elements. Rigid links using LINK180 elements are have been used to connect these lumped machine masses to the deck.

2.3.2 GEOMETRY:

The foundation is modelled has a three-dimensional space frame consisting of column, longitudinal beam and transverse beam shown in the figure 2.5 and the same solid model is done by finite method by doing meshing for the solid model by using solid 185 elements which is represented in the figure 2.6.

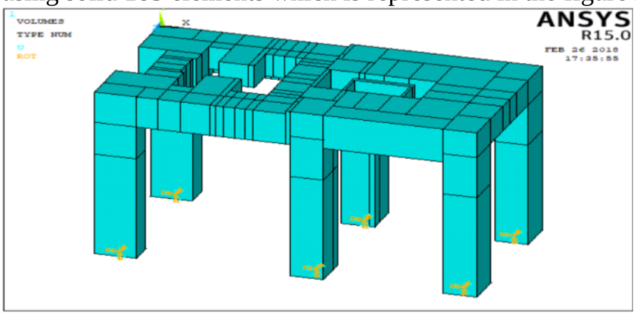

Figure.2.3. solid model

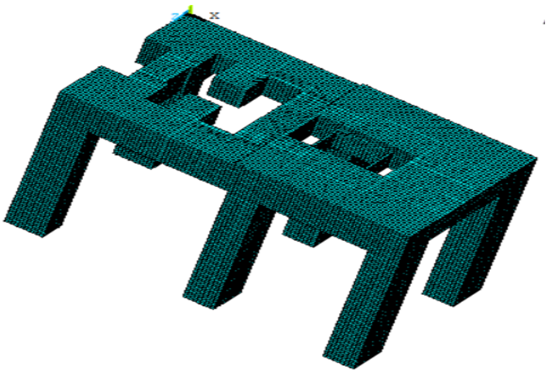

Figure.2.4. fem model

2.3.3 SUPPORT CONDITION:

Turbine and generator foundation is considered has fixed support at the top of the raft level where the column is resting and the analysis is carried. All the degree of freedom is restrained in the model shown in the figure 2.5.

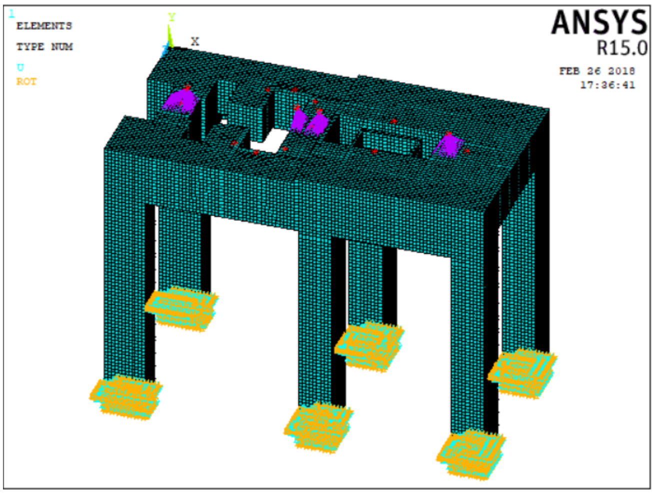

Figure.2.5. Fem Model with Support Condition And Mass Of Equipment

2.3.4 MASS MODELLING:

Lumped mass approach shall be used for computing modal masses of the foundation. The machine shall be modelled to lump its mass together with the mass of the foundation. For modelling the mass element in ANSYS "MASS21" elements are used at the bearing points A, B, C and E bearing points at the elevation of 750 mm from the top of the deck and then connected by the rigid links LINK 180 which transverse the load and does not undergoes any deformation. Figure 3.9 shows the lumped mass and the rigid links provided at the 4 bearing points.

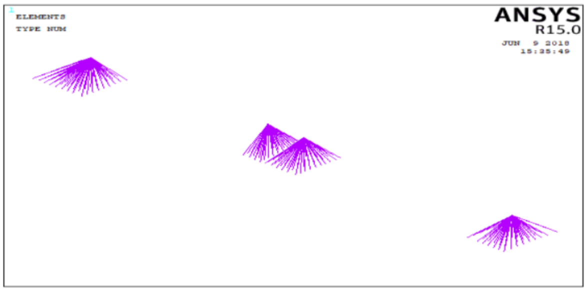

Figure.2.6. Mass Element and Link Element

2.3.5 MATERIAL CONSTANT:

Modulus of elasticity may be established after determining the relationship between stress and the elastic part of deformation. Natural frequency of turbo-generator depends om the value of dynamic elastic modulus value. Table 2.1 gives the varies dynamic elastic modulus for different grades.

Table.2.1, Range Of Dynamic Elastic Modulus As Per Is 2974 Part-3

GRADE OF CONCRETE	DYNAMIC ELASTIC MODULUS in N/mm^2
M20	25590-30000
M25	28500-34000
M30	31200-37000

2.3.6 DAMPING:

Energy dissipation that opposes free vibrations of a system is called has damping. The damping forces oppose the motion, the energy dissipated through damping cannot be recovered. The damping effect in forced vibration analysis reduces the amplitude but does not affect the natural frequency. As per IS 2974 part-3 suggested that the damping should be assumed as 2 percent of critical damping under normal operating loads and the higher damping of 5 percent may be used for emergency loads like blade failure, bearing failure, short-circuit, etc. and the damping is neglected for the free vibration analysis for only forced vibration analysis the damping must be considered.

2.4 DYNAMIC ANALYSIS: -

2.4.1 FREE VIBRATION ANALYSIS:

Free vibration analysis of the TG foundation is carried out to obtain the natural frequencies and mode shapes under the dynamic loading. In this process the external forces are not considered. The mass participation factors in each of the natural modes are also computed.

2.4.2 Forced vibration (Harmonic response) analysis:

Harmonic response analysis for a range of frequencies of excitation of 0-100 Hz with frequency step of 0.25 Hz is carried out for sinusoidal forcing function ($F_0 \sin\omega t$) applied at each bearing location in vertical/transverse directions individually. Amplitude sweep response for these dynamic loads are plotted. amplitude of forcing function (F_0) at rated speed at bearing locations are as per equipment loads which are tabulated in table 2.4

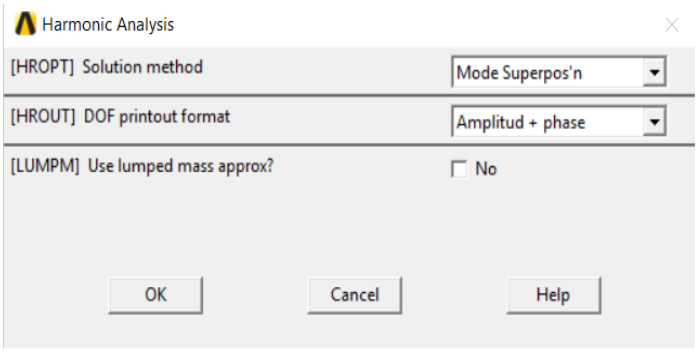

Figure.2.7. Harmonic Analysis Type

After the free vibration analysis, the external force is placed in the structure and then the forced vibration analysis is done. Harmonic analysis has many types in that "mode superposition" method is done in this case and the amplitudes are known for all the dynamic loads acting in vertical and transverse direction.

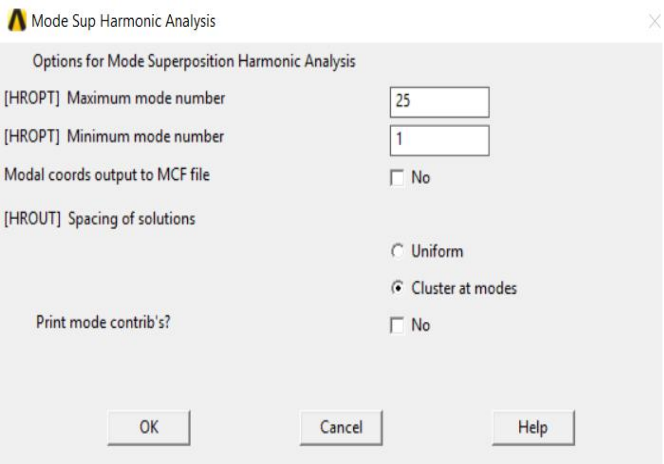

Figure.2.8. Option for Mode Superposition`

In figure 2.8the maximum and minimum mode number is selected and the spacing is given has cluster at modes. The maximum mode no is selected on the basis of the operating speed of the equipment which is given has 50 Hz. After the analysis of free vibration, we will get the natural frequency and mode shapes in this we should select the mode of operating frequency and select it has a maximum mode number.

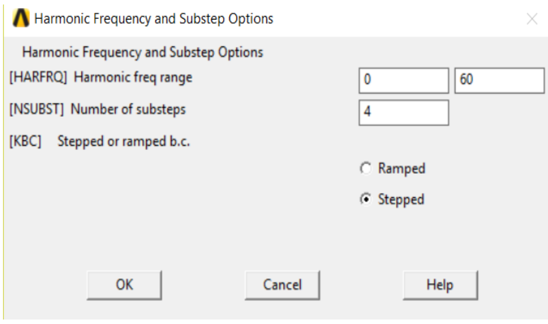

Figure.2.9. Modal Analysis Method

From the figure 2.9 harmonic frequency range is selected has 0 to 60 Hz and the number of substeps are selected has 4 and then the damping is provided has 2 percent and then analysis is done and the results are tabulated.

Table.2.2. Maas of Equipment Considered For Dynamic Analysis

LOAD ALLOCATION AT EACH POSITION							
LOAD POINT	POSITION	STATIC LOAD (kg)	ROTATING LOAD (kg)	DYNAMIC LOAD (kgf)		OPERATING TORQUE (kgf)	SHORT CIRCUIT TORQUE (KGF)
				AXIAL DIRECTION	VERTICAL DIRECTION		
A	CENTER OF TURBINE FRONT BEARING		5060	13640	27280	2815	
B	CENTER OF TURBINE REAR BEARING		6050	13640	27280	2285	
C	CENTER OF GENERATOR FRONT BEARING		4700	23250	46500	2014	
D1 & D2	CENTER OF GENERATOR	13000 & 13000					48000 & 48000
E	CENTER OF GENERATOR REAR BEARING		6500	23250	46500	2786	
F	CENTER OF EXCITER	900					
G1,G2 & G3	CENTER OF TURBINE EXHAUST OUTLET	8580,10230 & 9350					
T1	CENTER OF TURBINE FRONT BASE PLATE	30690					
T2	CENTER OF TURBINE REAR BASE PLATE	8690					

Table.2.3. Technical Data

SL.NO	DESCRIPTION	VALUE
1	WEIGHT OF TURBINE ROTOR	-14T
2	TOTAL WEIGHT OF TURBINE	-60T
3	WEIGHT OF GENERATOR ROTOR	9.7T
4	WEIGHT OF GENERATOR STATOR	21.7T
5	MAXIMUM TRANSPORTATION WEIGHT OF GENERATOR	25T
6	RATED SPEED OF TURBINE/GENERATOR	3000 RPM
7	CRITICAL SPEED OF TURBINE	2137/9198 RPM
8	CRITICAL SPEED OF GENERATOR	1340-1370 RPM
9	ALLOWABLE AMPLITUDE IN VERTICAL/HORIZONTAL DIRECTIONS	≤0.03 mm
10	ECCENTRICITY OF TURBINE OR GENERATOR ROTOR	NORMAL MODE: 0.02mm EMERGENCY MODE:0.1mm
11	AIR COOLER CAPACITY OF HEAT TRANSFER	450 KW
12	ELEVATION OF TURBO GENERATOR SHAFT AXIS	+9.250m
13	TEMPERATURE DIFFERENCE TO BE CONSIDERED	+50⁰c

Table 2.2 is data of mass of equipment considered for the dynamic analysis at all the bearing points in the form of static load, rotating load, dynamic load in axial and vertical direction, operating torque and short circuit loading. Table 2.3 contains the technical data of the equipment, rated speed of the turbine and generator, critical speed of the turbine and generator and the allowable amplitude in both the directions are given.

Table.2.4, Amplitude of Forcing Function at Bearings

BEARING NO AS	AMPLITUDE OF FORCING FUNCTION (F_0) IN VERTICAL DIRECTION (NEWTON)	AMPLITUDE OF FORCING FUNCTION (F_0) IN TRANSVERSE DIRECTION (NEWTON)
BRGA	240855.12	120427.56
BRGB	240855.12	120427.56
BRGC	410548.5	205274.25
BRGE	410548.5	205274.25

In table 2.4 the amplitude of forcing function in vertical and transverse direction for the bearing points are given. By applying the dynamic loads in vertical direction at one bearing point the amplitude is seen for all the bearing points and then for the same bearing point at transverse direction the dynamic load is applied and the amplitudes are tabulated.

3 RESULT AND DICUSSION

3.1 MODE SHAPES:

Pattern of vibration executed by a mechanical system at a frequency is called mode shape. For the varying frequency mode shapes are developed. Figure 3.1, 3.2 and 3.3 represents the mode shape in X, Y and in Z direction for the frequency of 6.09 Hz in X direction, 29.45 Hz in Y direction and 5.456 Hz in Z direction.

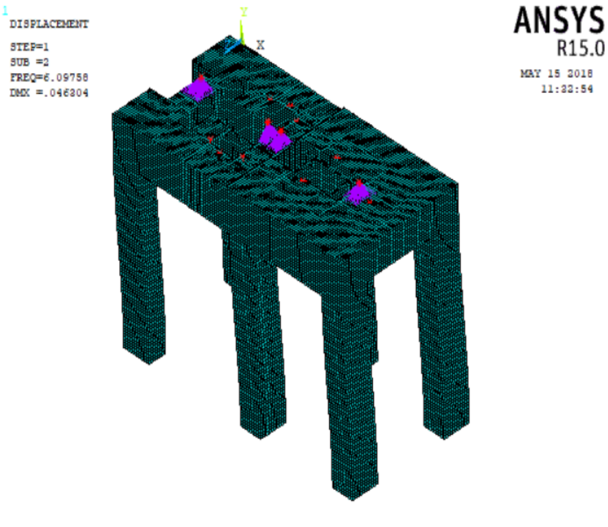

Figure.3.1. Mode shape in x direction

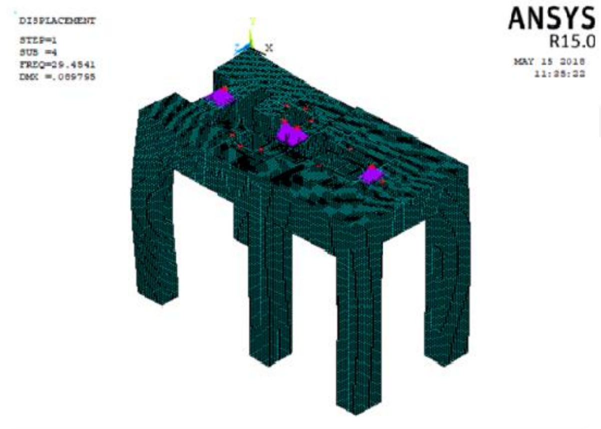

Figure.3.2. mode shape in y direction

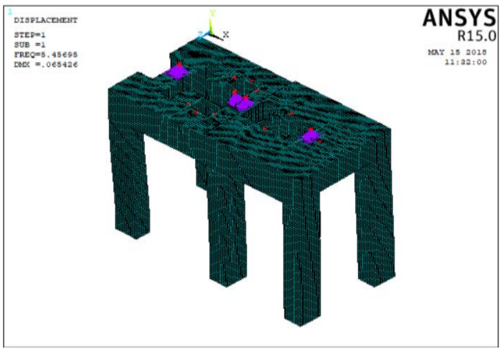

Figure.3.3. Mode Shape in Z Direction

Table.3.1. Frequencies Separation Check

DESCRIPTION	X (Hz)	RATIO	Y (Hz)	RATIO	Z (Hz)	RATIO
RATED SPEED TG 3000 RPM	6.097	0.1219	29.451	0.589	5.456	0.109
CRITICAL SPPED OF TURBINE 9798 RPM	6.097	0.037	29.451	0.180	5.456	0.033
CRITICAL SPEED OF GENERATOR 1370 RPM	6.097	0.267	29.451	1.289	5.456	0.238

Frequency ratio is a term that relates the operating speed of the equipment to the natural frequencies of the foundation. Main requirement of the designer is that the frequency of the operating speed of the equipment and the foundation should differ by certain margins to avoid the resonance developing with the foundation and equipment. The margin can be in the ratio of fn/fm ratio which is natural frequency to operating frequency. the fundamental natural frequency should be at least 20 percent away from the operating speed.

3.2 HARMONIC RESPONSE ANALYSIS:

Amplitude response (displacement) has been computed for an excitation frequency range of 0-100 Hz and the plots generated. Maximum steady state values of vertical and transverse amplitudes of displacement at operating frequency range of 45 Hz to 55 Hz at the bearing locations due to vertical and transverse forces applied at the corresponding bearing location are well within the limits. The permissible amplitude of displacement in vertical, transverse, and axial directions at all bearing locations shall not exceed 30 microns. External dynamic force is applied at a bearing point A in the vertical direction and then the amplitude versus frequency graph is plotted for all the bearing points and the maximum peak value is selected in the graph between the 45 to 60 Hz which is operating speed from the figure 3.4,3.5. when the vertical unbalanced load is acting transverse amplitudes are also considered but the amplitude in the transverse direction is very less hence it is neglected.

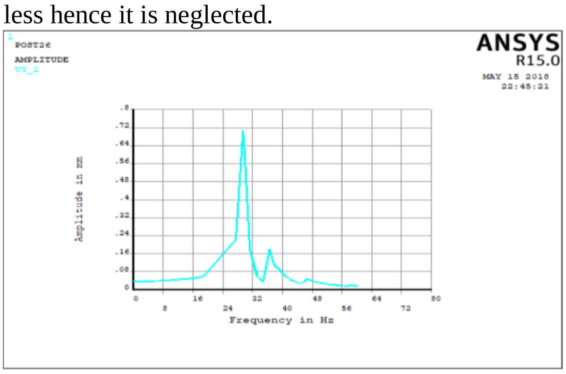

Figure.3.4. Unbalance Load Applied Vertically At Brg#A And Amplitude At Brg#A

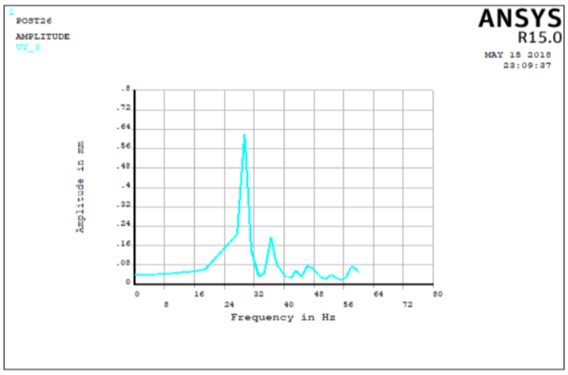

Figure.3.5. unbalance load applied vertically at brg#b and amplitude at brg#b

Table.3.2. amplitude values for the corresponding frequency in vertical direction

Particulars	Frequency in Hz	Amplitude in micron A	B	C	E
240855.12 N load is applied in Y direction at bearing point A	16	51.162	26.568	21.123	0.868
	40	65.41	8.074	11.924	46.72
	50	28.27	6.015	4.906	2.151
240855.12 N load is applied in Y direction at bearing point B	16	26.56	54.267	47.8	11.729
	40	8.07	31.323	41.20	80.484
	50	6.01	26.486	21.47	18.271
410548.5 N load is applied in Y direction at bearing point C	16	36	80.43	71.72	25.18
	40	2.03	70.24	84.16	126.313
	50	8.36	36.598	31.16	32.839
410548.5 N load is applied in Y direction at bearing point E	16	1.479	19.99	25.181	44.07
	40	79.65	137.18	126.313	62.10
	50	3.667	31.142	32.839	33.53

Table.3.3. amplitude values for the corresponding frequency in transverse direction

Particulars	Frequency in Hz	Amplitude in micron A	B	C	E
120427.56 N load is applied in Z direction at bearing point A	16	48.79	37.4	30.36	4.09
	40	8.11	9.69	8.94	1.93
	50	11.49	3.84	3.36	0.61
120427.56 N load is applied in Z direction at bearing point B	16	36.37	15.57	17.02	20.29
	40	12.42	12.90	8.60	2.8
	50	2.05	16.76	16.81	5.57
205274.25 N load is applied in Z direction at bearing point C	16	49.82	29.15	31.66	43.28
	40	19.28	15.59	9.36	5.97
	50	3.49	27.86	28.55	11.81
205274.25 N load is applied in Z direction at bearing point E	16	6.81	34.63	43.36	89.35
	40	3.18	5.78	6.62	4.14
	50	0.562	8.63	12.07	4.74

Table .3.4. final amplitude at bearing points in vertical and transverse direction

Bearing point	SRSS amplitude in Vertical Direction (micron)	SRSS amplitude in transverse Direction (micron)
A	17.84	1.33
B	32.50	3.7
C	29.64	3.87
E	29.61	1.52

Table 4.6, gives the final amplitude after the SRSS method is applied and for all the bearing points the amplitudes in both the vertical and transverse directions.

4 ACKNOWLODGENMENT

I am extremely thankful to internal guide **Mrs. Navyashree B.R, Assistant Professor, Dept. of Civil Engineering, Sahyadri College of Engineering and Management, Mangalore**, for her valuable guidance, encouragement and suggestions offered throughout my project work. She played an important role in completion of my project and for making me work to the best of my abilities. I express my gratitude **to Mr. Vaibhava S, Inamdar, Director of Purna Design Engineers Pvt, Ltd, Bangalore.** for providing mean opportunity to work as a project in his firm and gain industrial knowledge. I'm very grateful to him for his guidance in every stage of the project and for the successful completion of the work assigned.

5. CONCLUSIONS

Free vibration analysis is done to know the Natural frequencies, Mass participation factor and modal shapes. Natural frequency obtained after the analysis are checked by considering Frequency Ratios which should be less than 0.8 or more than 1.2 for the operating speed, critical speed of the turbine and the critical speed of the generator is checked where all the ratios are satisfying. The modal shapes are considered at least 100 to know mass participation factor. Mass participation was found to be more than 95 percent in every direction. Forced vibration analysis is done to know the amplitude of vibration when the dynamic loads are acting in vertical direction and transverse direction at bearing points A, B, C and E. the amplitudes in these bearing points are plotted in vertical direction and also in transverse direction and the peak values are considered at the operating speed 50 Hz. For the operating speed the amplitudes should not exceed 30 microns.

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