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# Harmonic Analysis of Rotary Compressor using FEA

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***ABSTRACT***

***By theoretically analyzing dynamic behavior of the crankshaft, the rolling piston and the blade in Rolling-Piston Rotary Compressors, constraint forces and sliding speed at each pair of movable machine elements are obtained, and unbalanced inertia forces and compressor vibrations are evaluated. Natural Frequencies for compressor housing with and without Base frame are estimated using Ansys.***

***Key Words:*** ***Harmonic analysis, Frequency and sub steps, amplitude, Modal frequencies, mounting plate***

## 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.

## 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 frequency response analysis with self-weight excitation over the frequency range on 211mm PCD plate and for the stability over the 176mm PCD plate there by suggesting a better mounting plate for the compressor performance.

## LITERATURE REVIEW

There have been some problems because of the

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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 modelling 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[6-9] are used in predicting the response and modal frequencies of the compressor and 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 [10-15]. In this work, study was carried out on various thicknesses of the compressor housing.

## MODELING AND MESHING OF THE PLATE

The compressor's Mounting Plate is modelled in UNI GRAPHICS software with three different models: 211mm Regular plate, 176mm Regular plate, and 176 mm 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 hyper mesh 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 Fig3.

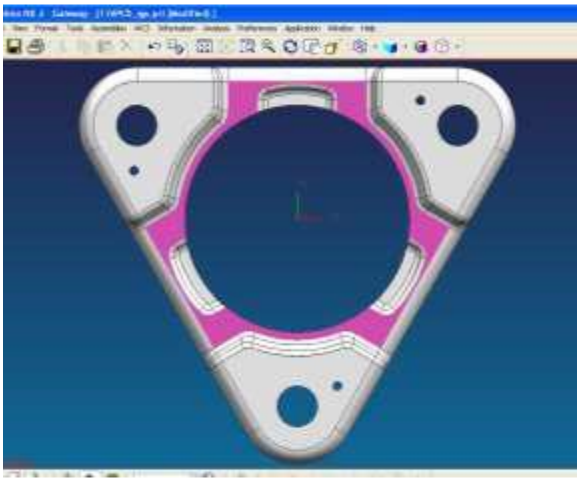

*Figure 1: The geometric model of mounting plate*

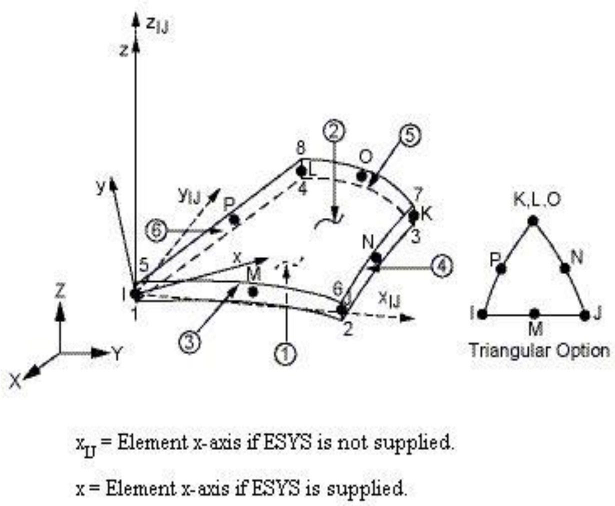


*Figure 2: Shell93 element geometry*

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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.

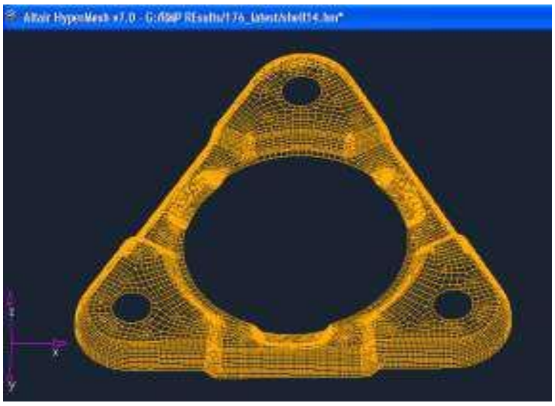

*Figure 3: Mesh generated for mounting plates*

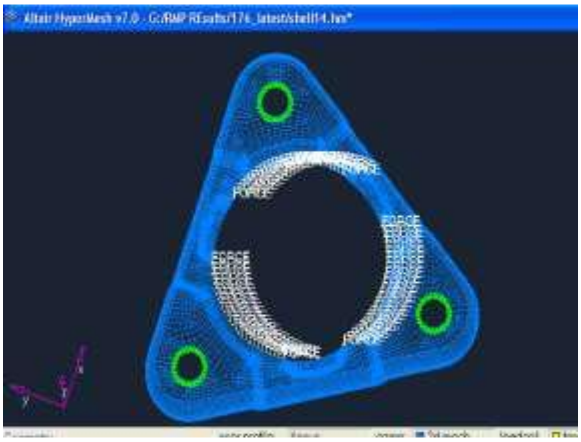

*Figure4: Finite element model of the plate with boundary conditions*

## RESULTS AND DISCUSSIONS

In fig.5 showing the graph of harmonic response of 211mm mounting plate, the amplitude of displacement is found to be 1.143µm (4.50E-05") at its fundamental frequency of 60Hz at leg1.

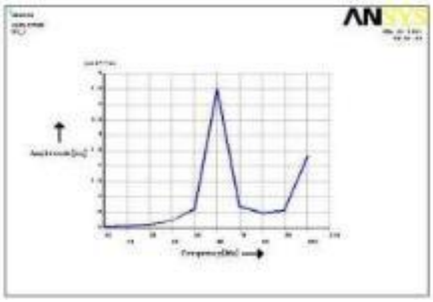

*Figure5: Amplitude Vs Frequency at Leg-1*

In figure5 showing the variation of displacement of the mounting plate, the amplitude of displacement is found to be 1.15µm (4.53E-05") at its fundamental frequency of 60Hz at Leg-2.

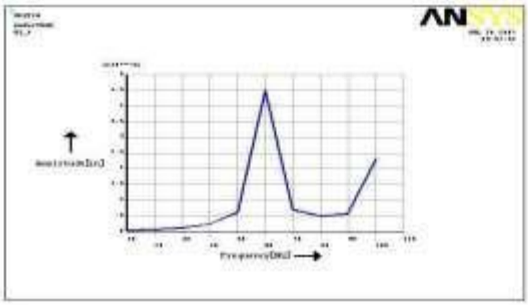

*Figure6: Amplitude Vs Frequency at Leg-2*

In figure7 showing the variation of displacement response of the mounting plate, the amplitude of displacement is found to be 1.145µm (4.51E-05") at its fundamental frequency of 60Hz Leg-3.

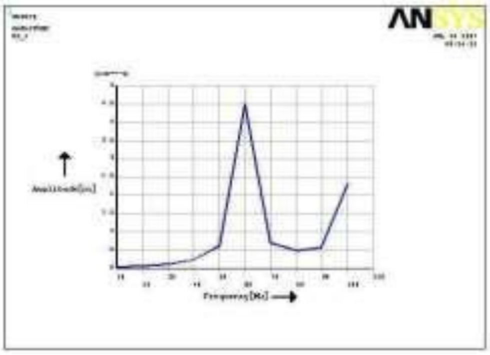

*Figure7: Amplitude Vs Frequency at Leg-3*

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## EXPERIMENTAL RESULTS

An experiment was conducted and results of experiment are the displacements of at the three legs for the excitation frequency in the range of 10 to 10000 Hz. The experiment was conducted in a closed room that was acoustically sealed from all the sides and walls and room so situated that there will not be any disturbances entering into the room form outside. The acoustic material used is a sponge sheet projecting form wall into the room. The whole room is so designed that the base of the room is nowhere in direct contact with the surroundings.

**Table1: Displacements along Z at 3 Legs**

| Freq (Hz) | Amplitude, μm | | |
|---|---|---|---|
| | Leg 1 | Leg 2 | Leg 3 |
| 10 | 6.50E-03 | 7.26E-03 | 4.98E-03 |
| 20 | 1.53E-02 | 1.69E-02 | 1.44E-02 |
| 30 | 2.37E-02 | 3.12E-02 | 5.61E-02 |
| 40 | 7.06E-02 | 6.07E-02 | 6.05E-02 |
| 50 | 1.70E-01 | 1.60E-01 | 1.35E-01 |
| 60 | 1.30 | 1.30 | 1.33 |
| 70 | 1.87E-01 | 1.78E-01 | 1.52E-01 |
| 80 | 1.17E-01 | 1.25E-01 | 1.27E-01 |
| 90 | 1.43E-01 | 1.46E-01 | 1.56E-01 |
| 100 | 7.16E-01 | 7.42E-01 | 7.67E-01 |

Even that floor or the basement of the room is so made that the whole weight of the room is taken up by the springs mounted on the columns coming from basement. There the springs used have very high stiffness and there will be no direct contact between the columns and the base of the room. For detecting the amount of vibrations at each leg of the mounting plate, accelerometers are used and placed at different points of the plate and some on the casing of the compressor. And the noises are found out at the same moment using very sensitive microphones that can detect even the sound made by the movement of the hands of the wristwatch and the sound of the heartbeat of the person. So this experiment needs to be carried out without the presence of a human being. So the whole set up is set with the accelerometers and microphones in place and then the compressor is made to run. At this moment the pressure of the gases that are fed into the compressor are varied to study the behavior in various conditions. Also the variations in voltage and current are also noted and if the voltage crosses the limit the pressure of the gases is reduced which will bring the compressor to the idle condition. So at various conditions, the results are noted. These various conditions maintained will be resulting in various ranges of frequencies. Hence the study in practical is in the range of 10-10000Hz frequency. The table1 shows the amplitudes in z direction in the range of 10-100Hz with 10 sub steps.

From the experimental results of the amplitudes of mounting plate, the amplitude of displacement is found to be 1.33µm (5.25E-05") at its fundamental frequency of 60Hz. Table2 shows the displacements in z direction of all the three legs from harmonic analysis of the plate with the range of frequency is 10 to 100Hz.

**Table2: Displacements along Z at 3 Legs**

| Freq (Hz) | Amplitude (Inch) | | |
|---|---|---|---|
| | Leg 1 | Leg 2 | Leg 3 |
| 10 | 2.96E-07 | 2.96E-07 | 2.96E-07 |
| 20 | 6.63E-07 | 6.64E-07 | 6.63E-07 |
| 30 | 1.23E-06 | 1.23E-06 | 1.23E-06 |
| 40 | 2.38E-06 | 2.39E-06 | 2.39E-06 |
| 50 | 6.28E-06 | 6.29E-06 | 6.28E-06 |
| 60 | 4.50E-05 | 4.53E-05 | 4.51E-05 |
| 70 | 6.97E-06 | 6.99E-06 | 6.97E-06 |
| 80 | 4.91E-06 | 4.92E-06 | 4.89E-06 |
| 90 | 5.72E-06 | 5.73E-06 | 5.72E-06 |
| 100 | 2.32E-05 | 2.32E-05 | 2.32E-05 |

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## COMPARISON OF ANALYSIS RESULTS WITH PRACTICAL RESULTS

By validating the analysis results with experimental results, the type and procedure of analysis followed can be checked. When the analysis and experimental results are found to be at par, then the same analyses and the same procedure can also be followed for the rest of the Mounting Plates. This is applied when the analysis results are having a variation of 10 to 15% from experimental results.The amplitude of vibrations at the three nodes, each one near to each leg is considered for validation. These results can be plot on a graph for a better comparison. This variation and the path followed by the amplitudes with respect to frequency can also be validated. Here the results from Analysis are found to have a variation of around 13.5% from experimental results. Since the Analysis results are in par with the experimental results, the analysis is carried out for two other models as per requirement. The two other models are 176mm PCD Plate and 176mm PCD Flat Plate. The conditions considered for these models are the same that are taken into consideration during the analysis of 211mm PCD Plate. Material and its properties remain the same for all the models

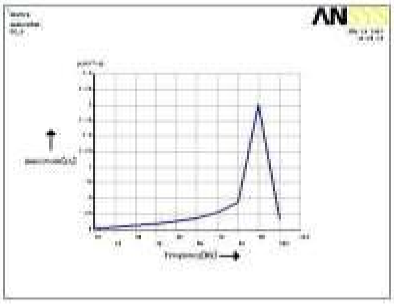

*Figure 8: Amplitude Vs Frequency at Leg-1*

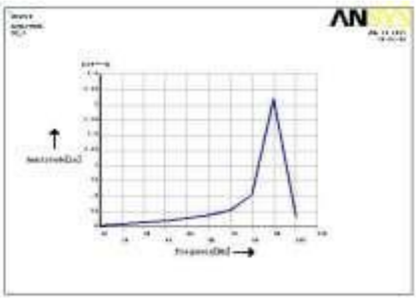

*Figure9: Amplitude Vs frequency at Leg-2*

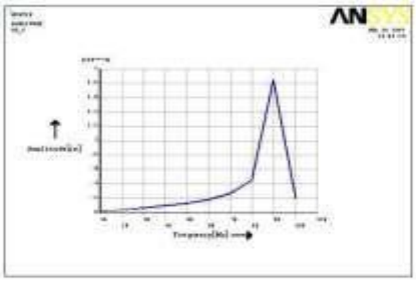

*Figure10: Amplitude Vs Frequency at Leg-3*

In the figure8 showing the variation of amplitude with the frequency of excitation under harmonic loading of the 176 mm mounting plate, the amplitude of displacement is found to be 5.105µm (2.01E-04”) at its fundamental frequency of 90Hz at leg1. In the above figure9 showing the variation of amplitude with the frequency of excitation under harmonic loading of the mounting plate, the amplitude of displacement is found to be 5.385µm (2.12E-04”) at its fundamental frequency of 90Hz at leg2. In the above figure10 showing the variation of amplitude with the frequency of excitation under harmonic loading of the mounting plate, the amplitude of displacement is found to be 4.75µm (1.87E-04”) at its fundamental frequency of 90Hz at leg3.

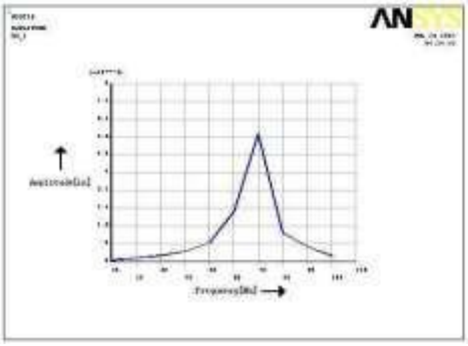

*Figure11: Amplitude Vs Frequency at Leg-1*

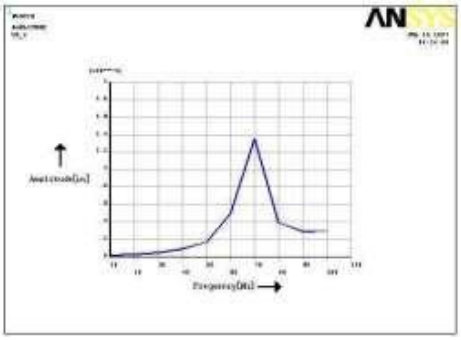

*Figure12: Amplitude Vs Frequency at Leg-2*

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In the figure11 showing the variation of amplitude with the frequency of excitation under harmonic loading of the 176 mm flat mounting plate, the amplitude of displacement is found to be 14.408µm (5.67E-04") at its fundamental frequency of 70Hz at leg1. In the figure12 showing the variation of amplitude with the frequency of excitation under harmonic loading of the mounting plate, the amplitude of displacement is found to be 8.509µm (3.35E-04") at its fundamental frequency of 70Hz at leg2. In the figure13 showing the variation of amplitude with the frequency of excitation under harmonic loading of the mounting plate, the amplitude of displacement is found to be 8.433µm (3.32E-04") at its fundamental frequency of 70Hz at leg3.

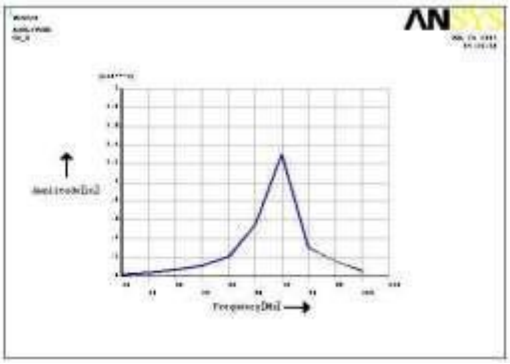

*Figure13: Amplitude Vs Frequency at Leg-3*

## PLATES WITH THICKNESS

**Table3: Natural frequencies in mounting plates with different thickness**

| Natural frequencies (Hz) | | |
|---|---|---|
| Set | 176mm flat plat with thickness | |
| | 0.123" | 0.133" |
| 1 | 69.02 | 71.823 |
| 2 | 69.192 | 71.998 |
| 3 | 69.943 | 72.646 |
| 4 | 125.09 | 133.66 |
| 5 | 138.09 | 147.32 |
| 6 | 138.69 | 148.00 |
| 7 | 151.17 | 159.10 |
| 8 | 169.27 | 177.79 |
| 9 | 169.93 | 178.48 |
| 10 | 189.44 | 201.10 |

For the plate of 176mm" Flat PCD - 0.123" and 0.133" thickness, the fundamental frequency of the model is 69.02Hz, which is far away from 176mm regular plate, which had the fundamental frequency as 89.064Hz. So, increasing the thickness of the plate to 0.123" had not shown the desired improvement. Now increasing the thickness of the plate further, to 0.133" (3.378mm) and the same analyses are carried out. This increase in thickness to 0.133" is increasing the thickness by around 18%. Modal analysis results in Mode shapes with Natural Frequencies of the model. This modal analysis was carried out to give the fist 10 natural frequencies. The natural frequencies with varying thickness are shown in table3.For 176mm Flat plate with thickness 0.133", the fundamental frequency is 71.823Hz. This is quite far off from regular 176mm plate. Even after increasing the thickness of the plate by 18%, there is not much improvement shown. Increasing the thickness of the plate further, there will be increase in weight considerably which is not desired and also the plate becomes expensive. So, the regular plate, which is having the fundamental frequency far away from the range of working frequency, is the better plate that can be used as a mounting plate for the compressor.

## CONCLUSIONS

The 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

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increasing the thickness of the Mounting Plate, frequency shift is possible. Hence, two thicknesses are considered such as 0.123" (3.12mm) and 0.133" (3.38mm). Considering the thickness of plate as 0.123" (3.12mm) the fundamental frequency is at 69.02HZ and for the plate of 0.133" (3.38mm) thickness fundamental frequency is at 71.823Hz. These are still lesser than the Fundamental Frequency of 176mm Regular plate, and so are not suggestible. 176mm Regular Plate is the better one with the thickness of 0.113" (2.87mm) having the highest fundamental frequency, which is also away from working frequency range.

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