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DESIGN AND ANALYSIS OF THERMOACOUSTIC REFRIGERATION SYSTEM

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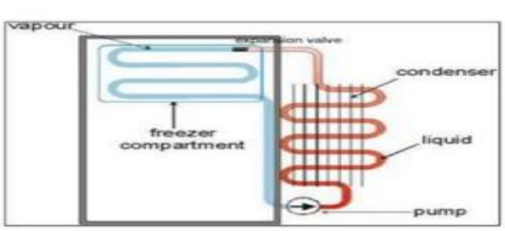
Abstract: The design and analysis of thermo-acoustic refrigerator have been the focus of considerable attention from the research community since 1980. This environmental friendly technology has the potential to replace conventional refrigerator once the improvements in design and technology are realized. Thermo-acoustic is a term used to describe the effect arising from sound waves creating a heat gradient, and vice versa. In this paper, a typical thermo-acoustic refrigerator consisting of acoustic driver (loudspeaker), resonator tube, thermocouple, stack, and a heat exchanger is designed. The effects of some design parameters such as wave patterns, frequency, and heat exchanger of thermo-acoustic refrigerator system were studied. It was found that a sine wave pattern lead to superior cooling effects compared to other wave patterns tested. Also adding the heat exchanger contributes significantly in increasing the temperature drop achieved by the thermo-acoustic refrigerator. The objectives of the project are to design and analyze a refrigerator system. A parametric model of the refrigerator is designed using 3D modeling software Catia and analyzes using Ansys Software.

1. Introduction:

Thermo acoustic engines (sometimes called "TA engines") are thermo acoustic devices which use high-amplitude sound waves to pump heat from one place to another (this requires work, which is provided by the loudspeaker) or use a heat difference to produce work in the form of sound waves (these waves can then be converted into electrical current the same way as a microphone does).



These devices can be designed to use either a standing wave or a travelling wave. Compared to vapor refrigerators, thermo acoustic refrigerators have no coolant and few moving parts (only the loudspeaker), therefore require no dynamic sealing or lubrication.

Operation

A thermo acoustic device takes advantages of the fact that in a sound wave parcels of gas adiabatically alternatively compress and expand, and pressure and temperature change simultaneously; when pressure reaches a maximum or minimum, so does the temperature. It basically consists of heat exchangers,

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a resonator and a stack (on standing wave devices) or regenerator (on travelling wave devices). Depending on the type of engine a driver or loudspeaker might be used to generate sound waves.

In a tube closed at both ends, interference can occur between two waves traveling in opposite directions at certain frequencies. The interference causes resonance and creates a standing wave. The stack consists of small parallel channels. When the stack is placed at a certain location in the resonator having a standing wave, a temperature differential develops across the stack. By placing heat exchangers at each side of the stack, heat can be moved. The opposite is possible as well: a temperature difference across the stack produces a sound wave. The first example is a heat pump, while the second is a prime mover.

Vapor-compression refrigeration system (VCRS)

In which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

Refrigeration may be defined as lowering the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. A device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, geothermal heat pump or chiller (heat pump).

The vapor-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Depicts a typical, single-stage vapor-compression system. All such systems have four components: a compressor, a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air.

II - LITERATURE SURVEY

Higgins, in 1777, he conducted the first experiment based on acoustic oscillations generated by heat. In this experiment he observed that when the hydrogen flame was placed at correct position within the organ pipe acoustic oscillations would take place. From this he concluded that heat energy can be converted into sound waves.

Sondhauss, He conducted the related experiment as the Higgins, He took a resonator with a glass ball attached to it and heating the junction of ball and the resonator. He observed that when the flame is kept near the junction the system first heat up or warm up and then the oscillation of the acoustic has been produce. But the solid review does not occur from this experiment. It was just an extension of Higgins setup.

Rott, in 1969, He gave the mathematical equations on thermo acoustic. In his papers he derives and solved linear equations based on thermo acoustic theory. His theories are the foundation by which most of the parameters and calculations are considered while making thermo acoustic models. The model made by him was linear model.

Gifford and Longsworth, They performed the experiment using low frequency pulse inside the resonator. They observed that cooling takes place inside the resonator. They named their model as pulse tube from which pulse tube refrigerator has derived.

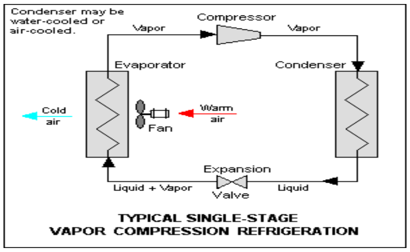
Wetzel, He makes an attempt in optimization of design of thermo acoustic refrigerators. He also developed algorithm for optimization. He noted that optimization of heat exchanger inside thermo acoustic refrigerator is an issue also optimizing of driver or speaker is another issue other than heat exchanger. His conclusion was theoretically efficient thermo acoustic refrigerators as compared to traditional refrigerators are possible if hang ups such better heat exchangers can be overcome.

Gardner and Swift, They discussed use of entrance of medium in thermo acoustic refrigerators. They note that the maximum efficiency takes place when the impedance of the acoustic is purely real. They observed that many refrigerators have large compliance tank at the end of resonator due to which it causes negative imaginary component of impedance, to introduce positive imaginary part to impedance inheritance can be used and make impedance purely real again.

III - DESCRIPTION AND WORKING PRINCIPLE

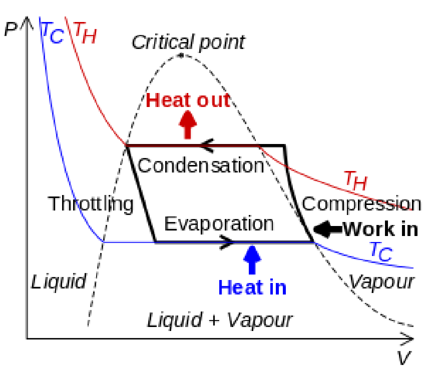
Description of the Project

The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated.



The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapor mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser.

To complete the refrigeration cycle, the refrigerant vapor from the evaporator is again a saturated vapor and is routed back into the compressor.



It should be noted that the above discussion is based on the ideal vapor-compression refrigeration cycle which does not take into account real world items like frictional pressure drop in the system, slight internal irreversibility during the compression of the refrigerant vapor, or non-ideal gas behavior.

Control

In simple commercial refrigeration systems the compressor is normally controlled by a simple pressure switch, with the expansion performed by a capillary tube or simple thermostatic expansion valve. In more complex systems, including multiple compressor installations, the use of electronic controls is typical, with adjustable set points to control the pressure at which compressors cut in and cut out, and temperature control by the use of electronic expansion valves.

In addition to the operational controls, separate high pressure and low pressure switches are normally utilized to provide secondary protection to the compressors and other components of the system from operating outside of safe parameters.

In more advanced electronic control systems the use of floating head pressure, and proactive suction pressure, control routines allow the compressor operation to be adjusted to accurately meet differing cooling demands whilst reducing energy consumption.

IV - COMPONENTS USED IN THERMO ACOSTIC REFRIGERATOR SYSTEM

Thermo acoustic refrigerator mainly consists of a medium as a working gas, a speaker (sound generator), resonator, stack, heat exchangers.

1. Working Medium gas

To achieve high efficiency gas with low kinematic viscosity is preferred this viscosity is shown by inert gases like Xenon, Helium etc. Due to low kinematic viscosity the gas molecules are free to vibrate even in a small portion which results in high utilization of gas molecules to participate in heat transfer. Since inert gases has issue like cost, refilling, leakages etc. High pressure air can also use as working medium. Thermal penetration depths & the natural frequency of the resonator are also dependent on the choice of working fluid.

2. Sound Source

Sound Source is the source of acoustic waves which is also known as Acoustic driver. The acoustic driver produces high pressure sound waves. Just like a compressor in vapor compression cycle (VCR), acoustic driver is heart of thermo acoustic refrigerator. Sound waves are produce due to vibration of flexible cone or diaphragm. The diaphragm is made up of plastic, paper, metal etc. & narrow end of the coil is attached to the coil which produces sound name as voice coil. The voice coil contains two magnets namely permanent magnet & electromagnet. The audio signal transmits or travels in the form of waves it may be transverse & longitudinal. These waves are further travels through stack.

3. Condenser

In systems involving heat transfer, a condenser is a heat exchanger used to condense a gaseous substance into a liquid state through cooling. In so doing, the latent heat is released by the substance and transferred to the surrounding environment. Condensers are used for efficient heat rejection in many industrial systems. Condensers can be made according to numerous designs, and come in many sizes ranging from rather small (hand-held) to very large (industrial-scale units used in plant processes). For example, a refrigerator uses a condenser to get rid of heat extracted from the interior of the unit to the outside air.

4. Resonator

The resonator is a device which contain working medium in it. There are two types of resonator half wavelength and quarter wavelength. Half wavelength resonators are the resonators which are open at one end and close at one end. Due to closed end the gas inside the resonator cannot move due to which velocity node and pressure anti-node is not form. The acoustic driver creates velocity node and pressure anti-node which causes the natural frequency to be half of acoustic wavelength. Quarter wavelength resonator tubes are made by sealing one end and making the length approximately one quarter of the desired resonant frequency wavelength. A large volume is attached at the open end which creates boundary conditions of zero pressure at the end which cause velocity node and pressure anti-node at the end of the tube. This indicates that natural frequency of resonator will have wavelength four times the resonator length. Mainly thermo acoustic resonators used are half wavelength or quarter wavelength but they are not exact because ideal resonators are hard to build.

5. Stack

Stack is the element where thermo acoustic effect takes place. It is the most sensitive part of the design in thermo acoustic refrigerator because small change in dimensions of the stack can lead huge difference it the performance. The efficiency of the thermo acoustic refrigerator depends on the stack. This problem arises because there is point within the resonator where velocity and pressure oscillations work together to maximize thermo acoustic effect. Since this point is infinitesimally small whose cross section is also small which would produce no cooling effect if stack is operated at only this point? The cooling power and the efficiency of refrigerator is inversely proportional to each other, as the length of stack increases the cooling power of thermo acoustic refrigerator increases but the efficiency decreases, since the further cross sections of the stack are from optimal point. The stack materials used are of low thermal conductivity and have high heat capacity. Material used for stack is photographic film or Mylar sheet. There are two types of stack formation parallel plate stack and spiral stack. The another consideration while preparing stack is stack thickness, because it should provide sufficient heat capacity but the thickness must be reduce so that there must no blockage in the stack. If blockage would present then the acoustic wave would not pass through the stack and if the thickness is too thick then there would be formation of eddies near the stack.

V - DESIGN METHODLOGY OF THERMO-ACOSTIC REFRIGERATOR SYSTEM

5.1 Introduction to CATIA

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company Dassault Systems. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite. CATIA competes in the high-end CAD/CAM/CAE market with Cero Elements/Pro and NX (Unigraphics).

CATIA can be applied to a wide variety of industries, from aerospace and defense, automotive, and industrial equipment, to high tech, shipbuilding, consumer goods, plant design, consumer packaged goods, life sciences, architecture and construction, process power and petroleum, and services. CATIA V4, CATIA V5, Pro/ENGINEER, NX (formerly Unigraphics), and Solid Works are the dominant systems.

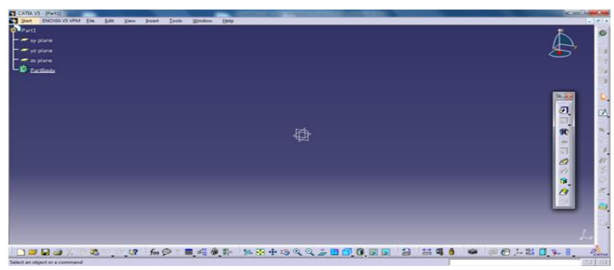


Fig: 5.1: Home Page of CatiaV5

Modeling of Refrigerator System in CATIA V5

This Refrigerator System is designed using CATIA V5 software. This software used in automobile, aerospace, consumer goods, heavy engineering etc. it is very powerful software for designing complicated 3d models, applications of CATIA Version 5 like part design, assembly design.

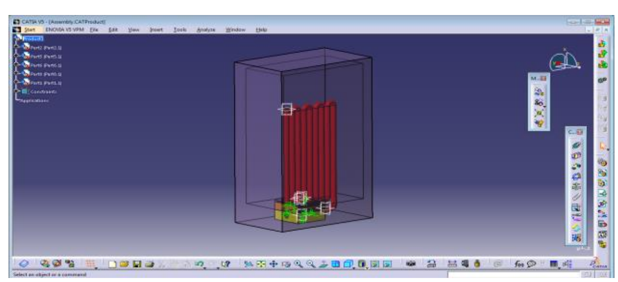


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Fig: 5.2: Model design in CATIA-V5

VI - ANALYSIS OF THERMO-ACOSTIC REFRIGERATOR SYSTEM

6.1 Procedure for FE Analysis Using ANSYS:

The analysis is done using ANSYS. For compete assembly is not required, is to carried out by applying moments at the location along which axis we need to mention. Fixing location is bottom legs of rod assembly machine.

6.2 Preprocessor

In this stage the following steps were executed:

- **Import file in ANSYS window**

File Menu > Import> STEP > Click ok for the popped up dialog box > Click

Browse" and choose the file saved from CATIAV5R20 > Click ok to import the file

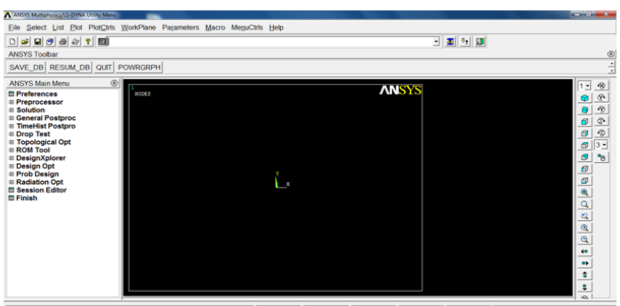

Fig.6.1: Import panel in Ansys.

6.2.1 Meshing:

Mesh generation is the practice of generating a polygonal or polyhedral mesh that approximates a geometric domain. The term "grid generation" is often used interchangeably. Typical uses are for rendering to a computer screen as finite element analysis or computational fluid dynamics. The input model form can vary greatly but common sources are CAD, NURBS, B-rep and STL (file format). The field is highly interdisciplinary, with contributions found in mathematics, computer science, and engineering.

Meshing is an integral part of the computer-aided engineering (CAE) simulation process. Furthermore, the time it takes to create a mesh model is often a significant portion of the time it takes to get results from a CAE solution. From easy, automatic meshing to a highly crafted mesh, ANSYS provides the ultimate solution.

Powerful automation capabilities ease the initial meshing of a new geometry by keying off physics preferences and using smart defaults so that a mesh can be obtained upon first try. Additionally, users are able to update immediately to a parameter change, making the handoff from CAD to CAE seamless and aiding in up-front design. Once the best design is found, meshing technologies from, ANSYS provide the flexibility to produce meshes that range in complexity from pure hex meshes to highly detailed Hybrid meshes.

VII - DISCUSSION ON ANALYSYS RESULT

Thermal Analysis Results

7.1 Results of Nodal Temperature:

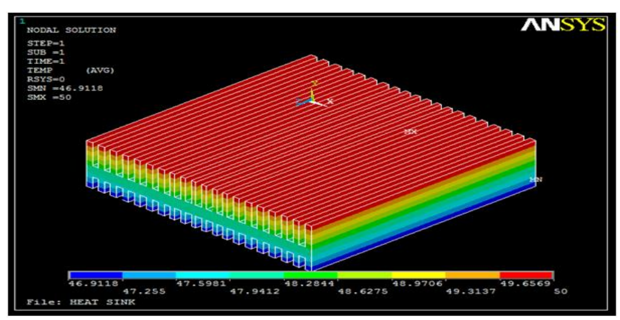

Fig: 7.1: Nodal Temperature of Heat Sink

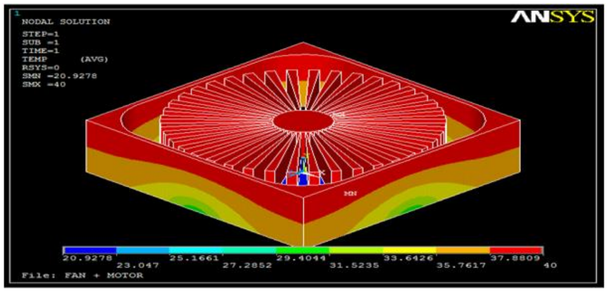

Fig: 7.2: Nodal Temperature of Fan + Motor

7.2 Results of Thermal Gradient:

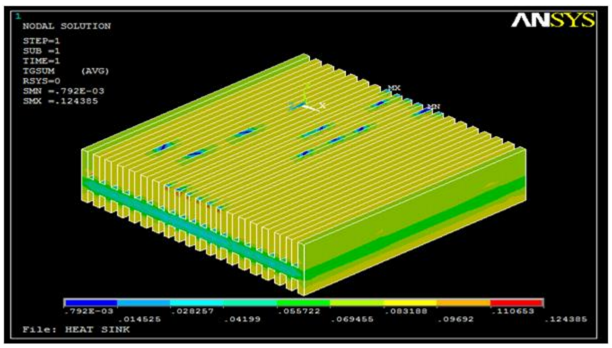

Fig: 7.3: Thermal Gradient Analysis of Heat Sink

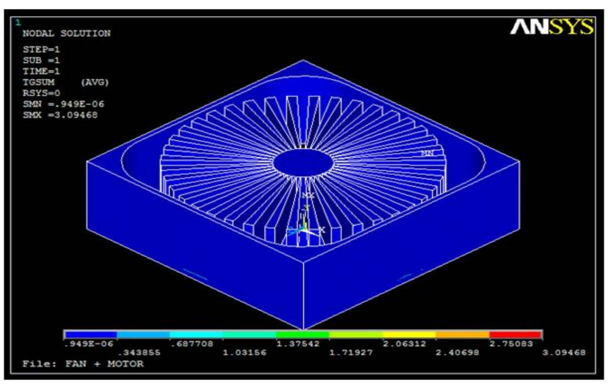

Fig: 7.4: Thermal Gradient Analysis of Fan + Motor

7.3 Results of Thermal Flux:

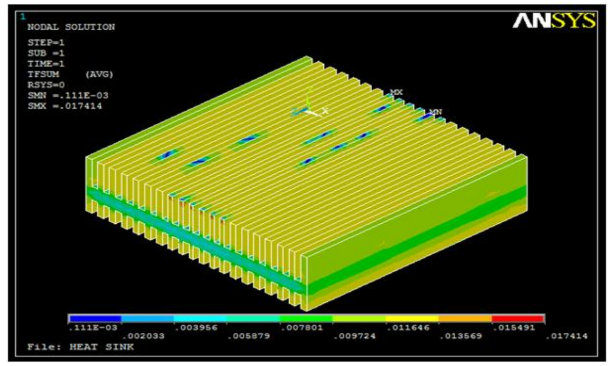

Fig: 7.5: Thermal Flux Analysis of Heat Sink

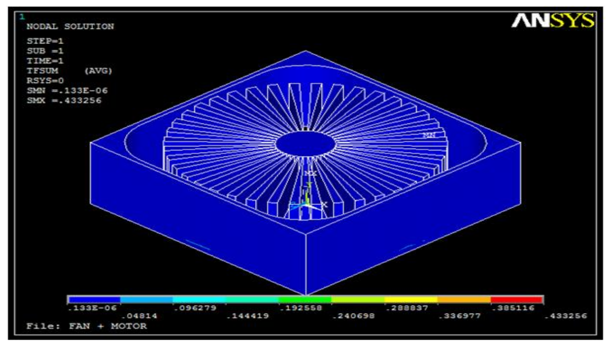

Fig: 7.6: Thermal Flux Analysis of Fan + Motor

Results of Heat Flow:

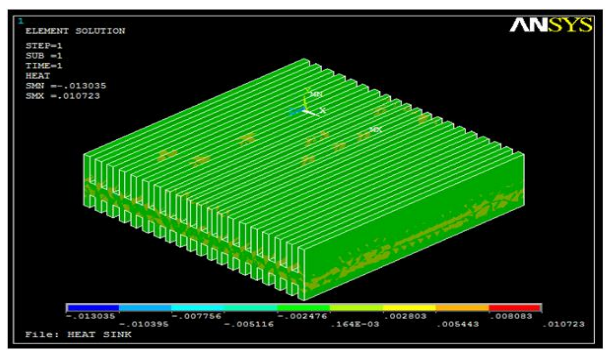

Fig: 7.7: Heat Flow Analysis of Heat Sink

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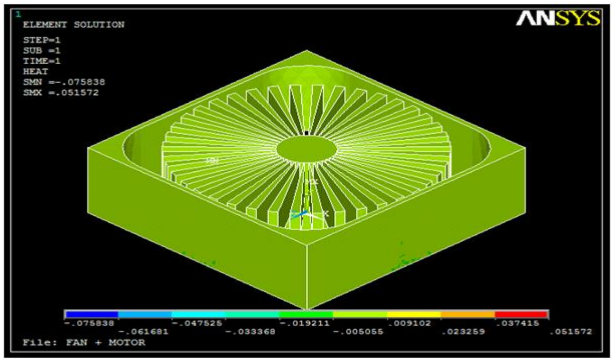

Fig: 7.8: Heat Flow Analysis of Fan + Motor

Pressure Analysis Results – Refrigerator Body - Aluminum

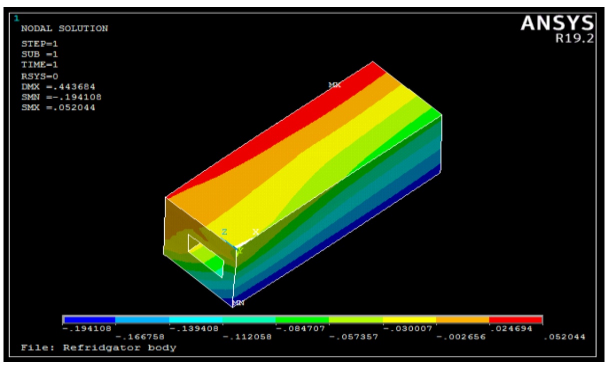

Fig: 7.9: Displacement Analysis of Refrigerator Body - Aluminum

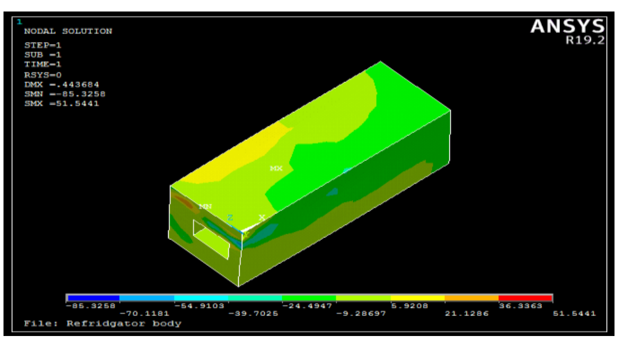

Fig: 7.10: Stress Analysis of Refrigerator Body - Aluminum

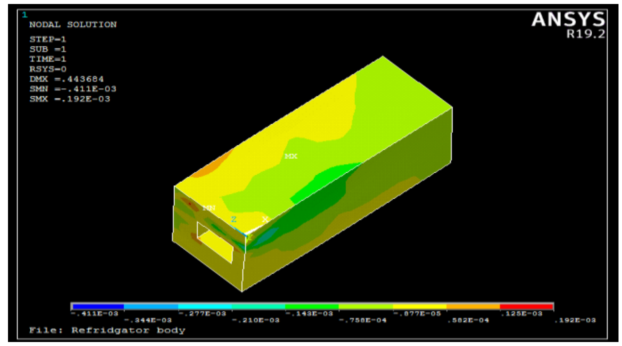

Fig: 7.11: Strain Analysis of Refrigerator Body - Aluminum

Pressure Analysis Results – Refrigerator Body - Steel

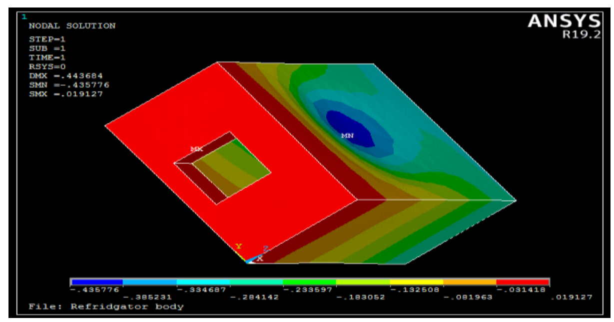

Fig: 7.12: Displacement Analysis of Refrigerator Body - Steel

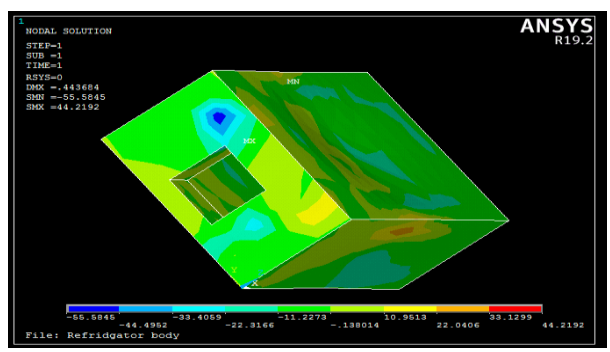

Fig: 7.13: Stress Analysis of Refrigerator Body - Steel

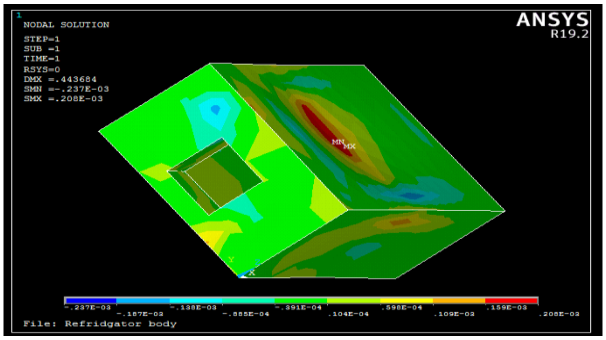

Fig: 7.14: Strain Analysis of Refrigerator Body - Steel

VIII - CONCLUSION

It can be seen from the above result that, our objective to analyze the better thermodynamic system which has been successful.

As shown above figures the pressure analysis and thermal analysis is done for the design where it is meshed and solved using Ansys. This is showing us that clearly each component in the system is having good output. The displacement, Stress and Strain, solving with the help of Ansys software. The Thermal gradient, Thermal flux and Heat flow, this solution solving with the help of Ansys software. So we can conclude our design parameters are approximately correct.

A highly nonlinear model for the behavior of the refrigerator is considered. A parametric study to investigate the influence of the control parameters on the response is conducted. The final result positive manner .There is no problem while in Final assembly design; without failure. For proving that above design is carried out for applying for future works.

The design of the Refrigerator mechanism worked flawlessly in analysis as well, all these facts point to the completion of our objective in high esteem. Finally, I report that original assembly is fine and design model results are shown without any failure.

IX.REFERENCES

- Khurmi R.S., Gupta J.K., “A Textbook of Refrigeration and Air conditioning”, S.Chand Publications, pg.no.-38-67, 68-107, 654.
- Vinod Thombre-Patil, “Thermal Engineering”, Nirali Prakashan, pg. no. -1.34, 1.35.
- Kumar D.S., Nagraj Chaudhary, Rajput R.K. “Mechanical Measurement and Control”.
- List of Refrigerants, Wikipedia, and the free encyclopaedia.
- Desideri V, Proietti S, Sdringola P, Solar –Powered cooling systems: Technical & economic analysis on industrial refrigeration and air-conditioning applications .Elsevier B.V., vol.86, pp.1376-1386, Sep 2009.
- Taylor, R.A., Solbrekken, G., Comprehensive system-level optimization of thermoelectric devices for electronic cooling applications, Componnents and Packaging Technologies, IEEE Transactions on (Volume:31, Issue: 1)
- Brown, D. R.; N. Fernandez; J. A. Dirks; T. B. Stout (March 2010). "The Prospects of Alternatives to Vapor Compression Technology for Space Cooling and Food Refrigeration Applications" (PDF). Pacific Northwest National Laboratory (PNL). U.S. Department of Energy. Retrieved 16 March 2013.
- Hsu, Jeremy (2011-06-14). "Cold? Put this jacket on. Hot? Put this jacket on Climate-controlled coat goes from zero to 100 degrees C 'in the flip of a button'". NBC News. NBC. Retrieved 16 March 2013.

IJMTARC – VOLUME – IX – ISSUE – 38, JUL - SEP, 2022 ISSN: 2320-1363

- Ferro, Shaunacy (2013-03-15). "How Winter Woes Inspired A Nanotech Fix For Everything From Cold Necks To Knee Pain". Popular Mechanics. Bonnier Corp. Retrieved 16 March 2013.
- Kotlyarov, Evgeny; Peter de Crom; Raoul Voeten (2006). "Some Aspects of Optimization Applied for the Glove Box Air Temperature Control". SAE International: 1.
- Rajput R.K., "Textbook of Thermal Engineering" and "Refrigeration books" pg. no.-1202, 1420, 1471-73.