Design Modification and Analysis of Fixture to Accommodate Different Steam Turbine Casing

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Abstract

A fixture is a special purpose tool used to accurately and stably locate the work piece during machining process. Proper fixture design improves the quality, production of parts and also facilitates the interchangeability of parts that is prevalent in much of modern manufacturing. A machining fixture has two basic functions are to locate the component at a right position in relation with cutting tools and to hold the component tightly. Lack of rigidity causes vibration which is very dangerous. In the present study an attempt has been carried out to make universal type of fixture which is capable to handle different steam turbine casing having geometry changing attributes. Modeling has been carried out of existing fixture using solid modeling software. Based on the available data of existing fixture, force, vibration and control point calculations have been carried out analytically. Static structural and harmonic analysis have been carried out using finite element software. The high vibration and stresses have been found in existing fixture design, which will be eliminated by redesigning of the same. It has been found that frequency has been increased whereas equivalent stress and deformation has been reduced in modified design of fixture.
Keywords: Fixture design, Static structural analysis, Harmonic analysis, Finite element method

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I. INTRODUCTION

The successful running of any mass production depends upon the interchange ability to facilitate easy assembly and reduction of the unit cost. So, there is necessity of special purpose tools which are used to facilitate production operations like machining, assembling, inspection, etc. Fixtures are designed to hold, support and locate the work piece to ensure that each part is machined within the specified tolerances. Unlike the jig, it does not guide the cutting tool but provides only reference surface. It should be clamped to the table of the machine for work holding purpose upon which the work is done. A milling fixture is usually located on the machine table and bolted in proper position. The work piece in turn is located and clamped in the fixture. Unlike drill jigs, a milling fixture should be strong and rigid.

Iain Boyle et al. [5] created supporting process of fixture design through the development of computer aided fixture design (CAFD) tools and approaches. Hui Wang et al. [6] demonstrated case based reasoning (CBR) method for fixture design, a critical issue in the manufacturing of large and complicated equipment. Gaoliang Peng et al. [7] suggested that the fixture design improves the quality and production of parts and also facilitates the interchange ability of parts that is prevalent in much of modern manufacturing. Matthew S. Allen et al. [8] described about the fixed boundary conditions which are often difficult to simulate experimentally. In principle, modal sub-structuring or impedance coupling approaches can be used to predict the fixed base modes of a system from tests where the system has some other boundary condition if the motion at the connection point can be measured, but this approach can be highly sensitive to imperfections in the experimental measurements. J.H. Yeh and F.W. Liou [9] discussed about response frequency of a modular fixture system with multiple components in contact, and they have demonstrated that it is possible to monitor the contact conditions based on a fixture system's dynamic response frequencies. Yu Zheng and Wen-Han Qian [10] studied 3-D modular fixtures, particularly for complex objects. W. Li et al. [11] demonstrated agile fixture design and the achievements and deficiencies in the field of case-based fixture design. Shasha Zeng et al. [12] concerned with suppressing the machining vibration of the flexible work-piece by designing appropriate fixture layout scheme. Bravo et al. [14] proposed a method for constructing the three dimensional lobe diagrams by considering both the dynamic behaviour of the machine structure and the machined work-piece. The proposed method was validated by machining a series of thin walls. Campa et al. [15] presented a methodology based on the estimation of modal parameters of the part and the corresponding stability lobes for chatter avoidance in milling of flexible thin floors.

II. MODELING AND ANALYSIS OF EXISTING FIXTURE

3D CAD model of each part of existing fixture has been created and assembled using solid modelling software as shown in Fig. 1. The fixture consists of various parts like rotary table of machine, bottom square support, angle plates, horizontal supports etc. The nozzle and guide are fixed on turbine enclosure generally called the casing, which in addition to confining the steam serves as support for the bearings. For existing fixture design, feed rate, chip removal rate, average chip thickness, specific cutting velocity, spindle and motor power consumption have been calculated analytically. For vibration analysis, mass, stiffness and amplitude have been calculated using fundamental equations. The control points which are responsible for rigidity of the component have been calculated using Galerkin technique of finite element method. In this Galerkin approach trigonometric trial function has been assumed and based on that trial function domain residual has been determined. By minimizing the residual solution can be obtained.

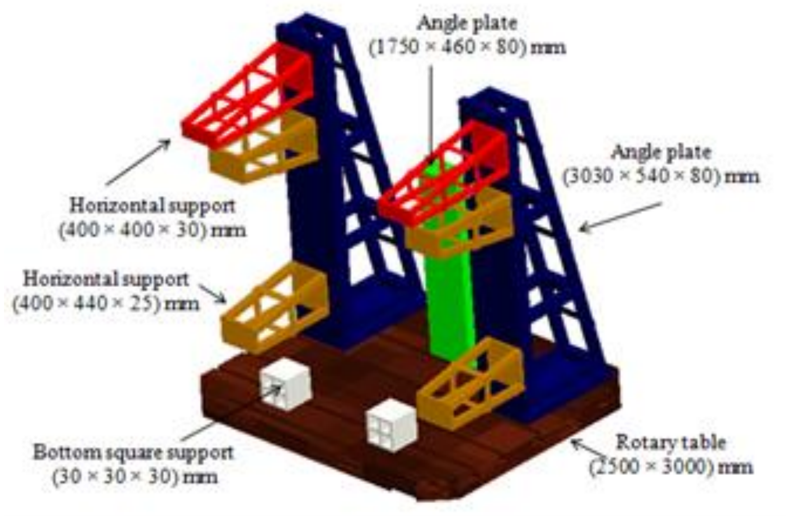
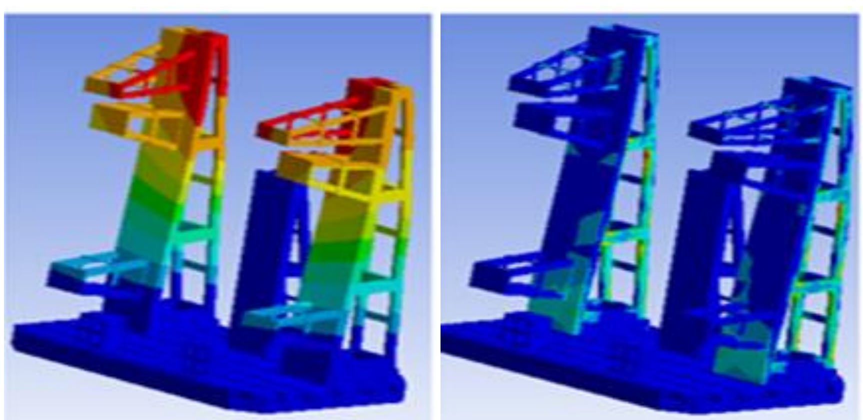


Fig. 1: Existing fixture model

A. Analysis of Existing Fixture:

The static structural and harmonic analysis have been carried out for existing fixture design using ANSYS software. The material properties like modulus of elasticity, modulus of rigidity, Poisson's ratio, density, thermal conductivity etc. have been assigned to different components of fixture and then appropriate boundary conditions have been applied as per operational condition of fixture. 10-node tetrahedral elements have been used for meshing of given model. The equivalent von-Mises stress and deformation have been determined for side and face milling as well as drilling operation. The values for the same are 3.2 MPa and 0.083 mm for side and face milling operation whereas 9.36 MPa and 0.167 mm for drilling operation respectively in static structural analysis. For harmonic vibration analysis external forces of 0.4 kN and 15.6 kN on side support; member and on bottom support have been applied respectively. The equivalent stress, deformation, natural frequency, phase angle and amplitude have been determined after analysis. The values for the same are 137.8 MPa, 3.29 mm, 41 Hz, -90.45° and 0.7 mm for side and face milling as shown in Fig. 2.



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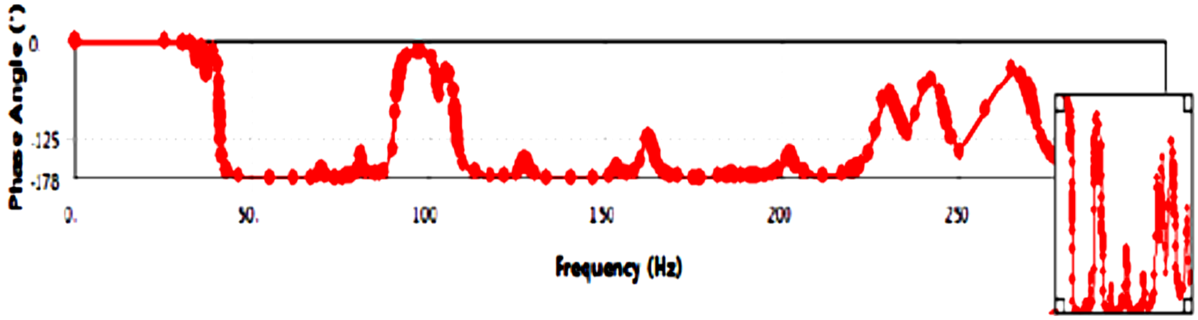

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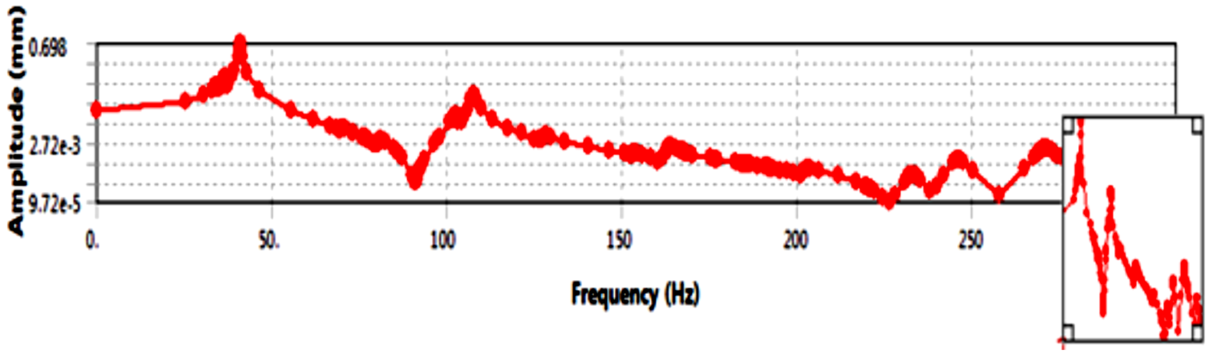
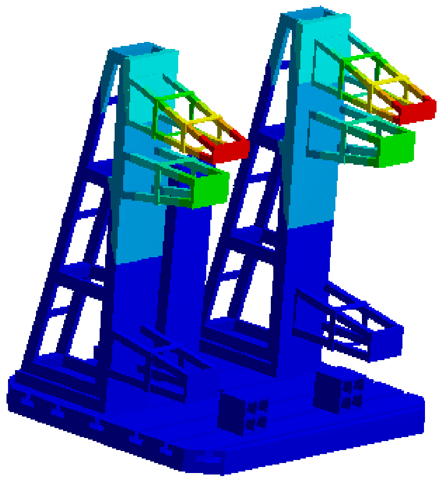


(d)

Fig. 2: Harmonic vibration analysis (a) maximum deformation = 3.29 mm, (b) maximum equivalent stress = 137.8 MPa, (c) phase angle = -90.45° (d) amplitude = 0.698 mm & frequency = 41 Hz for side & face milling operation

The values for the deformation, equivalent stress, phase angle and amplitude are 171.25 MPa, 6.3 mm, 34.4 Hz, -86.13° and 1.1 mm for drilling operation respectively as shown in Fig. 3.



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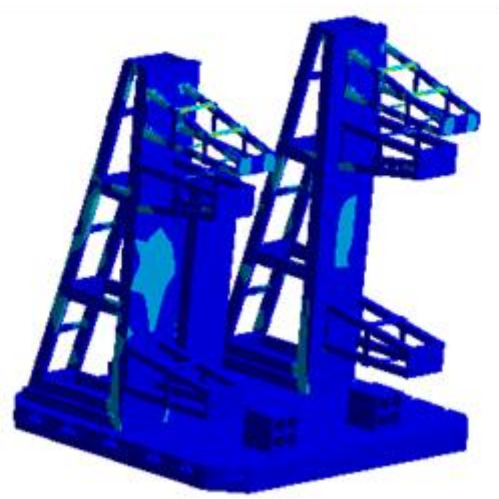

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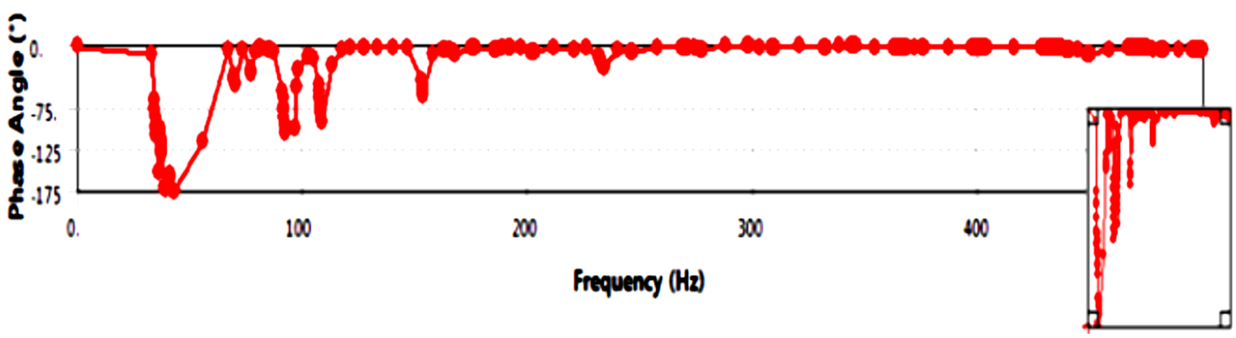

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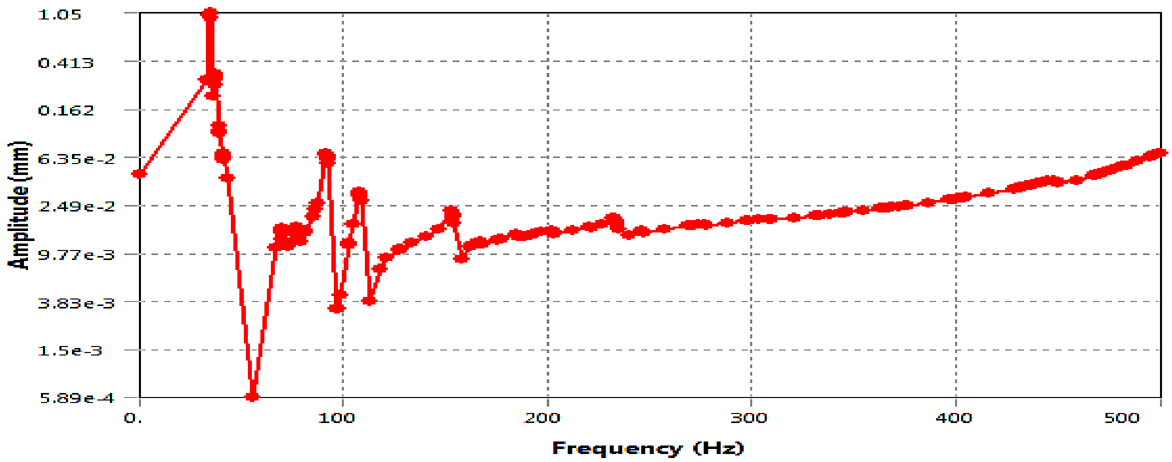


(d)

Fig. 3: Harmonic vibration analysis (a) maximum deformation = 6.31 mm, (b) maximum equivalent stress = 171.25 MPa, (c) phase angle = -86.13° (d) amplitude = 1.05 mm & frequency = 34.44 Hz for drilling operation

III. Design Modification and Analysis of that Fixture

As per analysis of existing fixture, it was found that the high vibrations are induced because of the less number of truss members or stiffeners. To reduce vibration, modifications in existing fixture have been carried out. To modify existing fixture design mainly three major changes have been carried out. Numbers of truss members have been increased in existing model to eliminate vibration. By addition of horizontal support members rested on angle plate, vibration has been reduced due to unrestricted motion during drilling operation. The material for support member have been changed from mild steel to cast iron or alloy steel. Vibration was created due to unrestricted vibratory motion during drilling operation in old design, which is eliminated by the addition of horizontal support members which are rested in new designed angle plate. For job tilting purpose, the control points have been relocated at an angle of 30°, 28° and 33° in the direction of front view, right hand side view and top view respectively. The modified fixture design has been made versatile to fix different customers steam turbine casing. After modified different components of fixture design, whole assembly has been remodeled and same as shown in Fig.4.

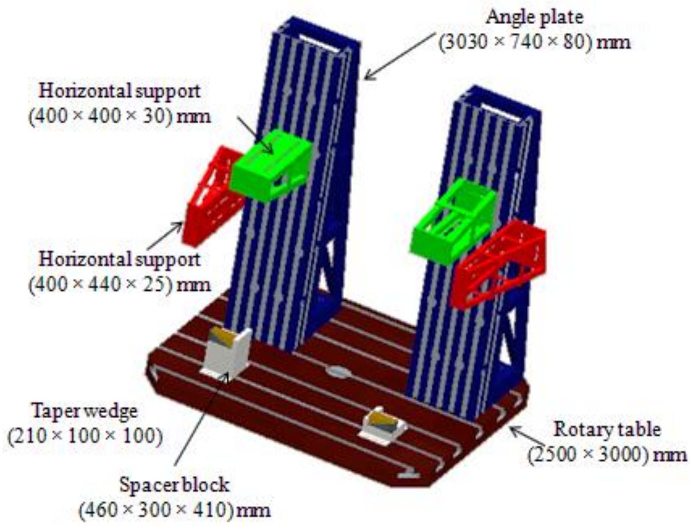
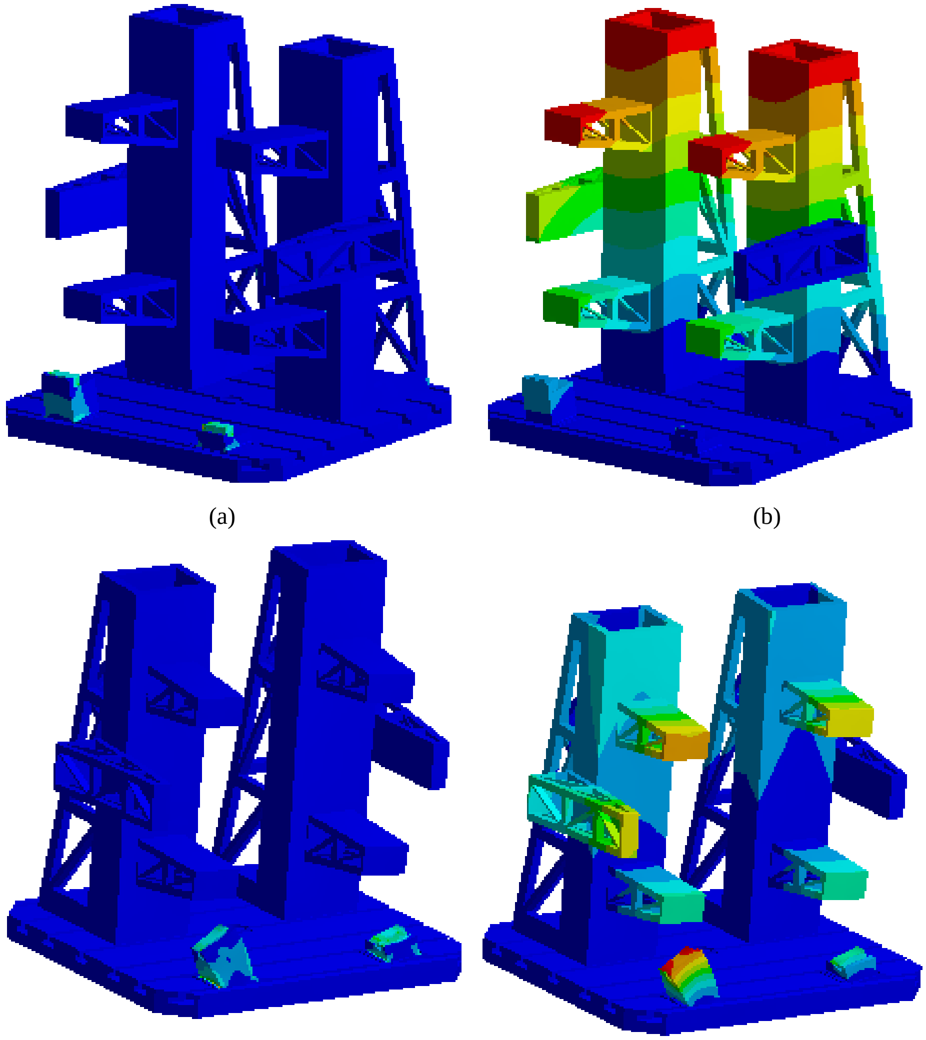


Fig. 4: Modified assembly model

B. Analysis of Existing Fixture:

The static structural and harmonic analysis have been carried out for modified fixture design same as existing design. The equivalent von-Mises stress and deformation have been determined for side and face milling as well as drilling operation. The values for the same are 2.83 MPa and 0.012 mm for side and face milling operation whereas 9.36 MPa and 0.167 mm for drilling operation as shown in Fig. 5 after static structural analysis.

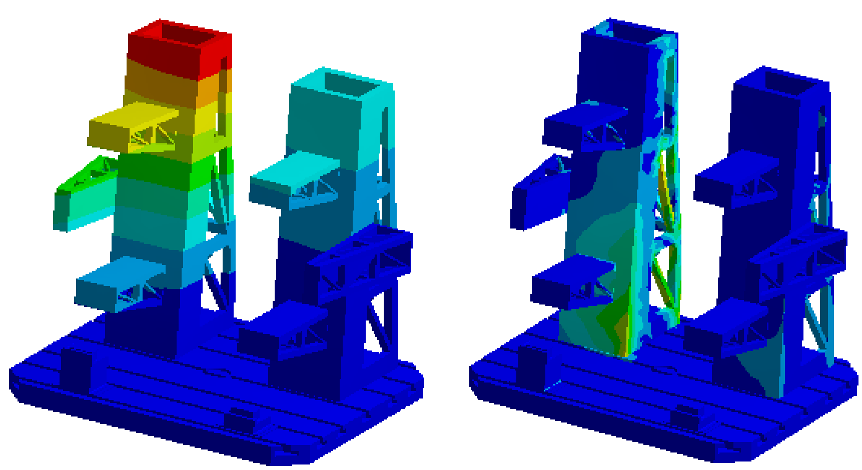


(a) (b)

(c) (d)

Fig. 5: Static Structural Analysis (A) Maximum Equivalent Stress = 2.83 Mpa And (B) Maximum Deformation = 0.012 Mm For Side And Face Milling Operations (C) Maximum Equivalent Stress =9.36 Mpa And (D) Maximum Deformation = 0.167 Mm For Drilling Operations

The equivalent stress, deformation, natural frequency, phase angle and amplitude have been determined using harmonic analysis with same boundary conditions as existing fixture. The values for the same are as 15.34 MPa, 0.5 mm, 58.9 Hz, 59.4° and 0.37 mm for side and face milling whereas 10.51 MPa, 0.37 mm, 82 Hz, 59.4° and 6.98 mm for drilling operation respectively as shown in Fig 6-7.



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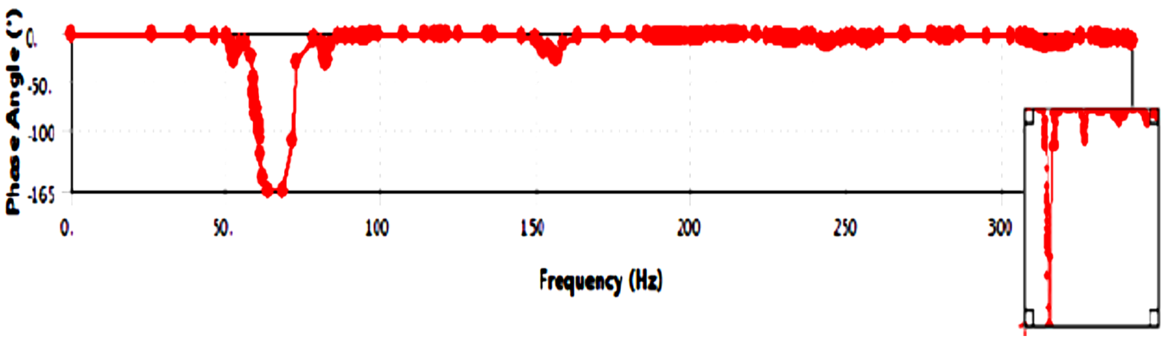

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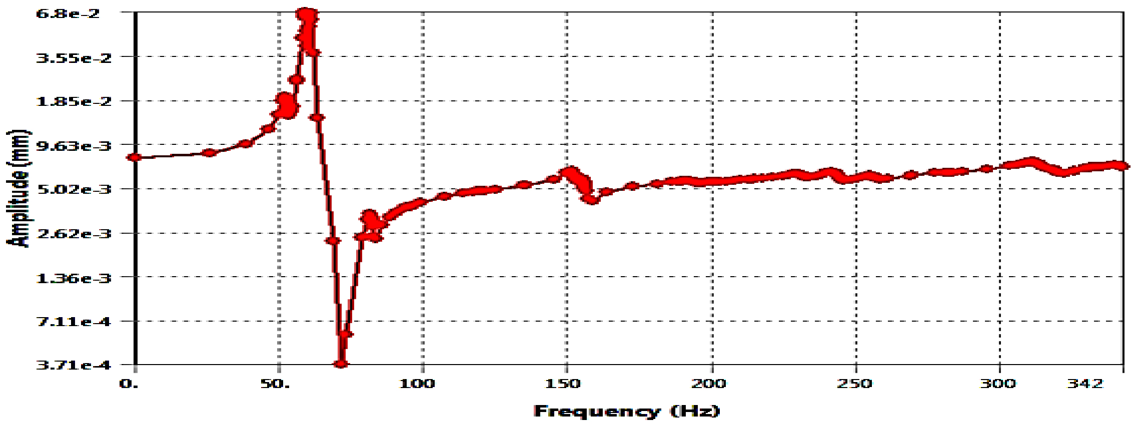
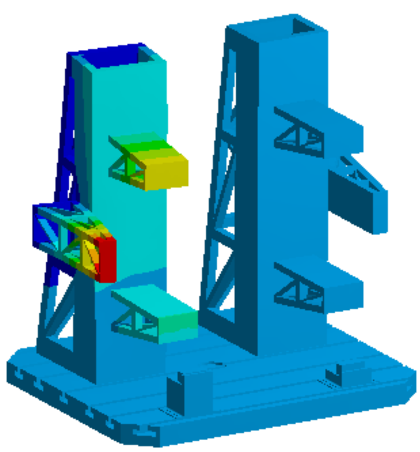


(d)

Fig. 6: Harmonic vibration analysis (a) maximum deformation = 0.5 mm, (b) maximum equivalent stress = 15.34 MPa, (c) phase angle = 59.4° (d) amplitude =0.37 mm & frequency = 58.39 Hz for side & face milling operation



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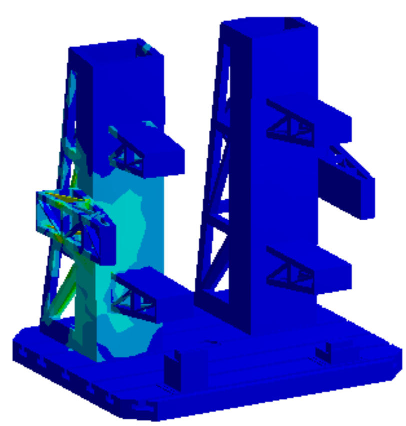

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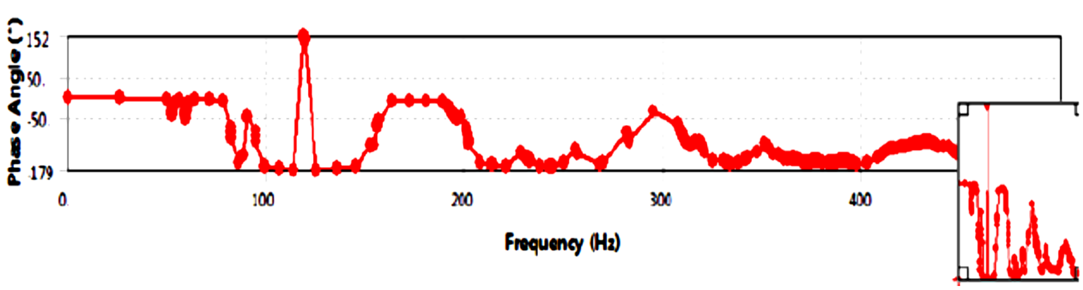

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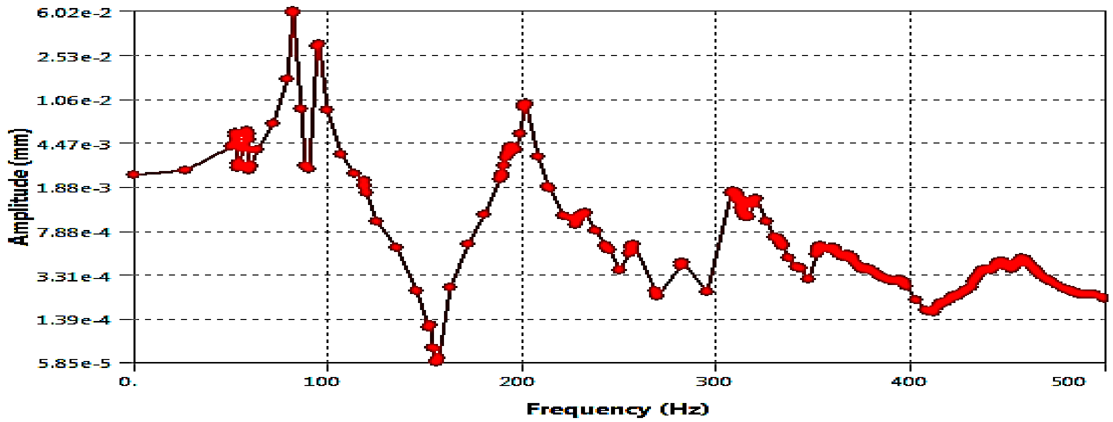

(d)

IV. Comparison of Modified Design with Existing Design of Fixture

The comparison of analysis results for the existing and modified model has been carried out for the static structural and harmonic analysis and same has been shown in Table 1 and 2 respectively.

Table – 1
Comparison of static structural analysis results for the existing and modified models

Operation	*Parameters*	*Existing Model*	*Modified Model*	*% Difference*
Side and face milling operation	*Equivalent stress (MPa)*	*3.21*	*2.83*	*11.84*
	Deformation (mm)	*0.084*	*0.012*	*85.7*
Drilling operation	*Equivalent stress (MPa)*	*9.36*	*4.23*	*54.8*
	Deformation (mm)	*0.167*	*0.009*	*94.6*

Table - 2
Comparison of harmonic analysis results for the existing and modified models

Operation	*Parameters*	*Existing Model*	*Modified Model*	*% Difference*
Side and face milling operation	*Equivalent stress (MPa)*	*137.8*	*15.34*	*88.87*
	Deformation (mm)	*3.29*	*0.5*	*84.80*
	Frequency (Hz)	*41*	*58.39*	*42.41*
	Amplitude (mm)	*0.698*	*0.37*	*46.99*
Drilling operation	*Equivalent stress (MPa)*	*171.25*	*10.5*	*93.87*
	Deformation (mm)	*6.31*	*0.37*	*94.14*
	Frequency (Hz)	*34.44*	*82.08*	*138.3*
	Amplitude (mm)	*1.05*	*6.98*	*56.48*

The comparison for harmonic analysis results for the existing and modified models have been shown graphically for better understanding. In the graph, blue colour bar is for existing model whereas orange colour bar is for modified design. The different parameters have been taken on X-axis whereas values for those parameters have been taken on Y-axis as shown in figure 8.

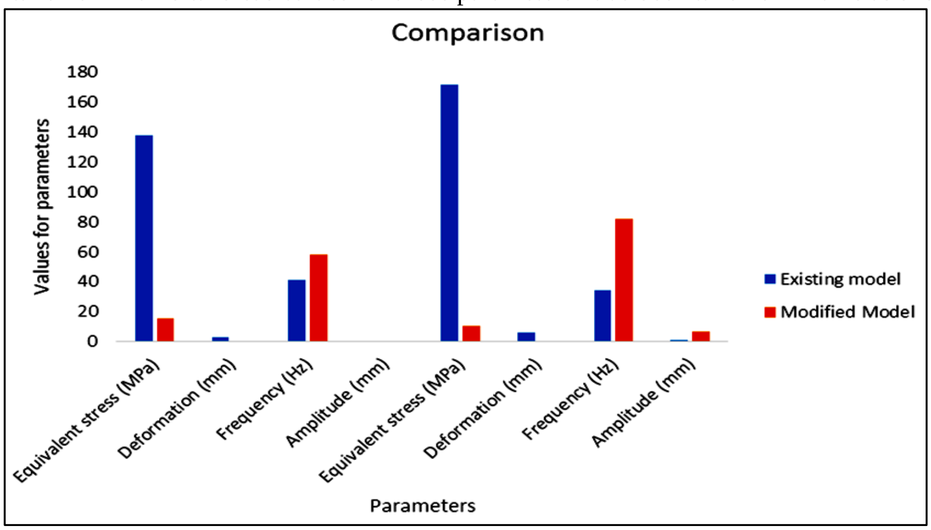

Fig. 8: Comparison of harmonic analysis results for the existing and modified models

V. CONCLUSIONS

The modified design model is universal type of fixture and has versatility to handle various steam turbine casings. Analysis of existing fixture shows low frequency and high equivalent stress value by static structural and harmonic analysis. By the addition of more truss members and some basic modification in fixture design helps to reduce equivalent stresses by 11.84 % and 54.8 % in side and face milling and drilling operations in static structural analysis. Based on harmonic analysis, modified fixture model helps in less vibration, less equivalent stress and less deformation. It has been found that frequency has been increased by 42.41 % and 138.3 % in side and face milling and drilling operations, whereas equivalent stress and deformation has been reduced by 88.87 % and 84.8 % in side and face milling operation whereas 93.87 % and 94.14 % in drilling operation respectively.

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