IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 11, Issue 5 Ver. VI (Sep-Oct. 2014), PP 40-45
www.iosrjournals.org

Design and Clamping Force Analysis of Vacuum Fixture to Machine Aerospace Components

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Abstract:*Machining of thin-walled (aluminium alloy) aerospace structures is a critical process due to the high warpage. Current practices in the fixture design and the choice of cutting parameters rely solely on conservative guidelines and the designer's experience.*

This paper presents evaluation of clamping force to fix the work piecein aVacuum fixture using Vacuum pump. The ISCARonline calculator is used to evaluate tangential and axial cutting force for a milling cutter. The component is practically subjected to forces (Axial &Tangential), are analysed and the optimum amount of clamping force necessary to hold the component for proper machining is calculated, using mathematical equations and shop formulas, which is then compared to finite element (FE) predictionsunder static analysis and Modal analysis at different modes, arriving at experimental and practical results, and at that particular time, how the cutting forces are acted is observed. Fixtures are designed in CATIA V5.
Key words: *Clamping Force, Fixture Layout, H FRAME and Modal analysis.*

I. Introduction

The company manufactures aerospace components. It has the facilities that can produce precision parts. In order to arrest the part at one particular location with respect to the machine, we will need a tool. This tool also helps in holding the component while it is machined. It ensures that the part does not lose its location, does not fly away or deform. All these parameters are taken into account and such tool is designed. These tools are Vacuum fixtures. When component has very small web thickness, providing mechanical clamps will not serve the purpose. Also bolts and screws are avoided. No holding device will ensure maximum or optimum clamping. In such cases vacuum fixtures are used. The mass production is running at success range depends upon the interchangeability to facilitate the reduction of unit cost and the easy assembly. A mass production method demands fast and easy methods of positioning work for accurate operations on it. Jigs and fixtures are production tools used to accurately manufacture duplicate and interchangeable parts. Jigs and fixtures are specially designed so that large number of components can be machined or assembled identically, and to ensure interchangeability of components.

Aim of this presented paper is to improve the design of the Vacuum Fixture by increasing the grid (in other words clamping area) in such a way that uniform clamping force is applied throughout the web of the rectangular frame while machining, to ensure that the part does not deform at high. The results are compared with mathematical calculations and then compared in ANSYS Software.

Four Sections were given in this paper. In Section 2, Literature review is presented. In Section 3, modelling of a fixture with the component is shown and solution methodology is presented. In Section 4, emphasis stress analysis and vibration analysis for the component. Results and discussions are also given in this section. Finally the conclusions are drawn in Section 5.

II. Literature Review

Li B *et al*. [1] have given the method to solve the clamping force optimization where the locators were assumed as deformable and the work piece as rigid body. The optimum clamping force is found to reduce the location error duo to the application of the machining forces.

Mohsen Hamedi *et al*. [6] have designed fixtures for machining operations; clamping scheme is a complex and highly nonlinear problem that entails the frictional contact between the workpiece and the clamps. Such parameters as contact area, state of contact, clamping force, wear and damage in the contact area and deformation of the component are of special interest.

Necmettin Kaya *et al*. [7] have used dynamic analysis to find out the deformation of the workpiece under machining. The entire tool path is discretized into 13 load steps. The workpiece-fixture model is analyzed with respect to tool movement. The workpiece is assumed to be elastic. The fixture is assumed as completely rigid.

Krishna Kumar *et al*. [4] used FEM to simulate the machining operation. The machining forces are considered as point force acting over the tool path. Static analysis is performed to simulate the machining operation. In which the material removal effect is not considered.

III. Solution Methodology

Methodology is first we select the machining parameters, fixing the number of locators, selection of fixture layout, calculation of the clamping force and cutting forces based on the mathematical and shop calculations and optimize the clamping force and observe the deformations of the H FRAME workpiece.

S NO	TYPE OF OPERATIONS	END MILLING
1	Cutter diameter	50 mm
2	Number of flute	4
3	Spindle speed	6000 (rpm)
4	Feed	4.064 (mm/min)
5	Radial depth (65% of cutter dia)	32.5 mm
6	Axial depth	4.826 mm
7	Helix angle	35°
8	Radial rake angle	2°
9	Cutter type	Insert type

Table 1. Shows the Machining Parameters

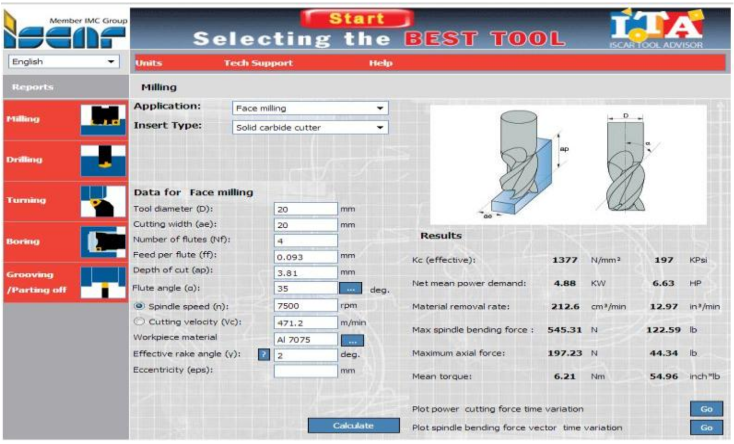


Fig.3.1 shows the calculations of cutting forces.

Theory of calculations: Calculations to find the necessary vacuum clamping force can be the utmost complicated. In many situations, however, for the milling operations, approximate determinations of these values are adequate. Required clamping force can be calculated based on cutting forces on applied on the work piece.

Required Clamping force = (Cutting Force ÷ Static friction of coefficient) × Factor of safety

Balancing force-moment method: Equilibrium occurs when the sum of all forces in the x, y andz direction is zero and the sum of moments at any point is zero.

$$\Sigma F = 0, \quad \Sigma M = 0$$

S NO	GRID(VACUUM AREA)	CUTTING FORCES	CLAMPING FORCES
CASE 1 BEFORE GRID IMPROVEMENT	9149mm^2	Tangential=103.67N Axial=197.23N	772.59N
CASE 2 AFTER GRID IMPROVEMENT	45038mm^2	Tangential=103.67N Axial=197.23N	3715.48 N

Table 2. Calculation Details based on milling cutter

MODELLING OF A FIXTURE AND H_FRAME COMPONENT

With the help of CATIA,3D model of vacuum fixture and h-frame component is developed and is shown in fig. 3.1 and 3.2. The mesh model of the H frame is carried out in hypermesh due to complexity and is shown in the fig. 3.3.

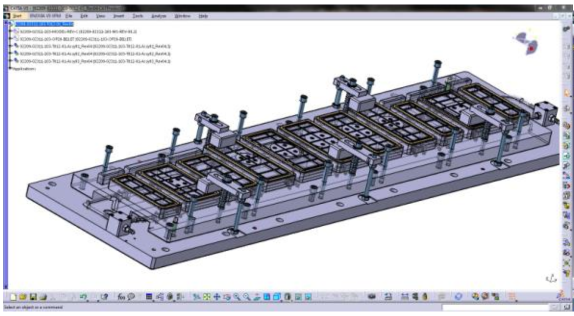


Fig 3.1 shows the catia model of Vacuum Fixture

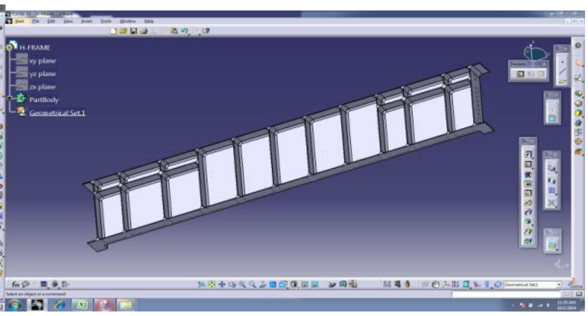


Fig 3.2 shows the 3D model of H_Frame

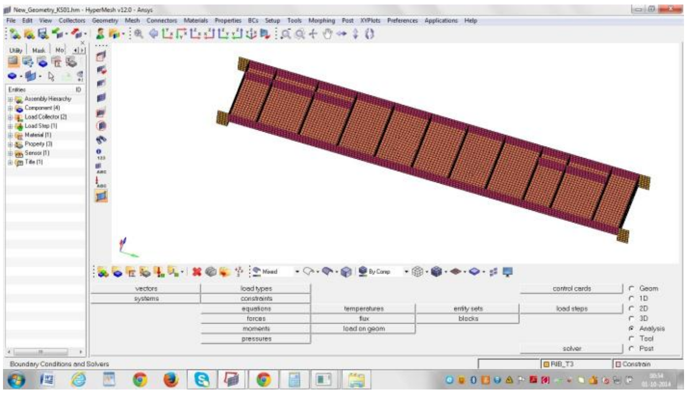


Fig 3.3 shows the meshed body of the H-frame

IV. Simulation Results And Discussions

4.1 STATIC ANALYSIS

This section covers the Finite Element Analysis of thin walled H-frame component in Ansys to verify the von – mises stresses which acts on the machining area and deflections created on the component. Following material properties have been taken to analysis of an H-frame under static condition.

MATERIAL PROPERTIES

Alluminium-7075 T7351 properties:

Young's Modulus (Ex) = 72Gpa
Poisson's Ratio = 0.33
Density = 2810Kg/m3 or 2.81e $^{-6}$kg/mm^2
Yield Strength –(331-393)Mpa
Tensile Strength – (421-476)Mpa

ELEMENT TYPE USED:

Element: Shell 63
Number of Nodes: 4
Number of DOF: 6 (Ux, Uy, Uz, Rotx, Roty,Rotz)

The 3D structure meshed with 4 Noded shell 63 elements. Vacuum pressure is acted on the suction slots at bottom side of the H Frame. The total vacuum pressure is divided into each slot and the obtained value is distributed on the bottom surface of the h-frame.

The result obtained from the simulation is shown in fig.1, 2, 3&4. Fig. 1 shows the deformation of the component and Fig. 2 shows the von-mises stresses, Fig. 3 shows the 1st principal stresses and Fig. 4 shows the 2nd principal stresses.

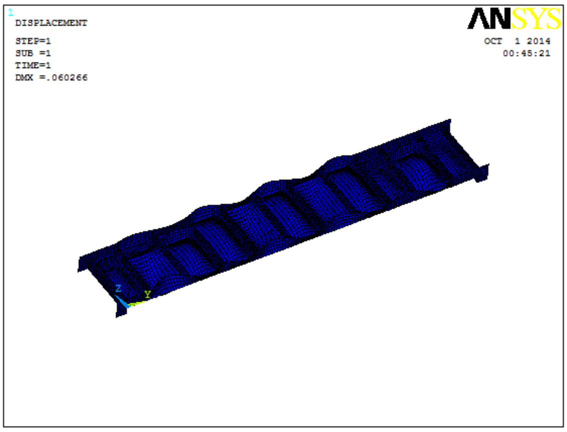


Fig 1 shows the deformation of H-FRAME

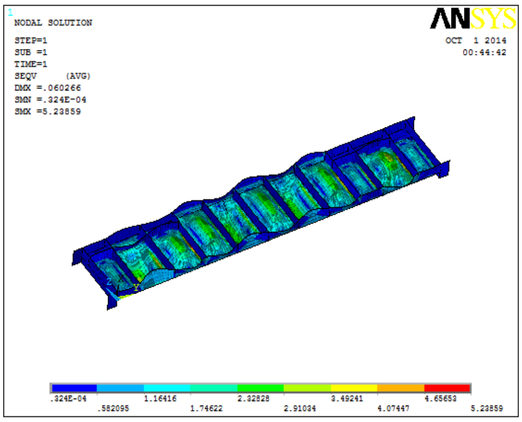
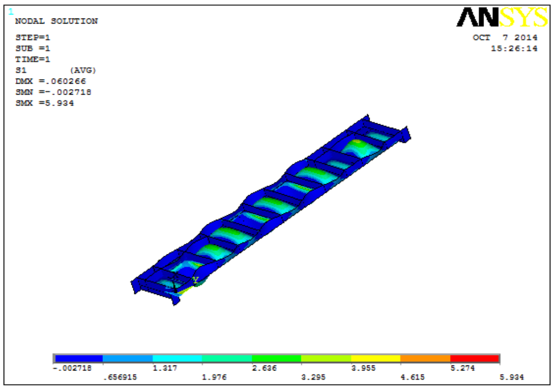


Fig2 shows the Von Mises stress of H-FRAME



`**Fig. 3** shows the 1st principal stresses

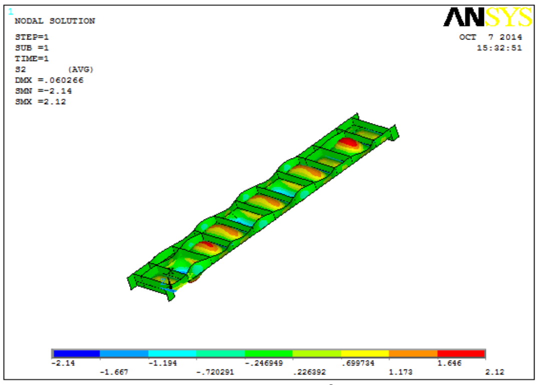


Fig. 4 shows the 2nd principal stresses

SL NO	DESCRIPTION	MAX DEFLECTION	MAX STRESSES
1	**Deformations**	0.060266	0.060266
2	**1st Principal stress**	0.060266	5.934
3	**2nd principal stress**	0.060266	2.12
4	**Von mises stress**	0.060266	5.239

Table.1 shows the details of static analysis.

Thus, the energy density for the givenmaterial condition, the critical value of the distortional material is given by the below equation. According to von Mises's failure criterion, the material under the loading of multi-axial point will yield when the distortional energy is greater than or equal to the critical value of the given material.

$$\frac{1+\nu}{3E}\sigma_{VM}^2 \geq \frac{1+\nu}{3E}\sigma_Y^2$$

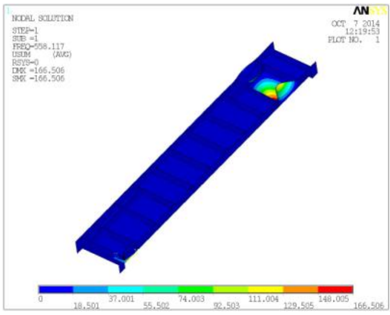
$$\therefore \quad \sigma_{VM} \geq \sigma_Y$$

So, by observing from the above explanation, the von mises stresses should be equal or greaterthan yield strength. Due to this fabrication process, induced stress due to cutting loads is 1/10th of the yield stress, so it will not affect the geometry of the component.

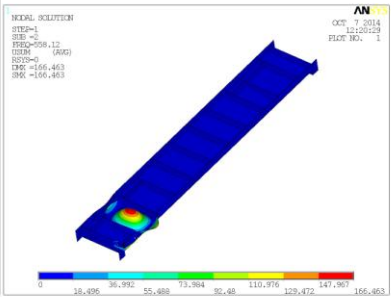
4.2 MODAL ANALYSIS:

The vibration characteristics (mode shapesand natural frequencies) of a machine component while it is being machined, the results are obtained by the modal analysis.

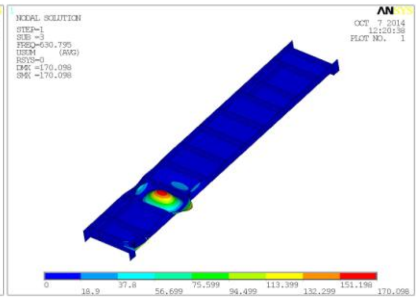
PCG LANCZOS Modal extraction method was carried out on H-FRAME component to determine the natural frequencies and mode shapes of a structure in the frequency range of 500-800 Hz.



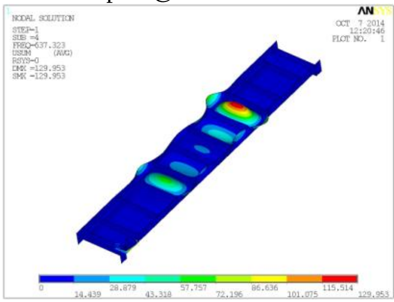
Mode shape 1@ 558.117Hz



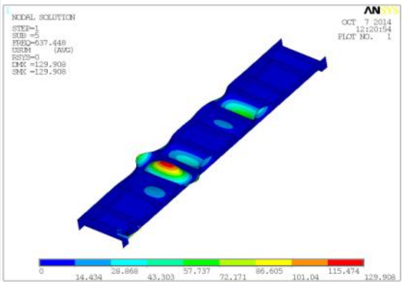
Mode shape 2@ 558.12Hz



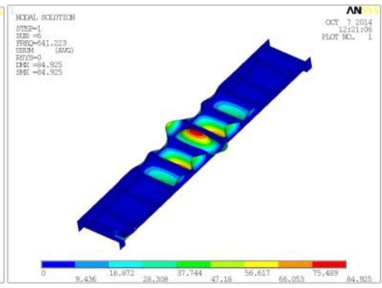
Mode shape 3@ 630.795Hz



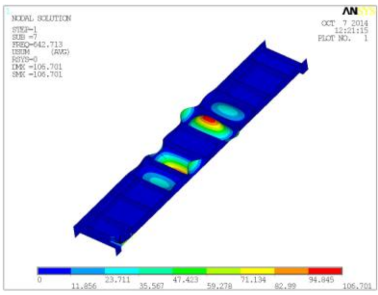
Mode shape 4@637.323Hz



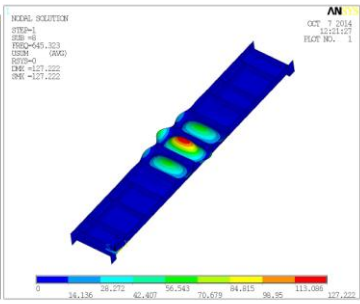
Mode shape 5@637.448Hz



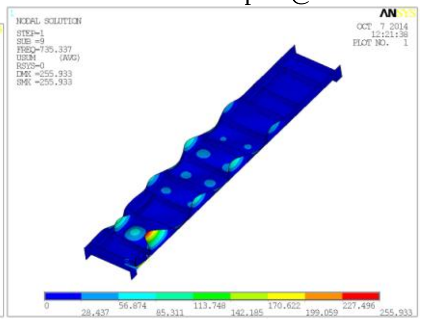
Mode shape 6@ 641.223Hz



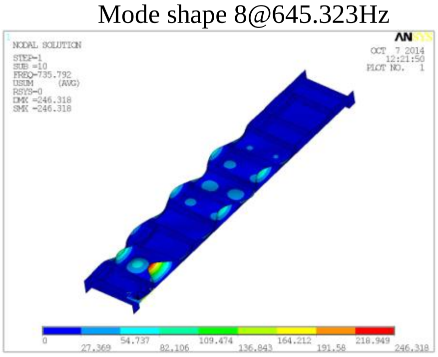
Mode shape 7@642.713Hz



Mode shape 8@645.323Hz



Mode shape 9@735.337Hz



Mode shape 10@ 735.792 Hz

Fig. 4.6 shows mode shapes of H-frame component.

The fig 4.6 shows the pattern of extracted mode shapes of aluminium alloy AL 7075-T7351 work piece, it is observed and evident that the mode shape 8^{th} has more deformation at frequency of 645.323Hz.It is also observed that under the range of(500-800)frequency are induced. Out of which the mode shape 8^{th} is critical and it may fail at 645.323Hz frequency.

V. Conclusion

The minimum clamping force which are enough to hold the workpiece are determined. The balancing force-moment method is used to determine the clamping force. The maximum value among these calculated values are taken as the optimum clamping forces and designed the vacuum fixture to hold the work piece in a fixture while machining. The deformation and the stresses induced in the work piece due to machining are predicted by performing static analysis using ANSYS. The modal analysis also carried out to find out the behavior of component in application. Thedeformations and frequencies are found to be within the safe conditions.

Acknowledgements

Authors thanks the Head of the department mechanical engineering and Director, SreeNidhi Institute of Science and Technology Hyderabad, Tata advanced systems limited (TATA SIKORSKY JV) Hyderabad, for extending all sort of help in bringing out this technical paper.

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