Performance Analysis of the Thermo Acoustic Refrigeration System (TAR)

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ABSTRACT: By utilizing sound energy, thermo acoustic refrigeration is a technique that holds great promise for the creation of environmentally friendly and renewable power systems. Thermo-acoustic refrigeration systems are eco-friendly cooling technologies that can be used to cool electronic parts, car air conditioners, commercial or residential refrigerators, and more. To get a better Coefficient of Performance (COP) and have a manageable temperature differential, the variables must be improved. The goal is to create an experimental thermos-acoustic refrigerator setup, measure the temperature difference in the resonating tube by positioning the stack in various locations, and measure the COP by adjusting the stack geometry and acoustic frequency. Components are developed using CAD software, preferably CATIA V5, and simulation is run using DeltaEC and ANSYS. Analytical findings are then compared. Based on the analytical findings, analysis was completed to determine the ideal value for COP from the DeltaEC simulation programme and the sound pressure value that corresponds to excitation with various pressure values. We came to the conclusion that the Ansys Workbench software was used to simulate fluid behavior under various pressures and frequency ranges in order to get a high COP.

Key words: DeltaEC, ANSYS software, thermos-acoustic refrigerator, Moving coil speaker, COP.

INTRODUCTION

Over the past three decades, thermo-acoustic refrigeration has been hailed as a cutting-edge cooling technique. The most promising, convenient, easy-to-use alternative cooling system to the already predominating domestic vapor compression refrigeration (VCR) units is the thermo-acoustic refrigerator. In order to establish a temperature difference across a stack of sheets, thermo-acoustic refrigeration uses the thermo-acoustic phenomenon. The thermo-acoustic effect takes place in the closed resonator tube filled with high-pressure (about 10 bar) gases (air or inert gas like helium) as a result of sound waves produced by the loudspeaker. The cold and hot heat exchangers are located on either side of the stack. The acoustically powered thermo-acoustic refrigeration system can utilize a commercially available loudspeaker with a proportional control mechanism. On the local market, however, commercial loudspeakers have an electro-acoustic efficiency of barely 3%. A driver is the name for the altered loudspeaker. The acoustic power input causes the working material to vibrate front and back at the necessary resonator frequency.

Despite the fact that thermal acoustic devices have been used for 30 years, many aspects are still unclear. It is unknown how the gas will behave inside the resonator tube, how it will interact with the solid surface (such as a stack plate or heat exchanger), and how this will affect heat transmission. A deeper understanding of the basic process is needed to enhance the design of these devices. Analyse, design, and test a thermo acoustic refrigerator to examine its performance as a first step, which is the aim of this thesis project. This study's main objectives are to build a prototype device and comprehensively analyze the thermo acoustic refrigeration effect. We'll build a simulation and analysis model to evaluate our theory.

Researchers Pranav Mahamuniet et al. studied the thermo-acoustic system. The temperature difference between the ends of the stack is mostly dependent on frequency and mean pressure. For frequencies between 250 and 500 Hz, the model was assessed in steps of 50 Hz.

A portable counter top invented by Normah Mohd-Ghazali and others Normah Mohd-Ghazali and others created the thermo acoustic cooling apparatus, which consists of a PVC resonator with a diameter of 60mm. The temperature dropped from 24 to 18.5 degrees Celsius in less than a minute. The temperature decreased from 23°C to 8°C when a 110mm diameter acrylic resonator was used.

N. M. Hari Haran et al. N. M. Hari Haran designed and created the Twin Thermo-Acoustic Heat Engine 39. The device produced extremely loud sound waves. Performance of the system is assessed using variations in the working fluid and resonator length. The performance of the system is assessed using the temperature differential, pressure oscillation amplitude, and resonance frequency.

According to Alcock et al., one of a thermo-acoustic system's key components that influence performance is the stack. A. C. Alcock looked on the efficiency of the ceramic substrates used in standing wave thermo-acoustic refrigeration as a stack material. The analyzed system's performance is affected by the stack's geometric configuration.

The effectiveness of the thermo-acoustic VP refrigeration system was investigated by Kaushik S. Panara and B. Ananda Rao. According to Kaushik S. Panara, the working gas, the resonator's shape, the pressure inside the resonator tube, the material of the stack, its length, and its location all affect how well the refrigerator functions. The benefits of simultaneous heating and cooling are combined by thermo-acoustic refrigeration systems. According to the results, the resonator tube without the stack experienced a temperature change of just 0.5°C.

Two stacks in a straight resonator tube were used in an experimental research on the thermo-acoustic cooling system by Ikhsan Setiawan et al. The 152 Hz resonator was constructed from PVC with a length of 112 cm utilizing air at atmospheric pressure. Stacks are built of parallel plate type material, with 0.3 mm thickness and 0.85 mm spacing. This distance is roughly four times the depth of heat penetration. The stack has a diameter of 20 cm and a length of 10 cm.

Akhavanbazaz et al. looked at three different heat exchanger configurations—no heat exchanger, one with a limited thermal contact area, and one with a large thermal contact area—to see how gas obstruction affected thermo acoustic refrigerator performance. The findings indicate that the blockage significantly affects the thermo acoustic process occurring inside the stack, which suggests that these parameters need to be optimized to boost the thermo-acoustic refrigerator's efficiency.

The working fluid and heat exchanger configuration was found to be important design factors influencing thermo-acoustic system performance by Minner et al after Herman and Wetzel et al investigated thermo-acoustic refrigerator design optimization using the short-stack boundary layer approximation. Knio conducted a numerical study on an idealized thermo-acoustic stack and thermally stratified flow near a thermo-acoustic refrigeration system. The area around the heat exchanger's energy flux density was demonstrated and the implications for heat exchanger design were examined.

Air and helium were used as the working medium by Bheemsha et al, who attained a cooling power of 10 W. The optimized stack's COP was found to be 2.5. The acoustic losses in the small diameter resonator tube were decreased by setting the diameter ratio (D2/D1) to 0.43.

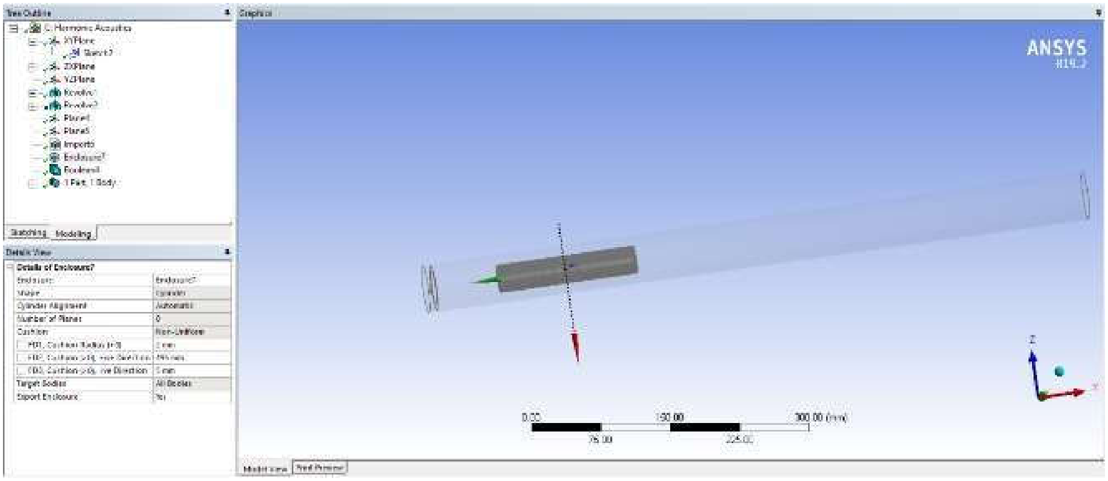
The performance of a thermo-acoustic refrigerator's operational state and working fluid variations were calculated by Tasnim et al. The cooling power, coefficient of performance (COP), and entropy generation rate of a thermo-acoustic refrigerator are used to assess its performance. The impact of working fluid variation is examined by varying the Prandtl number (Pr) between 0.7 and 0.28. The drive ratio (DR), stacks plate spacing (y0), and means pressure (pm) of the operational circumstances are all being looked into. The Prandtl number is reduced from 0.7 to 0.28 with stack plate spacing equal to 3.33 times the thermal penetration depth at atmospheric pressure and a drive ratio, increasing the coefficient of performance by 78%.

In addition, Tijani et al. provided a description of the design method for acoustically-driven thermo-acoustic refrigerators that deviate from Wetzel and Herman by taking into account a correlation between the refrigerator's targeted cooling power, the stack's consumed acoustic power, and the total power in the stack. Uncertainty surrounds the origin of this connection and the appropriate refrigerator configuration.

Gardner, Swift, and others they talked about the use of medium entry in thermo acoustic refrigerators. They observe that when the acoustic impedance is purely actual, efficiency is at its highest. They noticed that many refrigerators have huge compliance tanks at the end of the resonator, which results in a negative imaginary component of impedance. They discovered that by adding a positive imaginary component to impedance, inheritance may be utilized to restore impedance to being fully real.

TAR SYSTEM 3D MODELLING USING THE ANSYS DESIGNER PROGRAMME

Ansys designer modular methods like sketching and geometrical sets were utilized to calculate the speaker's resonance frequency through the application of modal investigations. It was chosen because, compared to other tools, meshing with Designer modular was noticeably simpler and took a great deal less time. In order to explore how fluid responds to sound at various pressure levels, the speaker was given an enclosure. Designer modular enclosures were constructed as boxes, cylinders, and spheres. The simplicity of post-processing was another factor in choosing this programme. The boundary region was not provided when utilizing custom-built enclosures, and enclosures made with other applications were incompatible. Ansys modeling’s are shown in Figures 1 and 2.



Details of Enclosure7

Enclosure	Enclosure7
Shape	Cylinder
Cylinder Alignment	Automatic
Number of Planes	0
Cushion	Non-Uniform
FD1, Cushion Radius (>0)	2 mm
FD2, Cushion [illegible] +ve Direction	[illegible] mm
FD3, Cushion [illegible] -ve Direction	5 mm
Target Bodies	All Bodies
Export Enclosure	Yes

Figure1. Modeling of speaker duct using Ansys

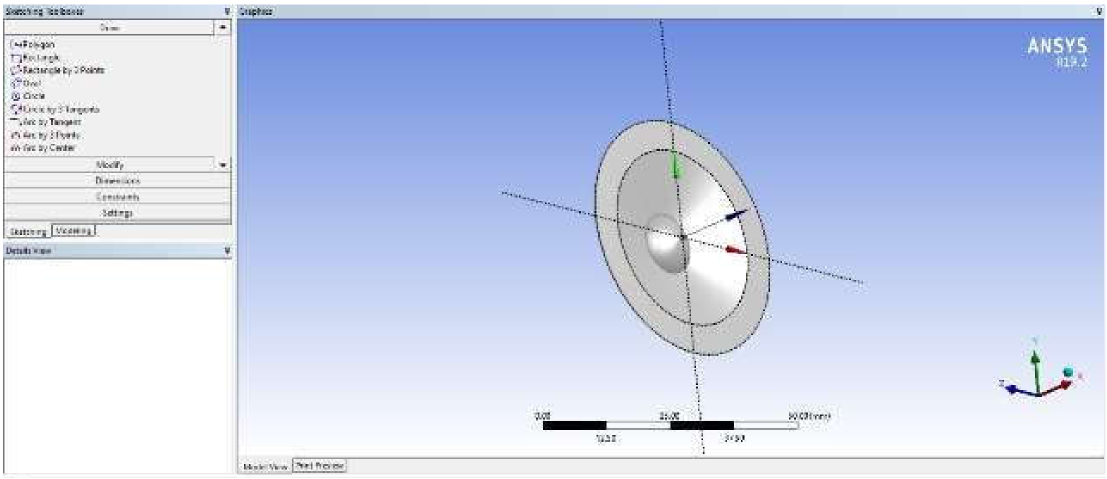


Figure2. Importing the stack geometry into Ansys

ANALYSIS OF TAR USING DELTAEC SIMULATIONSOFTWARE

Validation Description

A well-documented design is taken into consideration, modeled into DeltaEC, and the expected output is compared with real measurements in order to ensure the predicted data from DeltaEC and the manner it is used. A thermo acoustic refrigerator that uses helium at 3 bars and has a resonator tube that is 0.16096 m in diameter and 0.1158 m in length connected to another tube that is 0.086 m in diameter and 0.43 m long. This design minimizes losses by making the resonator tube after the stack smaller than the portion before the stack. Only the resonator tube is of interest when it comes to the validation of a software solution like DeltaEC.

In DeltaEC, the 0 segment, also known as the beginning segment, identifies global variables such as mean pressure (Pm) = 3*105 Pa, frequency (f) = 455Hz, begin temperature (T beg) = 300K, and dynamic pressure amplitude (Po) = 6000 Pa. Volume velocity and pressure are in phase. The magnitude of volume velocity is predetermined as a guess variable. The other guess variable is the heat that the ambient heat exchanger removes. Validation EC Model is shown in Figure 3.

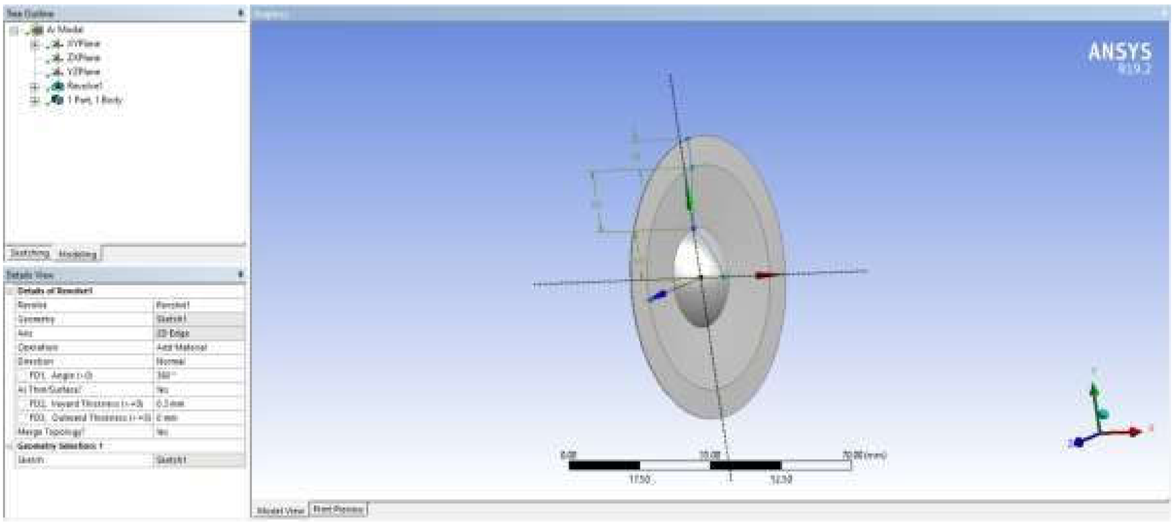
Figure3. Delta EC model Stage

ANALYSIS USING ANSYS SOFTWARE

Modal Analysis

The vibration characteristics of a structure or a machine part are determined by a modal analysis (natural frequencies and associated mode shapes). It can serve as the basis for many different types of investigations, such as identifying unrestrained bodies in contact analyses or figuring out the time step size needed for transient studies. The outcomes of the modal analysis can also be applied in a mode-based downstream dynamic simulation. Superposition techniques include, for instance, harmonic response analysis, random vibration analysis, and spectrum analysis. When building a structure to withstand dynamic loading, natural frequencies and mode shapes are essential factors to take into account.

A modal analysis template can be activated by double-clicking it in the toolbox or by dragging it into the project schematic and is deliberated in Figure 4. You can load the geometry by selecting Import Geometry from the context menu when you right-click on the geometry cell. For a view of the geometry, right-click on the model cell. The set up cell can also be edited by right-clicking it and choosing modify. At this point, the mechanical application will be started. Utilize the tools and capabilities of the mechanical application in the mechanical application window to finish modal analysis. Visit the modal analysis in the mechanical application help for further details on conducting a modal analysis in this application.



Details of Revolve1	
Revolve	Revolve1
Geometry	Sketch1
Axis	2D Edge
Operation	Add Material
Direction	Normal
FD1, Angle (>0)	360 °
As Thin/Surface?	No
FD2, Inward Thickness (>=0)	0.3 mm
FD3, Outward Thickness (>=0)	0 mm
Merge Topology?	No
Geometry Selection: 1	
Sketch	Sketch1

Figure4. Solid formation using revolve command

Results for Modal Analysis

Deformation and frequency of the models are deliberated in Figures 5 to 10.

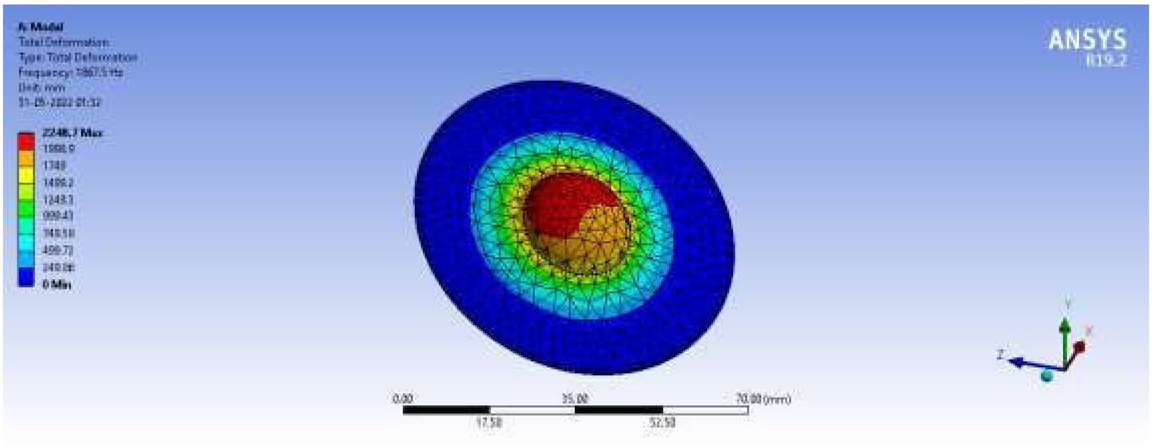


Figure5. Deformation at 1st frequency

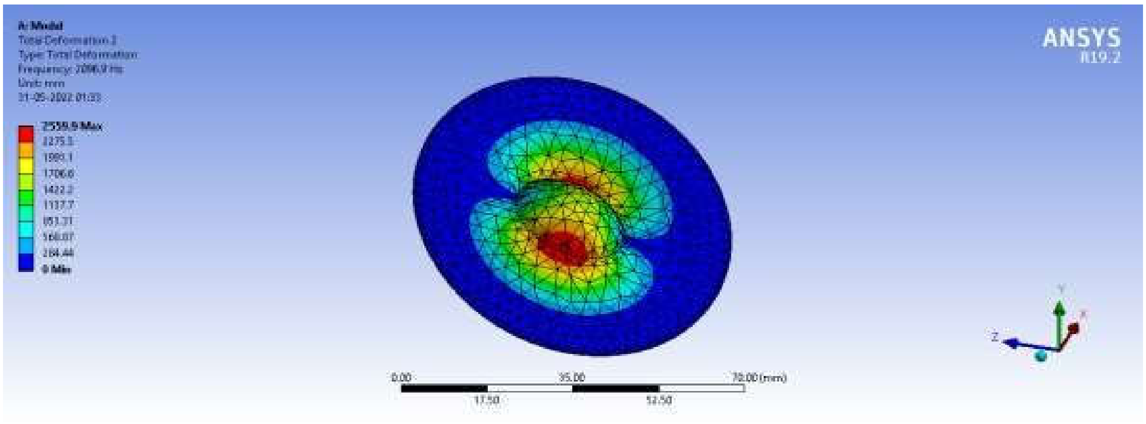


Figure6. Deformation at 2nd frequency

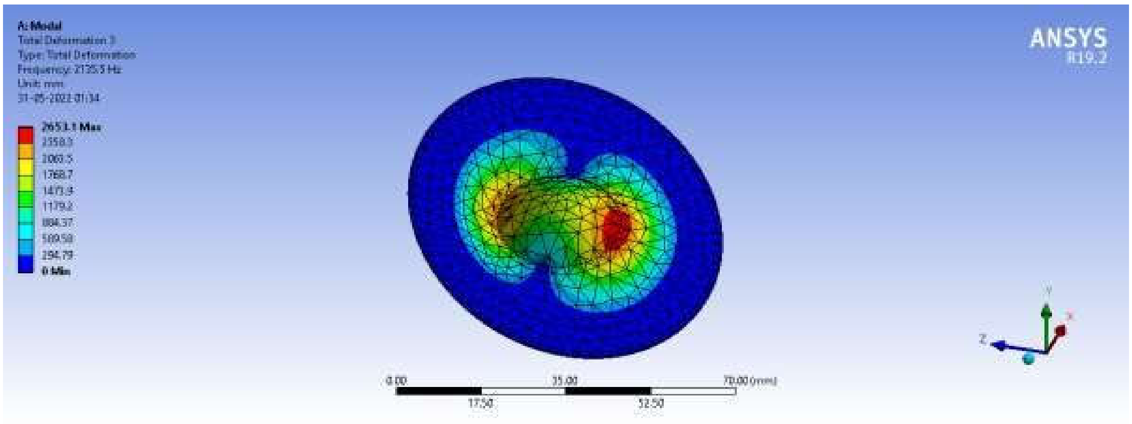


Figure7.Deformation at 3rd frequency

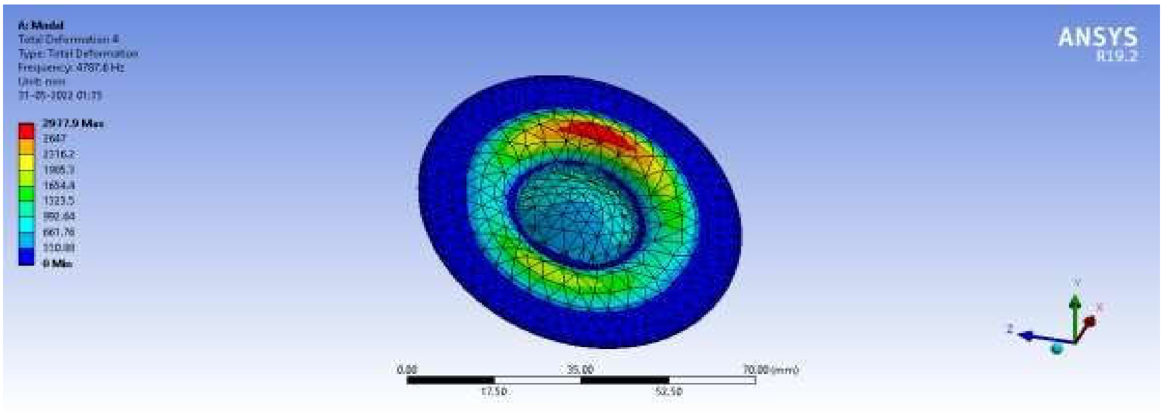


Figure8.Deformation at 4th frequency

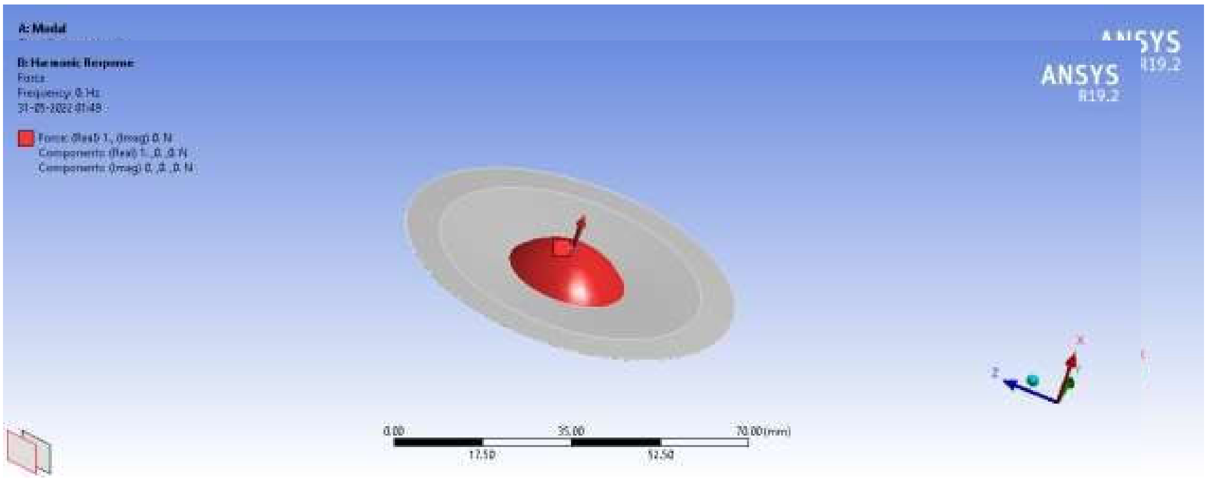


Figure9. Deformation at 5th frequency

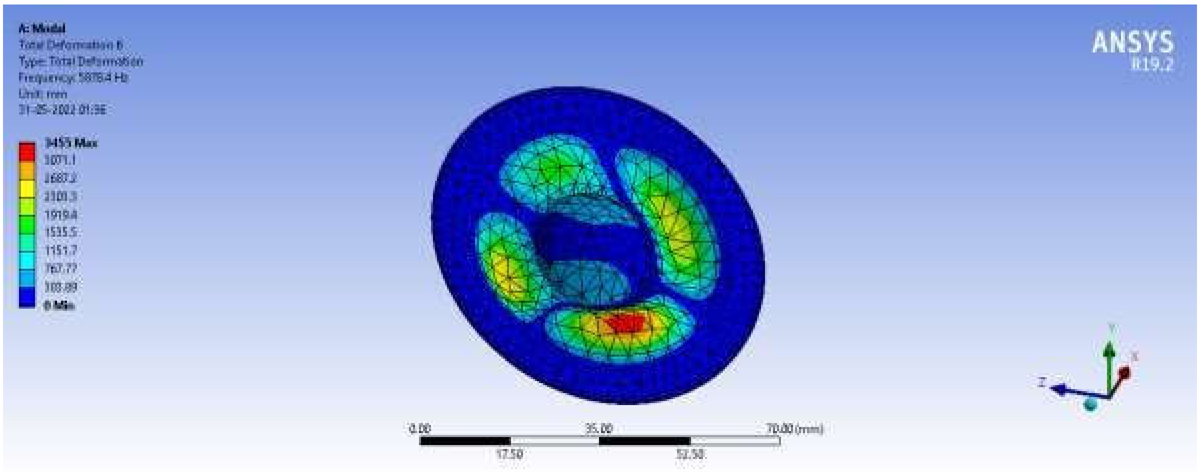


Figure10. Deformation at 6th frequency

Harmonic Response

A mechanical structure's reaction to dynamic loads that change sinusoidal over time is measured using a harmonic response analysis, which enables designers to confirm that the structure can tolerate resonance, fatigue, and other effects from forced vibration.

Drag the harmonic response and place it in the modal analysis model to create the relationship between the modal and harmonic responses and are illustrated in Figures 11 and 12.

Update the project now, and then import the modal parameters. To get a harmonic response from the speaker, apply a unit load.

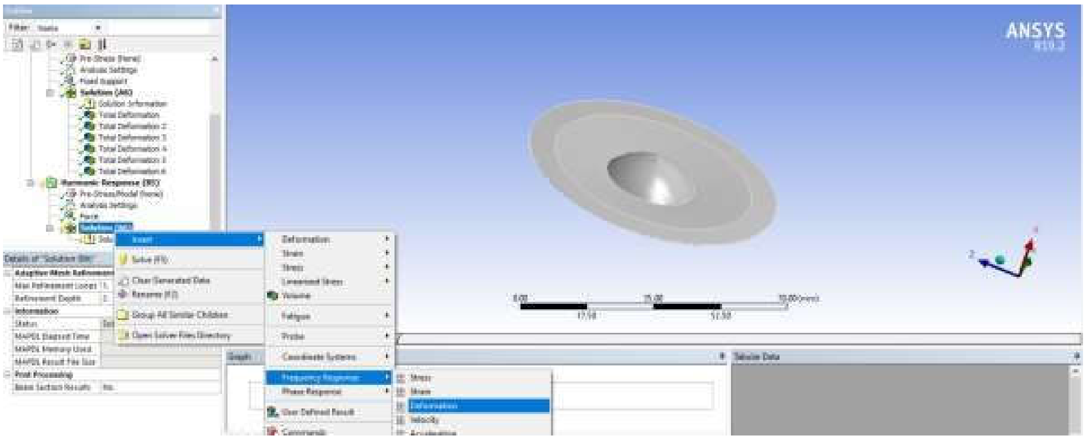


Figure11. Applying a unit load for analysis

Solving for result of frequency versus phase angle.

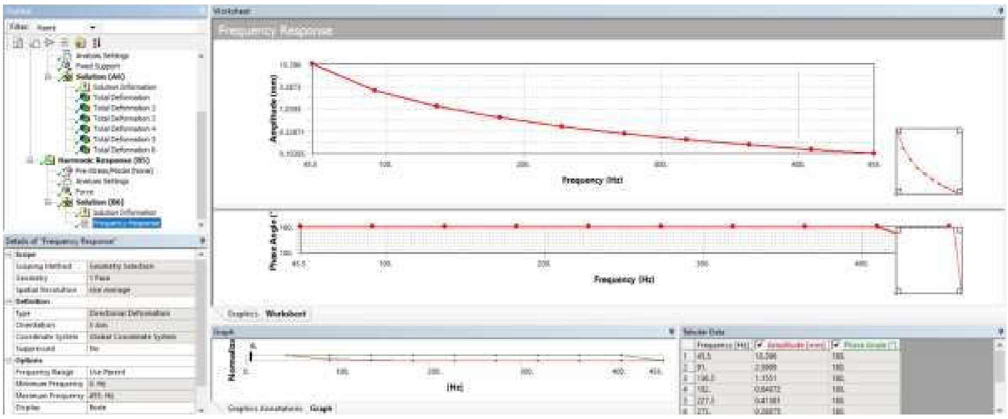


Figure12. Frequency response deformation

This is the result of harmonic response for a unit load in x direction.

HARMONIC ACOUSTIC ANALYSIS

As a parameter in the harmonic acoustic, we employ the discovered harmonic. To the harmonic acoustic setup we therefore drag the harmonic response solution.

Engineering data is modified and expanded from engineering data sources to include fluids like air, helium, and argon. These were chosen so that it would be possible to examine how sound pressure waves behave in various media under various pressures. The far field sound pressure level, or how far the sound is moving outside the boundary, is the second observation we are looking for from this research.

As we need to import the stack and arrange the two inside an enclosure where they will be studied, the geometry is once again modified in the designer moduler. The steps are showed in Figures 13 to 19.

To create flawless geometry, use these three steps:

- The first step is to import the stack at the proper location, 74 mm before the driver.
- The second step is to create the enclosure for the resonator tube, whose length of 560 mm was determined by analytical calculations.
- Finally, since harmonic acoustics can only apply in enclosures, performing a boolean operation that removes the volume and leaves empty spaces at stack positions.

STEP-1

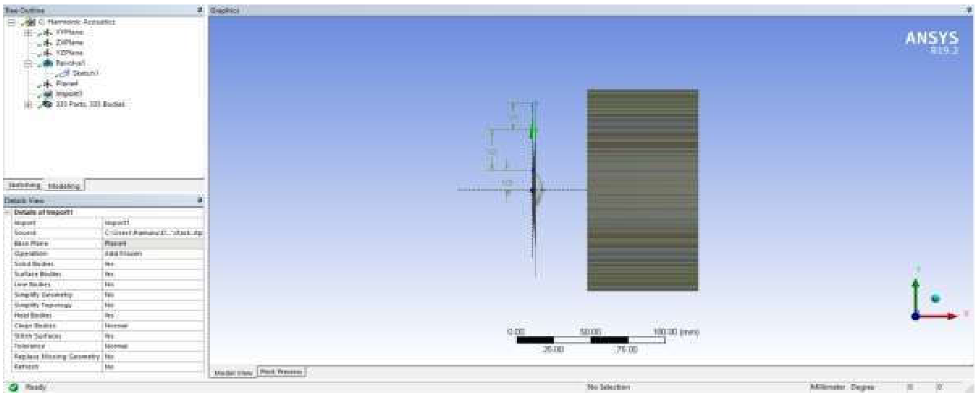


Figure13. Importing and positioning the stack

The stack is positioned at 74mm from the driver side and the stack is produced using CATIA V5 R18.

STEP-2

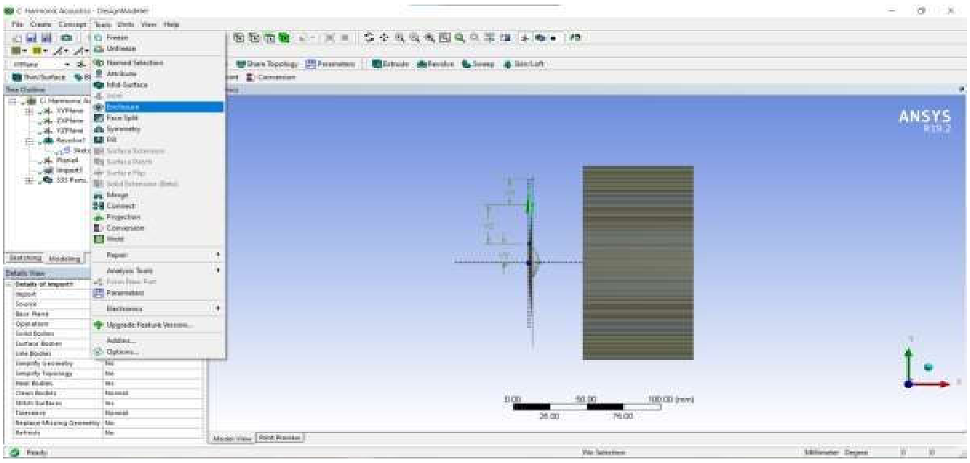


Figure14. Prepare the enclosure

Creating enclosure from tool option.

Step- 3

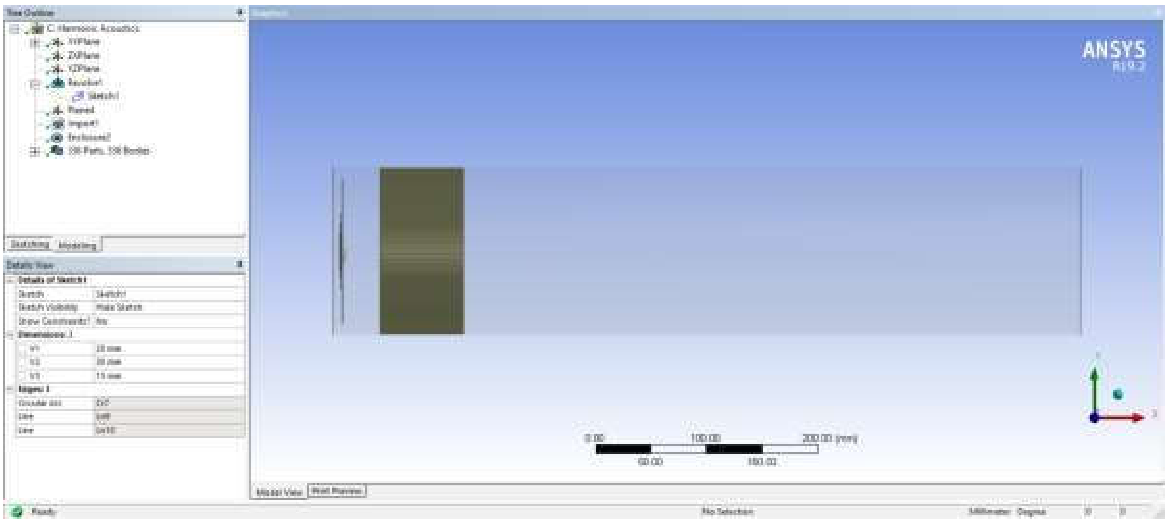


Figure15. Selection of type of enclosure

Step-4

Performing Boolean operation to remove stacks volume.

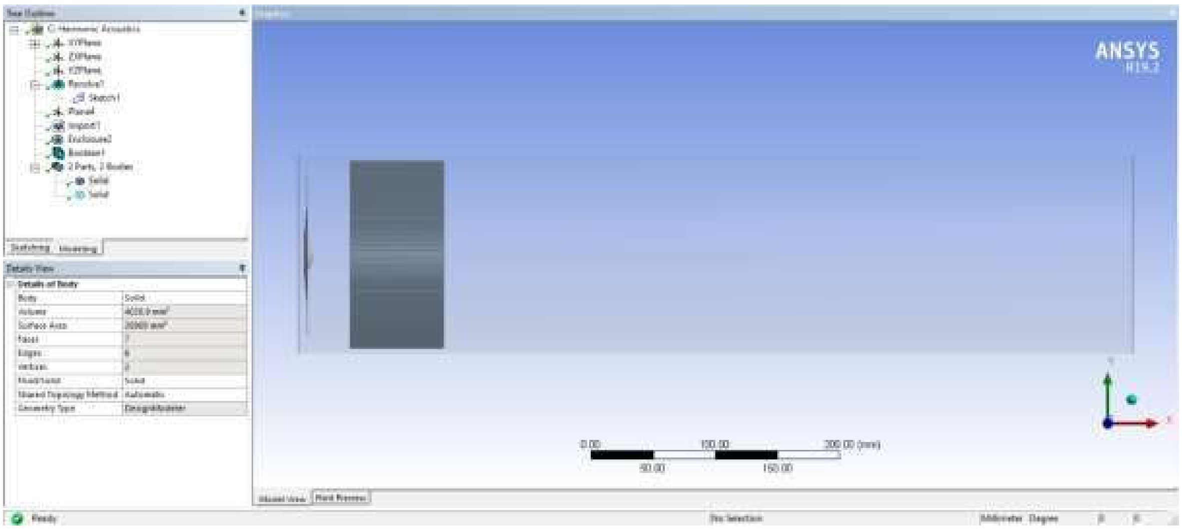


Figure16. Boolean Operation to subtract features

The transparent boundary layer is the enclosure. So proceed to modal post processing to obtain results. This is the required geometry setting to change between different gases. Both speaker and stack are in freeze condition where only their enclosure playsparrt and they are not a complete solid.

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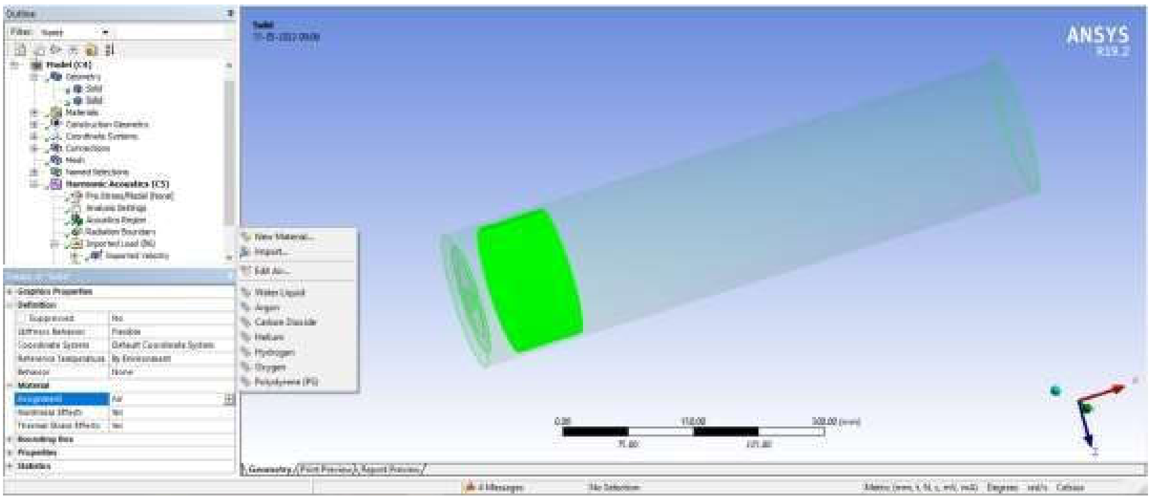

Figure17. Assigning fluid to the enclosure

Step 5

Define the radiation boundary to draw attention to the extent up to which the analysisis to be performed.

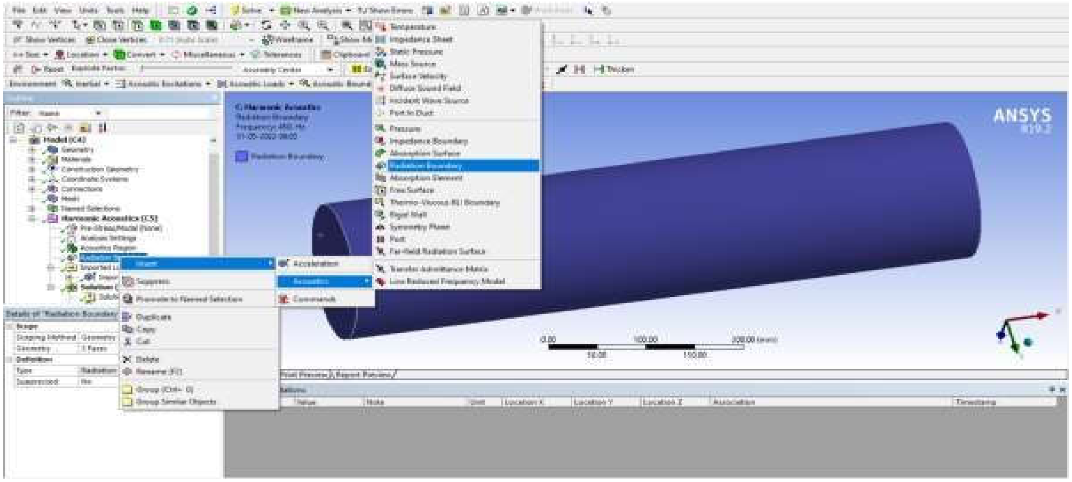

Figure18. Define the radiation boundary

Step 6

Meshing: Meshing is done using tetra dominant fine mesh feature. we obtain,

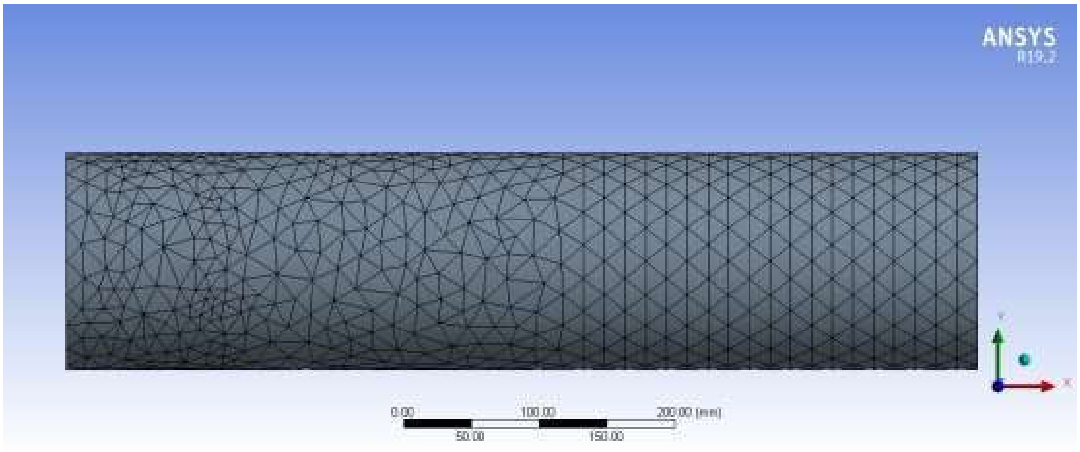

Figure19. Meshing the model

RESULTS IN ANSYS

Assumptions for analysis

1. The stack's length is significantly less than the standing wave's Ls wavelength. On the complete length of the stack, it can be assumed that the oscillating gas molecules have the same local pressure and velocity amplitude.

2. It is thought that there is no gas flow in the stack. Also disregarded is friction at the interior walls of the resonator.

3. The temperature difference at the ends of the stack should be minimal compared to the mean temperature, and the Tm gradient should stay stable over time. We ignore the conductivity of the plate material.

4. The refrigerator is operated in constant condition during the entire analysis. The temperature gradient within the stack is continuous throughout time and has a mean value of Tm for the gas. We ignore the conductivity of the plate material.

The sound wave formations in different mediums are explained by Figures 20 to 24.

Characteristics of sound waves in air medium

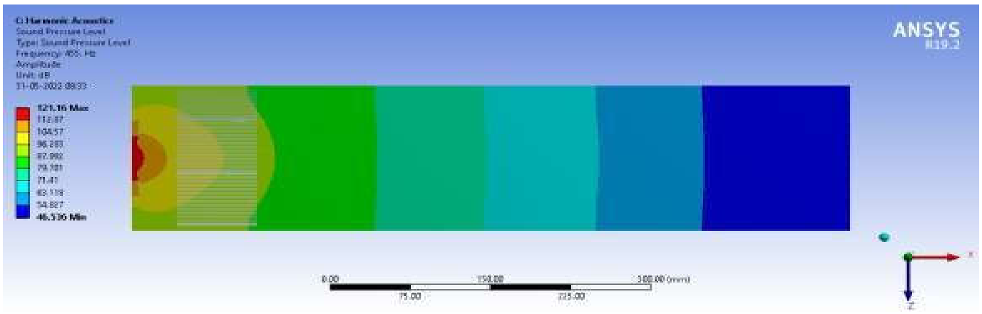

Figure20. Sound pressure level for air at 455 hz.

Using Ansys Workbench, we measured the sound pressure level. The greatest value was recorded at 121.16 dB, and the lowest value was 46.536.

Characteristics of sound waves in helium medium

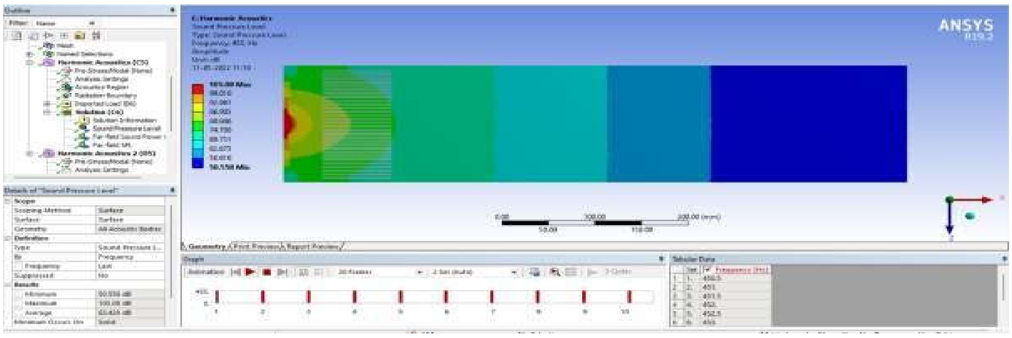

Figure21. Sound pressure level for helium at 455 hz

Sound pressure level was observed using Ansys workbench we have a maximum valueof 105.8 decibels and minimum value of 50.558 decibels.

Characteristics of sound waves in argon gas medium

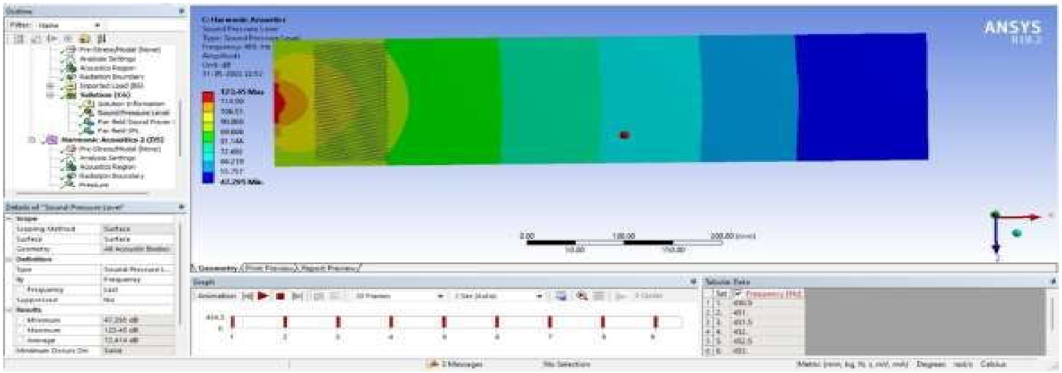

Figure22. Sound pressure level for Argon at 455hz.

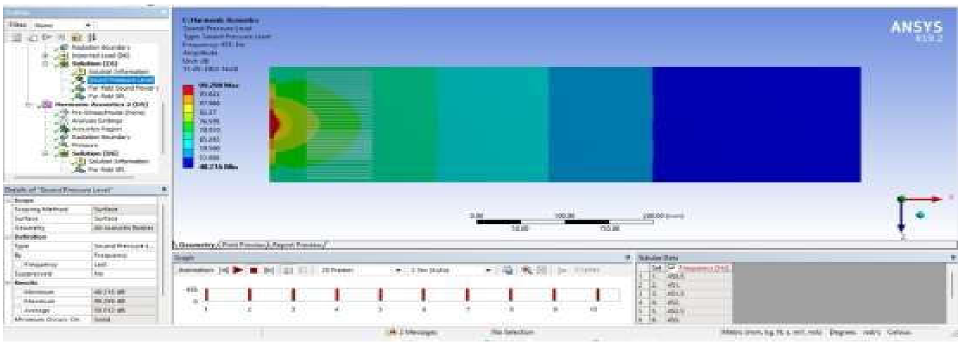

Figure23. Sound pressure level for hydrogen at 455hz.

Characteristics of sound waves in carbon dioxide medium

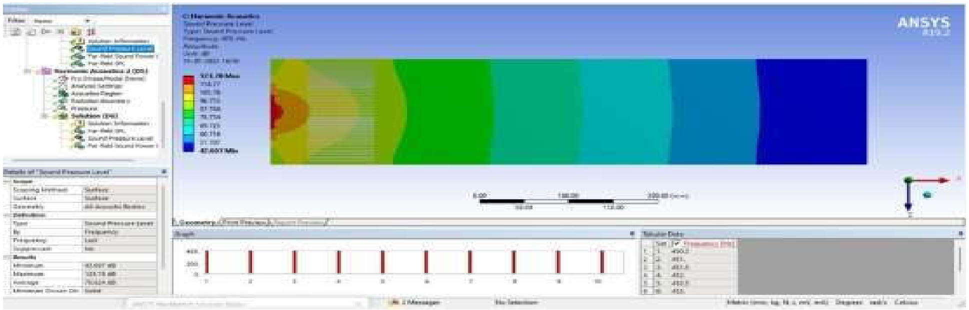

Figure24. Sound pressure level for carbon dioxide at 455 hz

Ansys Results

Table1. Results of sound pressure levels in different fluids.

TYPE OF FLUID	SPEED OF SOUND IN GAS	SPL WITHOUT INTERNAL PRESSURE MIN	SPL WITHOUT INTERNAL PRESSURE MAX	SPL WITH 3 BAR INTERNAL PRESSURE MIN	SPL WITH 3 BAR INTERNAL PRESSURE MAX
AIR	346.25	46.563	121.16	200.51	201.83
HELIUM	1019.2	50	105	200.51	200.66
ARGON	323	47.295	123.45	200.51	202.03
HYDROGEN	1320	48.216	99.298	200.51	200.6
CARBON DIOXIDE	258	42.697	123.78	200.51	202.95

Table2. Results for ansys analysis

TYPE OF FLUID	SPEED OF SOUND IN GAS	SPL WITHOUT INTERNAL PRESSURE MIN	SPL WITHOUT INTERNAL PRESSURE MAX	SPL WITH 3 BAR INTERNAL PRESSURE MIN	SPL WITH 3 BAR INTERNAL PRESSURE MAX
AIR	346.25	46.563	121.16	200.51	201.83
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HYDROGEN	1320	48.216	99.298	200.51	200.6
CARBON DIOXIDE	258	42.697	123.78	200.51	202.95

According to the results in the tables 1 and 2 above, helium and hydrogen are the best gases to utilise since their sound pressure values are lower than those of other gases and because helium produced promising outcomes whereas simulations produced lower sound pressure values. On the other hand, hydrogen has very low sound pressure level values but requires the most frequency to function. As a result, the thermos acoustic refrigeration system was chosen with helium as the best working gas.

CONCLUSION

A novel small thermo acoustic refrigerator's design analysis and simulation have been discussed. Different experimental setups are used to measure the performance indices, such as the COP and temperature differential. The computed and Delta EC predictions show a moderate degree of agreement, demonstrating the model's suitability for the design of small-scale thermoacoustic systems. The maximum measured cooling load of 11.9 W is discovered to be achieved.

The greatest gross cooling capacity, COP, acoustic power, and total power are predicted using DeltaEC. To check the sound pressure levels for various gases, we used the harmonic acoustics workbench in the Ansys software.

To learn how fluids react at various pressures and frequencies, Ansys Workbench was employed. Altering the frequencies, stack location, resonator tube form, and normalized parameters, among other things. We can raise the COP levels while simultaneously lowering the sound pressure level, which reduces noise.

The project's future objectives include maximizing operational conditions such as stack length, stack parallel plate thickness, resonator tube length, and stack positions, mean gas temperature, and pressure. To achieve significant temperature and COP variations.

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