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DESIGN AND ANALYSIS OF WIND TURBINE NACELLE TRANSPORT FRAME FOR ROAD TRANSPORT

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ABSTRACT

The Wind turbine is a Machine which produces electricity by using Kinetic energy of the wind and convert to mechanical energy. There are many mechanical components involves such as blades, hub, Nacelle etc. Transportation of wind turbine components is a very critical process due to its large size and weight which to be handled with precaution. This paper deals with the transportation of wind turbine nacelle transport frame from manufacturing site to erection site. Road conditions in India have many bumps and uneven road surfaces which cause sudden impact and vibration are two major factors which have a direct effect on a nacelle is being transported by road. The vibration that occurs in Nacelle structures and its transport frame is undesirable, not only because of the resulting unpleasant motions, noise and dynamic stresses which may lead to fatigue and failure of the structure. The result of the vibrational condition causes damage to nacelle bed frame. The Nacelle bedframe with transport frame is taken in the consideration and checked for its performance for road vibration condition. A transport frame model with a bed frame and yaw top is modeled using 3D software Pro/Engineer wildfire 5 and Analyzed using analysis software code called Ansys Workbench 16. It is usually much easier to analyze and modify a structure at the design stage than modify a structure with undesirable vibration characteristics after it has been built. For the damages caused to a wind turbine nacelle bed frame due to random vibration, the operating frequency of the existing transport frame was modified and dynamic analysis has been performed to prevent such damage.

Keywords: wind turbine nacelle, nacelle bed frame, existing transport frame, modified transport frame, ansys.

1. INTRODUCTION

The Nacelle is an enclosure which contains the electrical and mechanical components, namely bed frame, gearbox, main shaft, brake, speed and direction monitor, yaw mechanism, generator etc. [12]. A wind turbine nacelle of 1.5 MW can be weight of about 80 tonnes and to ship such a heavy load product is a massive task. A typical nacelle assembles at the site of the production, mounted on a transport frame and it is transported by a vehicle to an erection site of a wind turbine.

During transportation of product, hazards vary based on the mode of transportation [8]. Transportation on the roads might cause vibration based on the speed of travel, road conditions [2, 3]. The other major factor that contributes to damage during transportation is the effect of G - force and shock.

This investigation regards when the nacelle is mounted on existing transport frame, it was observed that the toppling condition occurs, this is due to the fact that centre of gravity of the nacelle lies outside of the transport frame. When the frictional forces and rotational moments are involved, there is often the possibility than an object could topple.

Initially on designing, the centre of gravity of a nacelle component lies inside the transport frame and it was nearer to the main shaft side. Due to manufacturing variation and installation of alternative components, centre of gravity of nacelle component shifted away from the transport frame and it was towards generator with the result that a overturning moment develops. In order to overcome this problem transport frame was modified with extension by considering the centre of gravity of the nacelle to lie inside the transport frame. The transport frame was modified to “I” cross section because it will have more moment of inertia when compared to “C” cross section. So, it can able to sustain more axial load when compared to C section.

During transportation, the vibration that occurs in Nacelle structures and its transport frame is undesirable, the dynamic stresses which may lead to fatigue and failure of the structure. The results of the vibrational condition cause damage to the nacelle. The resonance occurs causes initiation of crack on a nacelle bed frame which is made up of ductile cast iron (GGG 40.3). The stress intensity of the bed frame material is greater than the fracture toughness value of the material which may lead to unstable fracture [7, 10]. There are two issues that control the amplitude and frequency of vibration in a structure,

1. The excitation occurs, 2. The reaction of the structure to that certain excitation. Changing either the excitation or the dynamic characteristics of the structure will change the vibration stimulated [13]. The response of the structure to excitation depends upon the method of application and the location of the exciting force or motion, and the dynamic characteristics of the structure such as its natural frequencies. To modify the natural frequency of a structure, change either the stiffness or the mass [11]. Increasing the mass or lowering the stiffness will lower the natural frequency. In order to change the frequency of the system, the design of the existing transport frame has been modified by varying its cross section and also with the introduction of shell. The shell is made up of S355 material. The modified design of the transport frame with extension and shell was analyzed to check whether the design was safety, the natural frequency of the system was reduced and stress induced on the

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Nacelle bed frame was reduced, which doesn't cause crack to initiate on the bed frame.

2. BASIC DIMENSION OF TRANSPORT FRAME

a. Existing transport frame

Dimension of C section = 200 mm * 200 mm * 7.5 mm
Length actual, L = 3180 mm
Width, W = 3112 mm

b. Modified transport frame

Dimension of I section = 200 mm * 200 mm * 9 mm
Length actual, L = 4900 mm
Width, W= 3112 mm
ShellOuter diameter = 2712 mm
Thickness = 16 mm
Length = 844mm
Material of the modified Transport frame =Structural Steel 355
Total Nacelle weight = 80,000 kg
Bed Frame Weight = 14 tonnes
Yaw Top Weight = 3 tonnes
COG of nacelle from axis = 2489 mm
Nacelle weight except its bedframe and Yaw top = 63,000 kg

Table-1. Material properties.

Components	Material	Yield strength N/mm^2	Tensile strength N/mm^2	Density kg/m^3	Youngs Modulus N/mm^2
Nacelle Bed frame	GGG 40.3	240	400	7100	$1.69*10^5$
Yaw Top	Forged Steel	310	565	7870	$2*10^5$
Transport Frame	S355	355	630	7850	$2.1*10^5$

The material properties of Nacelle bed frame Yaw top and transport frame as shown in Table-1. The fracture toughness value of the material GGG 40.3 was 30 Mpa√m.

3. CAD MODEL

a. Existing transport frame

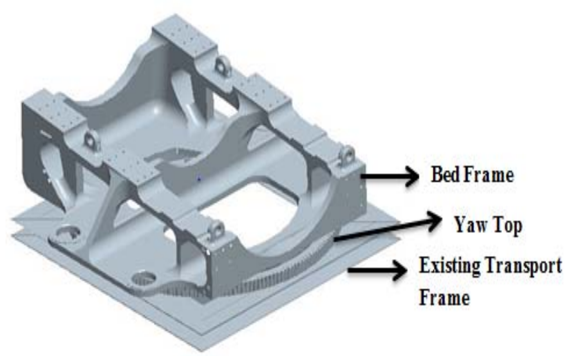

Figure-1. The assembly view of existing transport frame model with bed frame and yaw top.

The existing transport frame with a bed frame and yaw top is modeled using 3D software Pro/Engineer wildfire5. The assembly view of the existing Transport frame model with a bed frame and yaw top as shown in Figure-1.

b. Modified transport frame

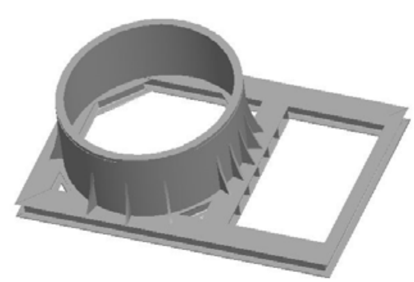

Figure-2. Modified transport frame.

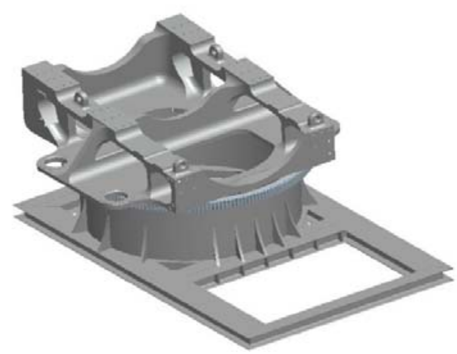

Figure-3. The assembly view of modified transport frame model with bed frame and yaw top.

The modified transport frame is modeled as shown in Figure-2 and the assembly view of the existing

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Transport frame model with a bed frame and yaw top as shown in Figure-3.

4. MESHING OF TRANSPORT FRAME

The finite element method (FEM) is a numerical technique for finding approximate results of boundary value problems. The meshing of transport frame with a bed frame and yaw top is done in Ansys Workbench 16 as shown in Figures 4 and 5. The mode used for meshing is tetrahedrons surface meshes. The size of elements is set aside as minimum as possible in order to get the exact results. The meshed existing transport frame model with a bed frame and yaw top has 334800 nodes and 1497663 elements while the modified model has 349861nodes and 1502834 elements.

Figure-4. Meshing of existing transport frame.

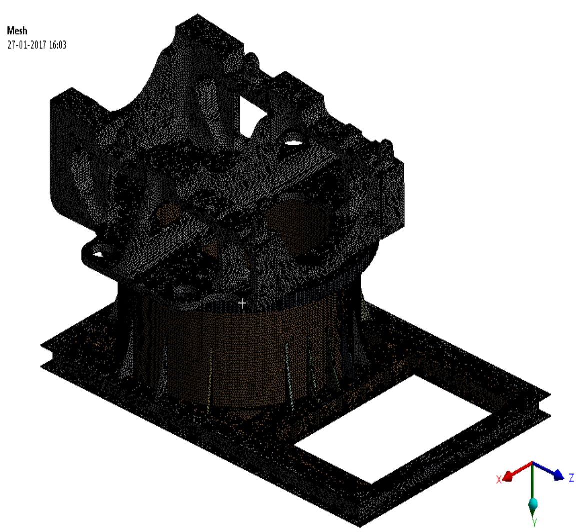

Figure-5. Meshing of modified transport frame.

5. BOUNDARY CONDITION

The total Nacelle weight except its bedframe and yaw top of about 63,000 kg is given as a point mass at the center of gravity of Nacelle. The Transport frame base was fixed and standard earth gravity 9.81m/s^2 is to be applied in a downward direction.

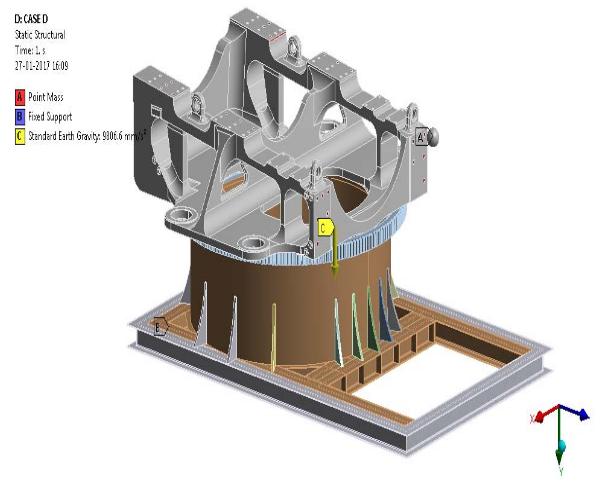

Figure-6. Boundary condition and load.

In the Figure-6 point A represents the point mass, B represent the fixed support at the base of the transport frame and C represents the standard earth gravity of about 9.81m/s^2.

6. RESULTS AND DISCUSSION

A. Static analysis

a. Existing transport frame

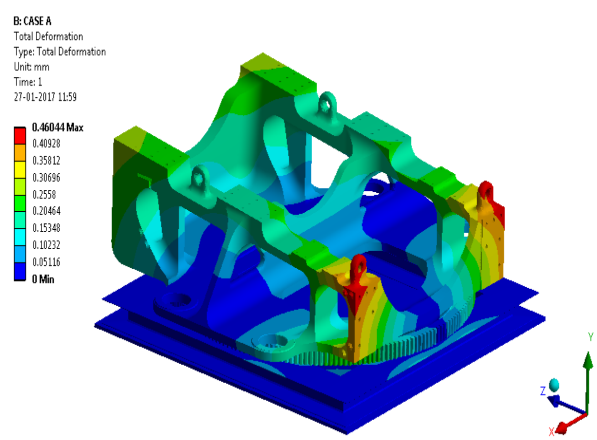

Figure-7. Total deformation on existing model.

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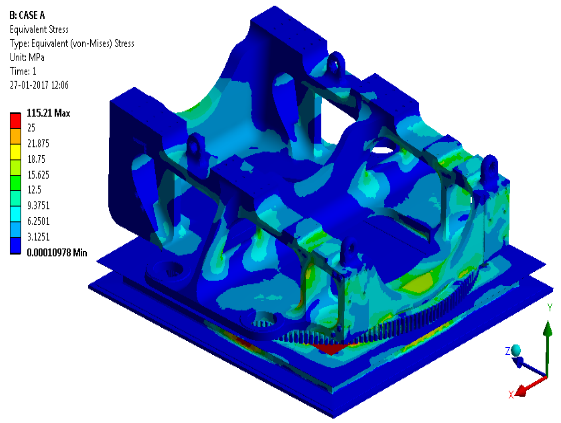

Figure-8. Equivalent stress on existing model.

b. Modified transport frame

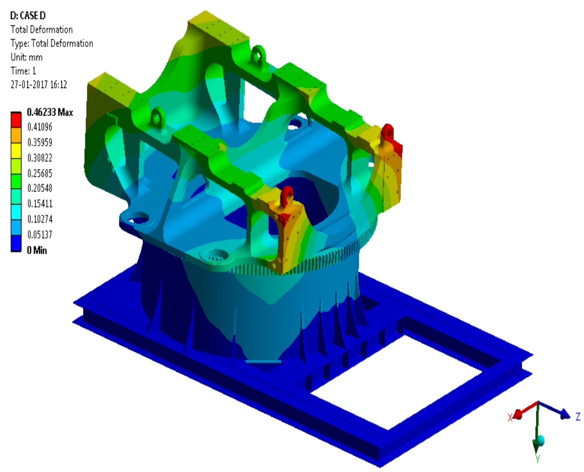

Figure-9. Total deformation on modified model.

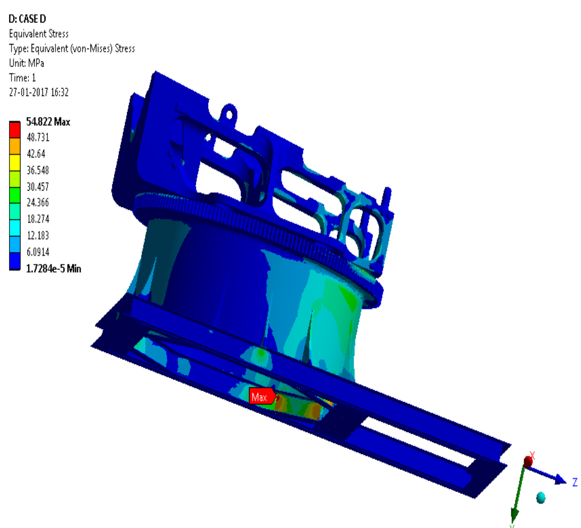

Figure-10. Equivalent stress on modified model.

Figures 7-8 represents the maximum deformation of about 0.46 mm and maximum stress of about 115 MPa occurs on the existing transport frame model. While Figures 9-10 shows that the maximum deformation of about 0.46 mm and maximum stress of about 54.82 MPa occurs in a modified transport frame during static structural analysis and also stress occurs in a Nacelle bed frame was less on modified model when compared to existing model.

B. Modal analysis

Modal analysis is used to determine the dynamic behavior of a body under vibrational conditions and the corresponding natural frequency is determined [5, 9].

For the modal analysis of the frame the boundary conditions are given as fixed support and point mass. It is not required to give acceleration due to gravity. The modal analysis is carried out on existing model and modified model.

Table-2. Results of modal analysis of existing model.

Mode	**Frequency**(Hz)
1	21.802
2	23.909
3	41.859
4	120.84
5	159.81
6	176.1

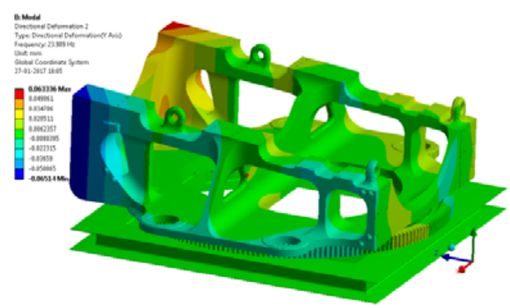

Figure-11. Second mode shape of existing model.

Table-3. Results of modal analysis of modified model.

Mode	**Frequency**(Hz)
1	17.391
2	18.851
3	34.346
4	77.885
5	107.79
6	137.1

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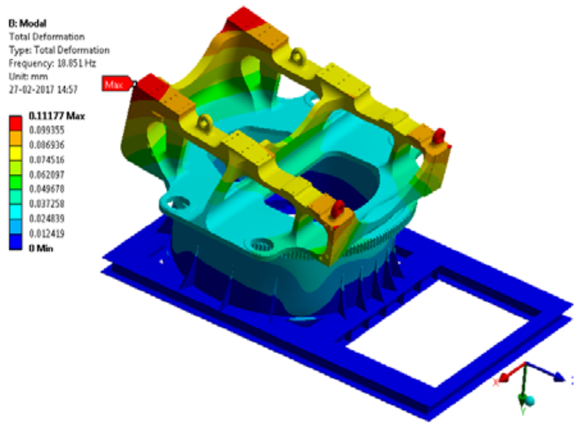

Figure-12. Second mode shape of modified model.

Tables 2-3 represent the natural frequency of the structure on existing and modified model. The natural frequency of the existing model in y direction is about 23.9Hz, which was reduced to about 18.8Hz on modified model. Figures 11-12 shows that mode shape of existing and modified structure in y direction.

C. Harmonic analysis

Harmonic response analysis helps to predict the sustained dynamic behavior of the structure, and it enables to verify whether the design will successfully overcome resonance, and other harmful effects of forced vibrations. For the harmonic analysis of transport frame the boundary conditions are given as point mass and the acceleration due to gravity.

a. Existing transport frame

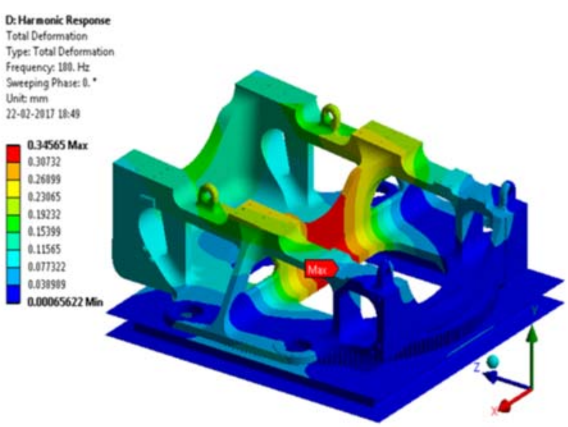

Figure-13. Total deformation on existing model.

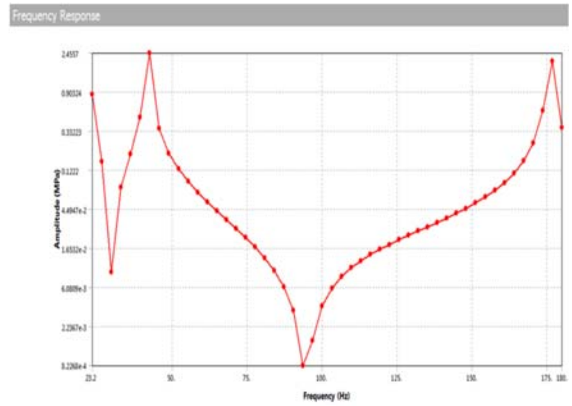

Figure-14. Frequency response on existing model.

b. Modified transport frame

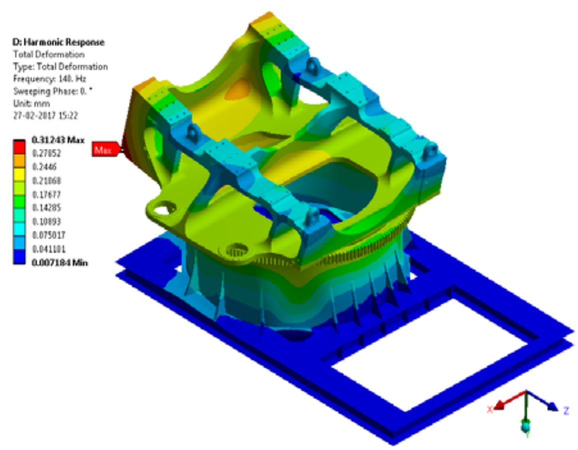

Figure-15. Total deformation on modified model.

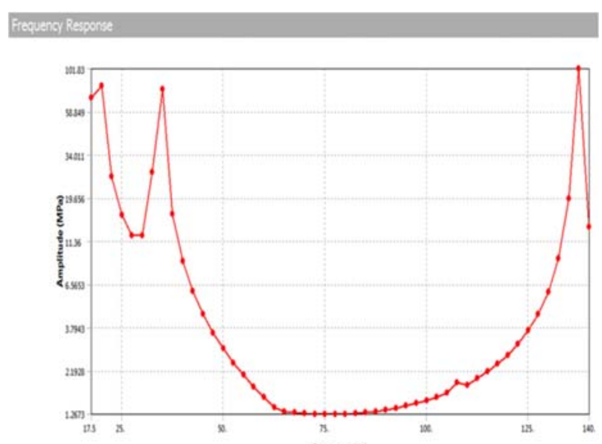

Figure-16. Frequency response on modified model.

From the Figures 14 and 16, it is clear that first peak occurs at a frequency of about 23.2 Hz on existing frame, whereas it was reduced to about 17.5 Hz on modified frame.

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D. Random vibration analysis

A Power Spectral Density (PSD) is used to measure signal power intensity in a frequency domain [4, 6]. In other words, it indicates at which frequency variations are strong and at which frequency variations are weak. The unit of PSD is energy (power density in G^2/Hz) versus frequency (Hz). Singh *et al*. [1] have measured the vibration levels in the truck when a heavy load is transported over major routes. The data measured and analyzed truck transport vibration for the major freight distribution routes using PSD for vertical modes are given as an input excitation at the base of the transport frame.

a. Existing transport frame

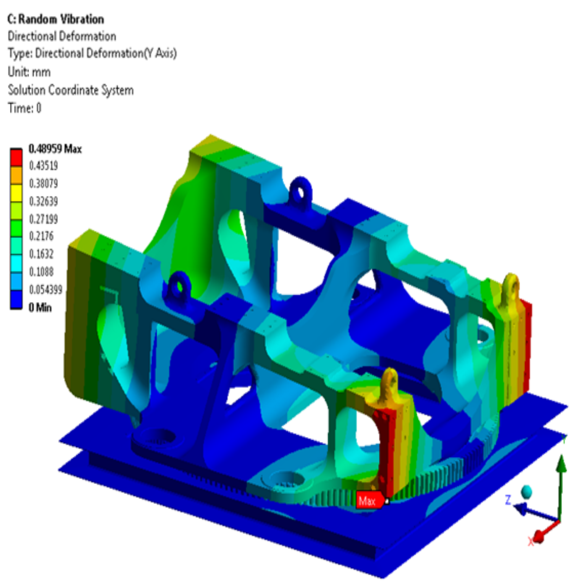

Figure-17. Total deformation on existing model.

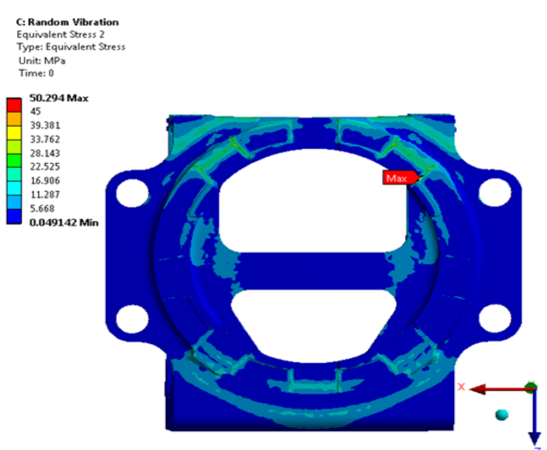

Figure-18. Stress on Nacelle bed frame when transported on existing transport frame.

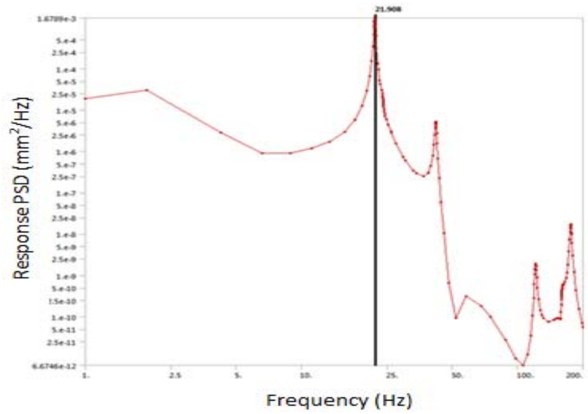

Figure-19. Frequency response PSD curve of existing frame.

In the existing model, the natural frequency of the structure vibrate at the same frequency of the vehicle at which maximum amplitude occurs in the frequency of about 22 Hz as shown in Figure-19, results resonance occurs. These random vibrations cause dynamic stress occurs and maximum stress occurs on the Nacelle bed frame was 50.29Mpa as shown in Figure-18, the stress intensity occurs in Nacelle bed frame material during transportation on existing transport frame is greater than the fracture toughness value of material leads to initiation of crack on the Nacelle bed frame during transportation.

b. Modified transport frame

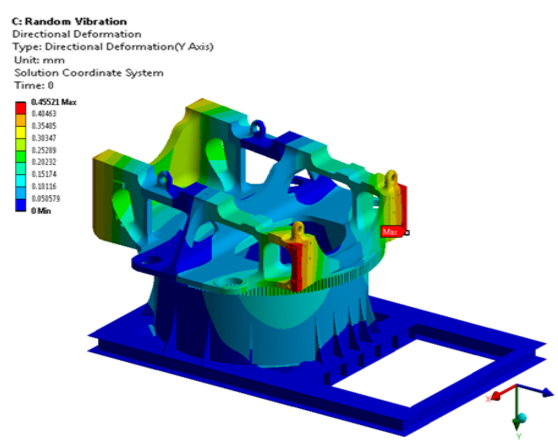

Figure-20. Total deformation on modified model.

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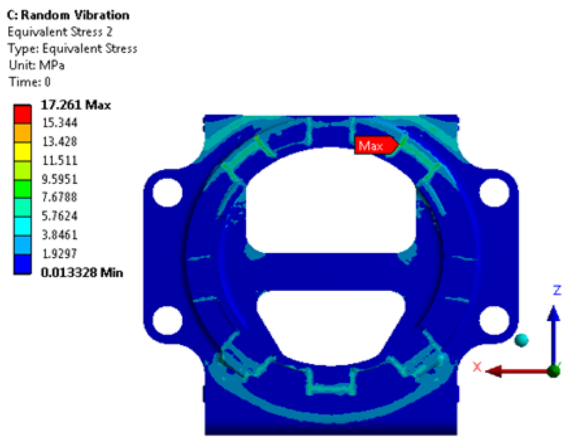

Figure-21. Stress on Nacelle bed frame when transported on modified transport frame.

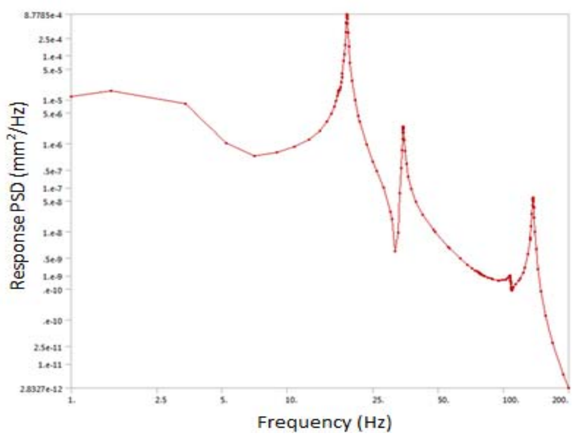

Figure-22. Frequency response PSD curve of modified frame.

In the modified model, total deformation occurs on the Nacelle bed frame was 0.45 mm as shown in Figure-20. The natural frequency of the system was reduced to about 18 Hz and stress induced on the Nacelle bed frame was reduced to about 17.26 MPa by random vibration analysis as shown in Figure.21-22.The stress intensity on Nacelle bed frame material was less when compared to its fracture toughness value which doesn't cause damage to the Nacelle bed frame during transportation.

7. CONCLUSIONS

The nacelle is mounted on a transport frame and it is transported by a vehicle to an erection site of a wind turbine. During transportation of Nacelle over the existing transport frame, large displacement and stress mainly concentrated on the nacelle bed frame by vibration stress and displacement. The resonance occurs causes initiation of crack on a nacelle bed frame which is made up of ductile cast iron (GGG 40.3). The stress intensity of the bed frame material is greater than the fracture toughness value of the material which may lead to unstable fracture. To modify the natural frequency of a structure, the design of the existing transport frame has been modified by varying its cross section and also with the introduction of shell. The shell is made up of S355 material. It is beneficial due to its high strength and suitable for heavy material transportation. Structural analysis is performed to predict the structural stability and design safety. Modal analysis is performed to identify the natural frequency of the transport frame and continuation of harmonic analysis was performed. The modified transport frame had been analyzed by random vibration, the frequency of the structure is reduced to about 18 Hz and the stress on nacelle bed frame is very low of about 17.26 MPa, which is less than the fracture toughness which doesn't cause damage to nacelle bed frame. The results of analysis of existing and modified model are mentioned in the below Table 4-6.

Table-4. Static structural analysis of existing and modified model.

RESULTS	Existing model	Modified model
Displacement(mm)	0.46	0.46
Stress (MPa)	115	54.82

Table-5. Harmonic analysis of existing and modified model.

RESULTS	Existing model	Modified model
Displacement(mm)	0.345	0.312
Frequency Response (Hz)	23.2	17.5

Table-6. Random vibration analysis of existing and modified model.

RESULTS	Existing model	Modified model
Displacement(mm)	0.489	0.455
Stress on Bed frame (MPa)	50.29	17.26
Frequency Response (Hz)	22	18

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