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Modeling and Analysis of Mounting Plate of a Rotary Compressor

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Abstract: *Compressors are fitted with mounting plates and is welded to the compressor bottom and through the holes of this plate; the compressor gets mounted on to the A/C housing. The vibrations from the compressor get transferred to the A/C housing there by producing noise, which is undesirable. These vibrations will be greater enough to produce noise when the natural frequencies of the compressor, the mounting plate and the A/C housing coincide resulting in resonance. In this work the static analysis of the plate with three different PCDs are modelled and analysed. The natural frequencies of the mounting plate and the corresponding mode shapes are plotted. Three different models have been considered for analysis and the investigations are carried out. The analysis results of the existing model are compared with two different models and the results are compared. Upon analysis of the three models, the better one out of them is suggested.*

Keywords: *Compressor plate; PCD; thickness of plate, modal analysis; Lancozos method*

I. Introduction

Compressor is the heart of the refrigeration circuit. It pumps and pressurizes the refrigerant to move it through the A/C system. Compressors work hard and run hot, up to several hundred degrees and several hundred pounds per square inch of internal pressure. They rely on only a few ounces of lubricant to keep their parts moving. If the lubricant is lost because of a leak, or the lubricant breaks down due to contamination, the compressor will not last. Sooner or later, the compressor will call it quits. A helical screw rotary compressor for a closed loop refrigeration system such as an air conditioning system for a bus or like vehicle is connected in series with a condenser and an evaporator, in that order, with the evaporator at a raised position relative to the compressor and utilizes a vaporizable refrigerant which is miscible with a lubricating oil employed to lubricate the moving components of the screw compressor. A slide valve underlies the intermeshed rotors and forms a portion of the screw compressor envelope, the rotors opening to a suction port connected to the outlet side of the evaporator above the rotors. A high pressure discharge port at one end of the intermeshed rotors leads to an auxiliary chamber bearing an unload cylinder which drives the slide valve and which opens at the top to a housing discharge port leading to the condenser. An oil separator is interposed within the auxiliary chamber above the unload cylinder. An oil drain passage leads from the auxiliary chamber to an oversized oil sump within the housing beneath the rotors. The slide valve slides in a recess within the casing underlying the rotors. This structural arrangement permits all condensed refrigerant and the oil to return by gravity flow to the oil sump whose capacity is at least 1.5 times the volume of the normal oil charge for the system. Condensed refrigerant miscible in the oil and the oil entraining the refrigerant, upon compressor shut down, accumulates in the sump but does not reach the intermeshed rotors and thus prevents clutch burnout by liquid locking during initiation of compressor operation with the clutch mechanically connecting the engine to the intermeshed helical screw rotors.

II. Problem Definition

Mounting Plate of a rotary compressor in use is having PCD of 211mm. As per the requirement there is a change of PCD of the mounting plate from 211mm to 176mm. This work deals with the Static, Modal and Harmonic analysis on 211mm PCD plate and for the stability over the 176mm PCD plate there by suggesting a better mounting plate for the compressor performance.

III. Literature Review

There have been some problems because of the vibrations caused by the compressor and these getting transmitted to the Air conditioner housing. So the analysis of compressor's various parts is being done to find out the main source of vibrations. The frequency analysis of compressor was carried out with theoretical modeling by Karczub,D.G [1], and Gorman [2] work gives the vibration studies of compressors. According to Bloch, H.P. and Hoefner, J.J.[3], Rotary compressors are most commonly used in sizes from about 30-200 hp. The most common type of rotary compressor is the helical twin screw-type (also known as rotary screw or helical lobe). Male and female screw-rotors mesh, trapping air, and reducing the volume of the air along the rotors to the air discharge point. Rotary screw compressors have low initial cost, compact size, low weight, and are easy to maintain. Rotary screw compressors are available in sizes from 3-600 hp and may be air- or water-cooled. Less common rotary compressors include sliding-vane, liquid-ring, and scroll-type. The harmonic analysis was performed by John P. Wolf [4]. Akella S, 1992[5] was used a finite element approach for the modal analysis.The finite element solvers[6-7] are used in the present work by adopting the method described by[8]. In this process, to study the Compressor Housing for PSD Analysis of Hermetic Sealed Rotary Compressor was done [9]. In this work, study was carried out on various thicknesses of the compressor housing.

IV. Modeling and Analysis of Mounting Plate

The compressor's Mounting Plate is a sheet metal model that is modeled in UNI GRAPHICS. Three models are made, which the three cases are considered in this work are: 211mm Regular plate, 176mm Regular plate, 176mm Flat Plate. Here in these three models, 211mm and 176mm regular plates have the same design and 176mm Flat plate is considered with the only objective that the tooling cost can be reduced by avoiding the curves in the model. Hence the models of 211mm and 176mm looks similar. Final geometric model is shown in Fig.1. The final geometric model is imported to Hypermesh for the refined mesh. A convergence check is made by quality checks on the elements. By maintaining same number of elements on each of the surface around the mounting holes, node to node connectivity is obtained. Automatic and manual smoothening options the model is refined and mesh quality is maintained. The Shell93 (Fig.2) element type from Ansys library is selected for the mesh generation and this is imported to Ansys FEA software for the analysis. SHELL93 is particularly well suited to model curved shells. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes. The deformation shapes are quadratic in both in-plane directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities. The converged mesh is shown in Fig. 3.

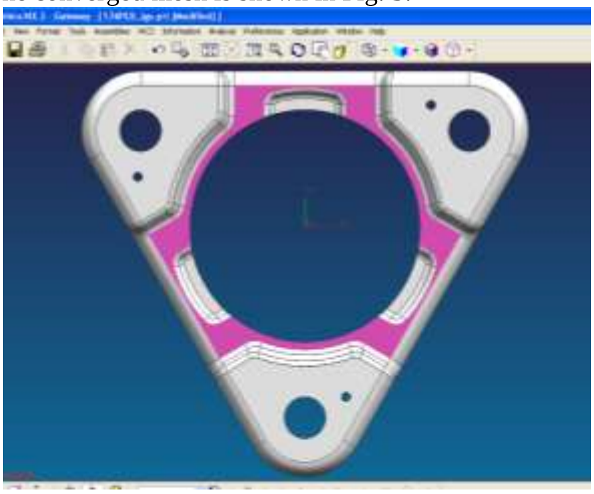


Figure 1: The geometric model of mounting plate

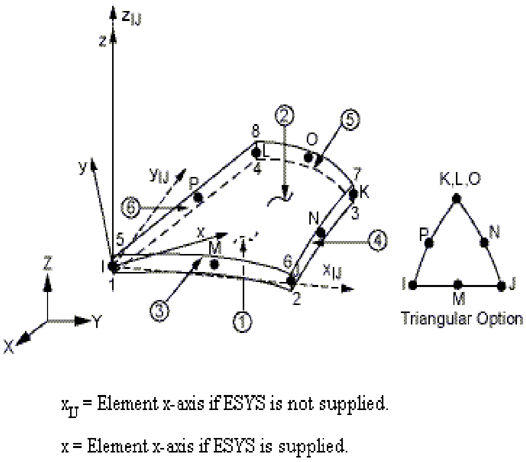


Figure 2: Shell93 element geometry

The material used for making the compressor is steel. The properties of the steel are density =0.284 Lb/in³ (7800 kg/m^3), Young's modulus= 2.9e7 Lb/in^2 (2e5 N/mm^2), Poisons ratio=0.275, Plate thickness=0.113 in (2.872mm), Overall Force Applied= 52.93 Lb (Weight of the Compressor) (238.2 N). The Mounting Plate is constrained at the three holes where it will be bolted to the A/C Housing. So these three holes edge nodes are selected and are constrained in all the three directions (i.e. along x, y and z). Compressor will be welded to this plate at the center such that the plate and the compressor are concentric. The compressor weight will be acting along the circumference of the compressor housing shell and thus the whole weight of the compressor is considered and is applied as a dead weight along the circumference by selecting the nodes on it. The weight is so divided that the whole weight is distributed to each node equally.

Static Analysis: A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. A static analysis can, however, include steady inertia loads (such as gravity and rotational velocity), and time-varying loads that can be approximated as static equivalent loads (such as the static equivalent wind and seismic loads commonly defined in many building codes). Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.

Modal Analysis: Modal analysis is to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It also can be a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic response analysis, or a spectrum analysis. The natural frequencies and mode shapes are important parameters in the design of a structure for any loading conditions. They are also required to do a spectrum analysis or a mode superposition harmonic or transient analysis.

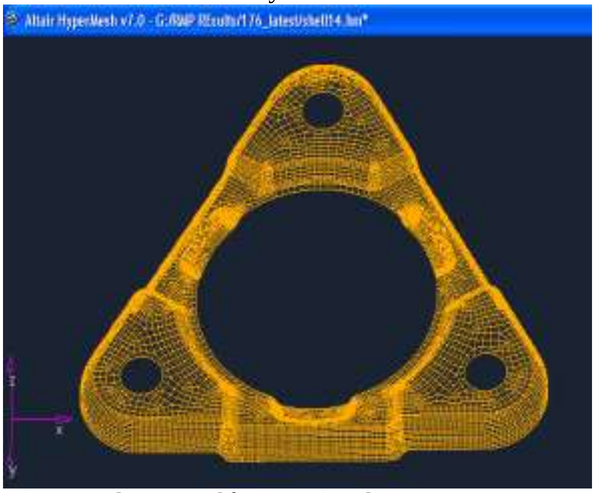


Fig. 3: Mesh generated for mounting plates

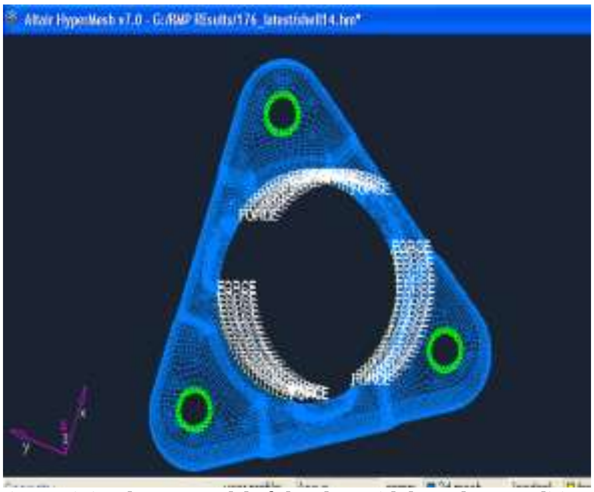


Fig. 4: Finite element model of the plate with boundary conditions

V. Results and Discussions

The static analysis of 211mm PCD mounting plate with static loading is shown in Fig5. Fig. 5 shows variation of deflection in the mounting plate under static loading condition. The static load applied is the weight of the compressor applied along the inner circumference of the mounting plate. From the figure it is observed that the maximum displacement of 0.04.656mm (0.00164 in) has occurred at a point on the inner circumference near Leg-1, which is shown as MX in the Fig.5. Under the same static loading condition, Fig. 6 shows the variation of Vonmises stresses. From the figure it is observed that the maximum stress in the plate is 37.36 MPa (5419.00 Lb/in²).

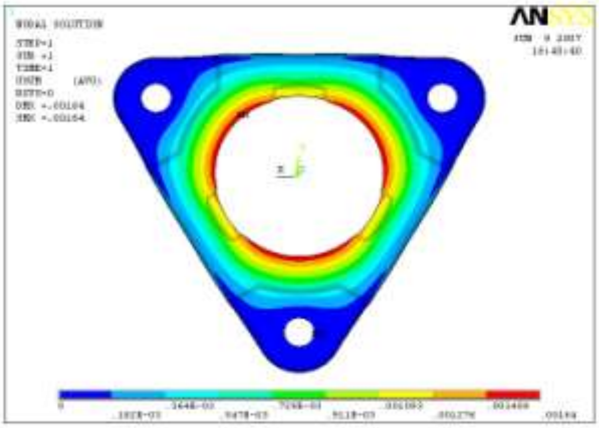


Fig. 5: Maximum deflections induced, 0.00164 in (0.04165 mm)

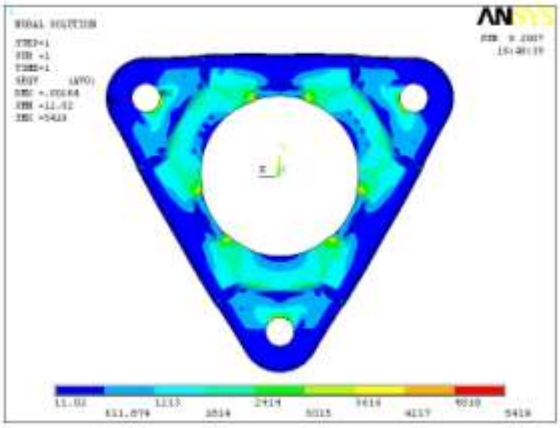


Fig. 6: Maximum Vonmises stresses, 5419 lb/in²(37.36 MPa)

176mm PCD of Mounting Plate: Considering the second case of the mounting plate, i.e 176mmPCD of mounting plate is considered and same load is applied on to this plate as well. The variation of deflection in the mounting plate under static loading condition is observed that the maximum displacement of 0.037364mm (0.001471 in) has occurred at a point on the inner circumference near Leg-1, the variation of Vonmises Stresses. is observed that the maximum stress in the plate is 67.44 MPa (9782.00 Lb/in²).

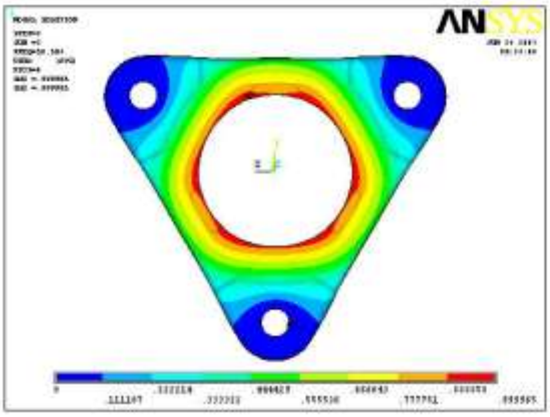
176mm PCD Flat Mounting Plate: Now considering the Third case of the mounting plate, that is 176mm flat mounting plate. The variation of deflection in the mounting plate under static loading condition is observed that the maximum displacement of .027356mm (0.001077 in) has occurred at a point on the inner circumference near Leg-1 where as the variation of Vonmises stresses observed that the maximum stress in the plate is 62.42 MPa (9053.00 Lb/in²).

Modal Analysis: Modal analysis results in Mode shapes with Natural Frequencies of the model. In modal analysis, Normalization of the Mode shapes is taken to Unity. Taking to Unity, the mode shapes when taken individually for each Translational and Rotational directions of each mode step, the orientation in which the mode shape will be equal to or near to Unity is the direction of the mode shape. When Normalization of the mode shape is taken to Mass Matrix, the resulted mode shape will be the value of deflection of the overall vector sum and not for the individual direction. Modal analysis of the three mounting plates considered resulted in First 10 Natural Frequencies and are as listed table1.

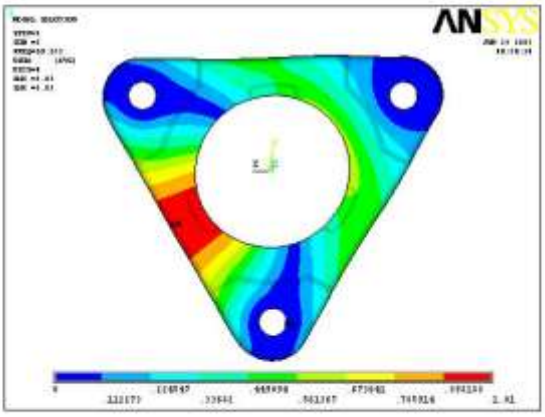
Table 1: Natural frequencies in the mounting plate with varying PCD

Natural frequencies (Hz)			
Set	Mounting Plate		
	211mm	176mm	176mm Flat
1	58.564	89.064	66.088
2	59.571	89.071	66.261
3	59.572	98.912	67.076
4	78.688	127.48	116.42
5	78.688	127.54	128.63
6	98.564	131.82	129.16
7	103.55	140.29	142.85
8	131.66	170.51	160.06
9	131.66	170.52	160.67
10	147.95	181.99	177.92

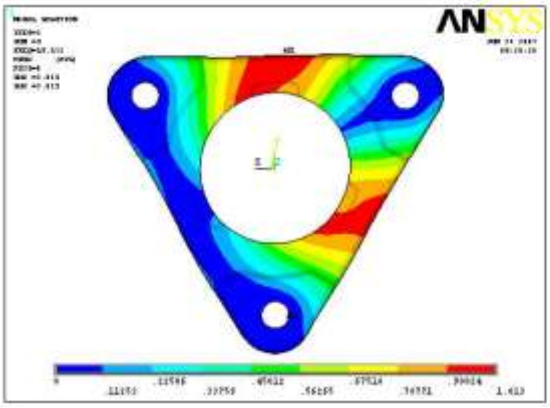
From Table:1 it is evident that the fundamental frequency of the three mounting plates are for 211mm mounting plate: 58.564 Hz, 176mm Mounting Plate: 89.064 Hz and 176mm flat mounting plate: 66.088 Hz respectively. The working frequency range of the compressor is found to be 45-55 Hz. The First 10 natural frequencies range of 211mm Mounting Plate is from 58.564 Hz to 147.95Hz. For 176mm Mounting Plate is form 89.064 HZ to 181.99 Hz. And for 176mm Flat Mounting Plate is form 66.088 Hz to 177.92 Hz. From this table it can be seen that the plates 211mm and 176mm Flat are having a natural frequency nearer to the working frequency range and the displacements or deformations in the plates need to be found out to select the optimized plate which meets the functionality. The plate that has the minimum deflections in the working frequency range will be the best suit for meeting the functionality. The mode shapes formed can be in any one of the 6 directions, one of the 3 Translational directions or one of the 3 Rotational directions. Initial few mode shapes are found out to be in Translational direction along the direction of Force, i.e. along Z direction. And the later ones are having Rotational direction of the mode shape. The first 6 modes of mounting plate of 211mm PCD is shown in Fig.7 and Fig.8 and 9 shows the mode shapes of other two mounting plates.



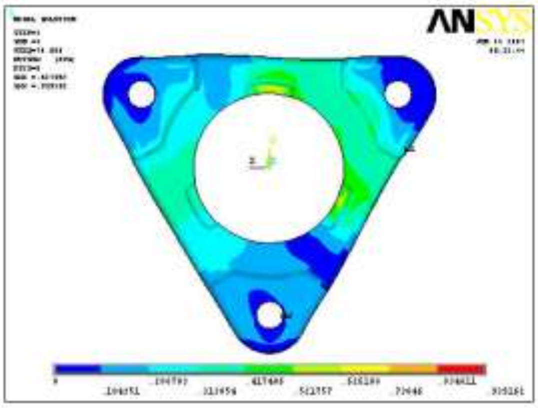
a. 1st mode shape at 58.564Hz



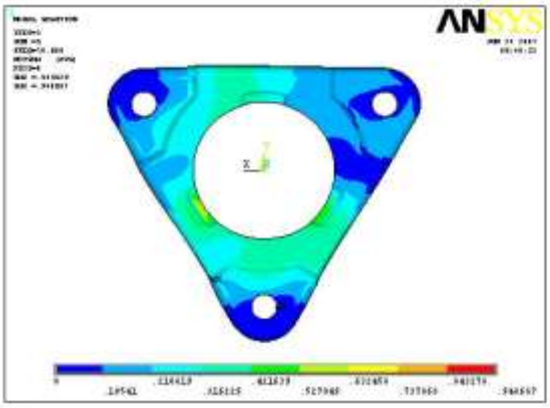
b. 2nd mode shape at 59.571Hz



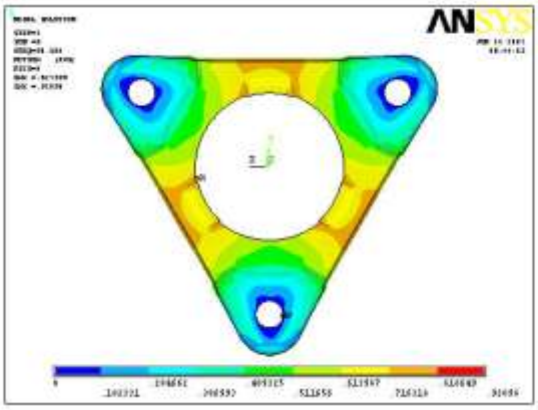
c. 3rd mode shape at 59.572Hz



d. 4th mode shape at 76.688Hz

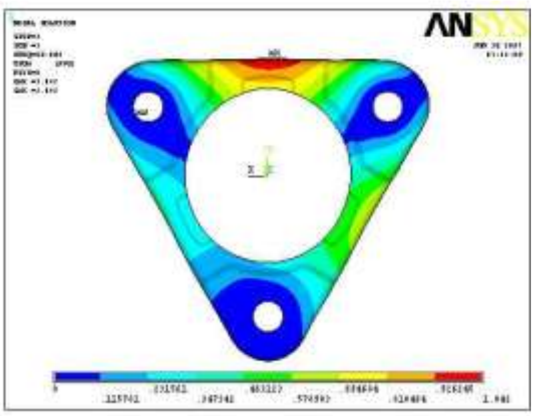


e. 5th mode shape at 78.688Hz

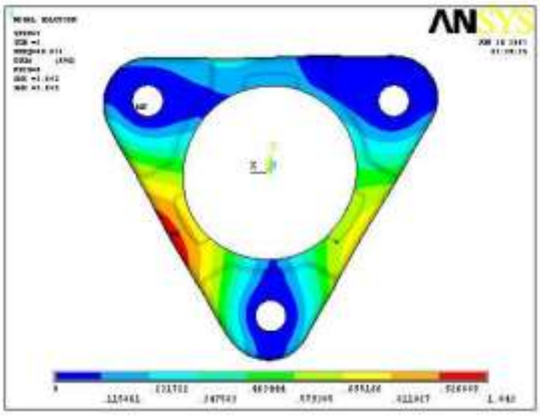


f. 6th mode shape at 98.564Hz

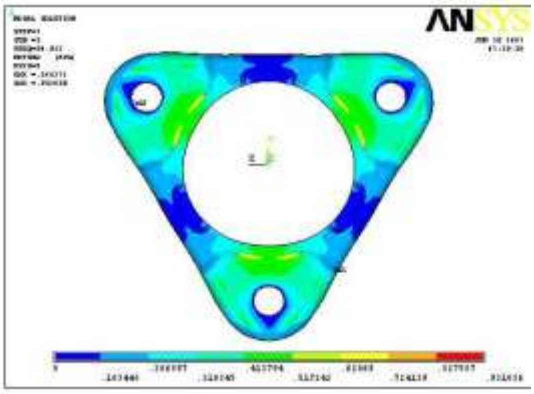
Figure 7: The first 6 modes of 211mm PCD mounting plate



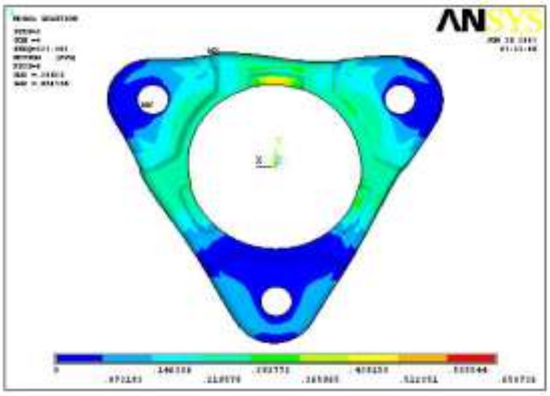
a. 1st mode shape at 89.064Hz



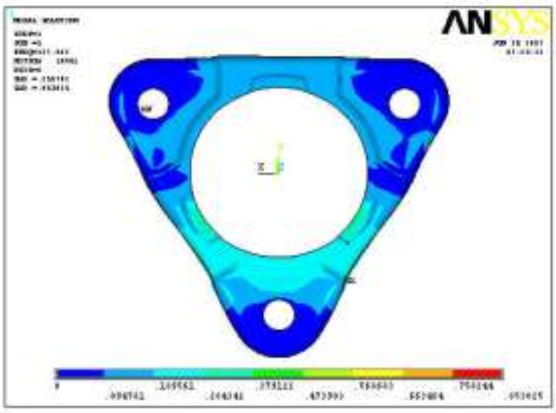
b. 2nd mode shape at 89.071Hz



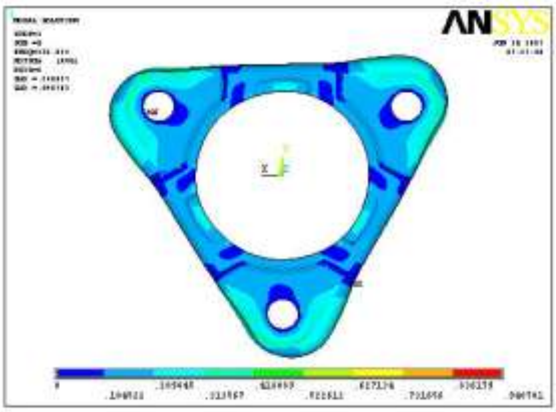
c. 3rd mode shape at 98.912Hz



d. 4th mode shape at 127.48Hz

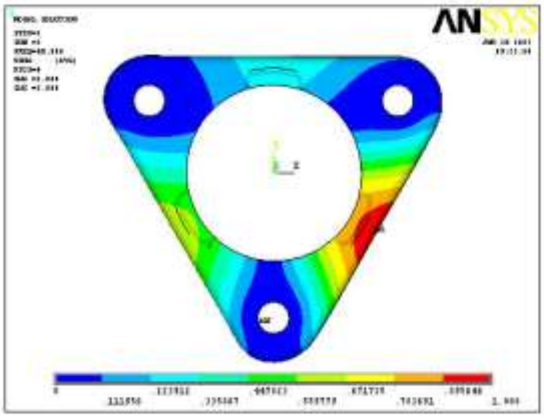


e. 5th mode shape at 127.54Hz

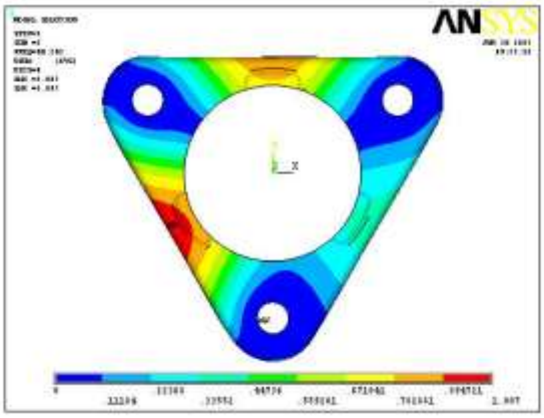


f. 6th mode shape at 131.82Hz

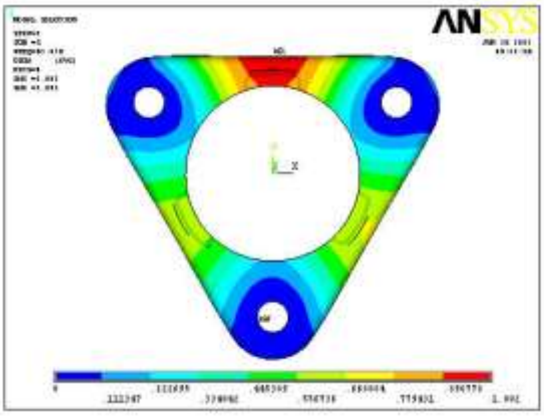
Figure 8: The first 6 modes of 176mm PCD mounting plate



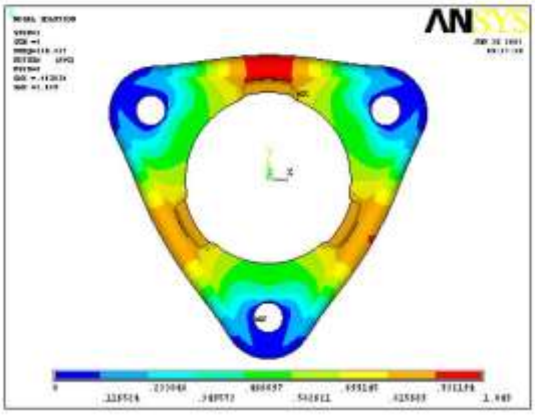
a. 1st mode shape at 66.088Hz



b. 2nd mode shape at 66.261Hz



c. 3rd mode shape at 67.076Hz



d. 4th mode shape at 116.42Hz

Figure 9: The first 4 modes of 176mm PCD mounting plate

VI. Conclusions

Maximum displacement and stress in Z direction for 211mm PCD plate is observed to be 41.656µm and 37.36 MPa respectively. 211mm PCD Plate has the fundamental frequency of 58.564Hz and it results in higher amplitude of vibrations. The First maximum displacement of 4.53E-05” (1.15µm) occurred at a frequency of around 60Hz. Maximum displacement and stress in Z direction for 176mm PCD plate is observed to be 37.36µm and 67.44 MPa respectively. 176mm PCD Plate has the fundamental frequency of 89.064Hz. So this mounting plate doesn’t cause much of vibrations. First maximum displacement of 5.68E-04” (4.26µm) occurred at a frequency of around 90Hz Maximum displacement and stress in Z direction for 176mm PCD Flat plate is observed to be 98.47µm and 62.42 MPa respectively. 176mm PCD Flat Plate has the fundamental frequency of 66.088Hz and so results in causing much of vibrations. First maximum displacement of 1.18E-04” (2.99µm) occurred at a frequency of around 70Hz. By increasing the thickness of the Mounting Plate, frequency shift is possible.

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