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Internal Support Optimization of Cryolines in Terms of Heat Load and Pressure Thrust Using Finite Element Methods

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Abstract: *Almost all cryogenic systems typically include cryogenic transfer lines. They serve the purpose of moving cryogenic fluids between two cryogenic equipment. One of the most crucial components of the cryoline is the fixed support (FS), which also serves as the anchor for the bellows. The FS must be able to handle the static weight of pipes as well as the bellows' spring and thrust forces. For the thermal, structural, and combined loads with thermal optimization criteria, the FS design will be optimized. ANSYS Software will be used for the analysis and Space Claim Software will be used for the modelling as well as geometry optimization. A thorough mesh sensitivity investigation and design optimization will be done in order to reduce the Von-Mises stress to within the material's permissible range. Mesh refinement continued iteratively until stress convergence will be attained. For the best mesh size a stress analysis will be done. The design process, construction information, and the outcomes of the heat load optimization using the steady state thermal module and the strength optimization using the static structural module of ANSYS will be presented in this study.*

Keywords*:* Deformation Profile, Fixed Spacer, Finite Element Method (FEM), ANSYS

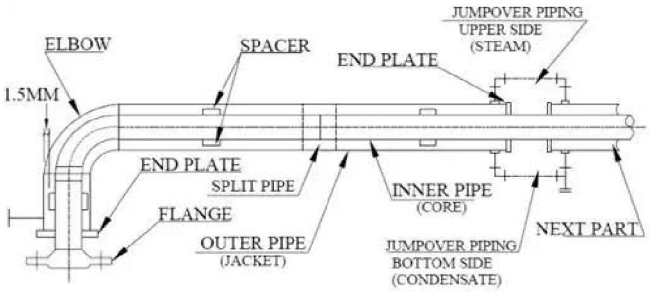
I. INTRODUCTION

Cryogenics is the study of the production of very low temperature (below –150 °C, -238 °F or 123 K) and the behaviour of materials at those temperatures. Absolute temperature scales in Cryogenics. These are Kelvin (SI units) or Rankine scale (Imperial & US units).

ITER is an international nuclear fusion research and engineering megaproject aimed at creating energy through a fusion process similar to that of the Sun.The ITER cryogenic system consists of the cryoplant, cryodistributionsystem and the system of cryogenic lines and manifolds.

Cryolines are vacuum jacketed line also called vacuum-insulated piping, is used to transfer supercooled gasses in liquid form. Cryogens like liquid helium, liquid oxygen, and liquid nitrogen must be kept cold during the transfer process, or some of the liquid will become gaseous and leak out.

The cryoline consists of straight, T, C and elbow sections and these sections contain bellows or flexible hoses, at least one fixed support and many sliding supports as per the design code guideline.

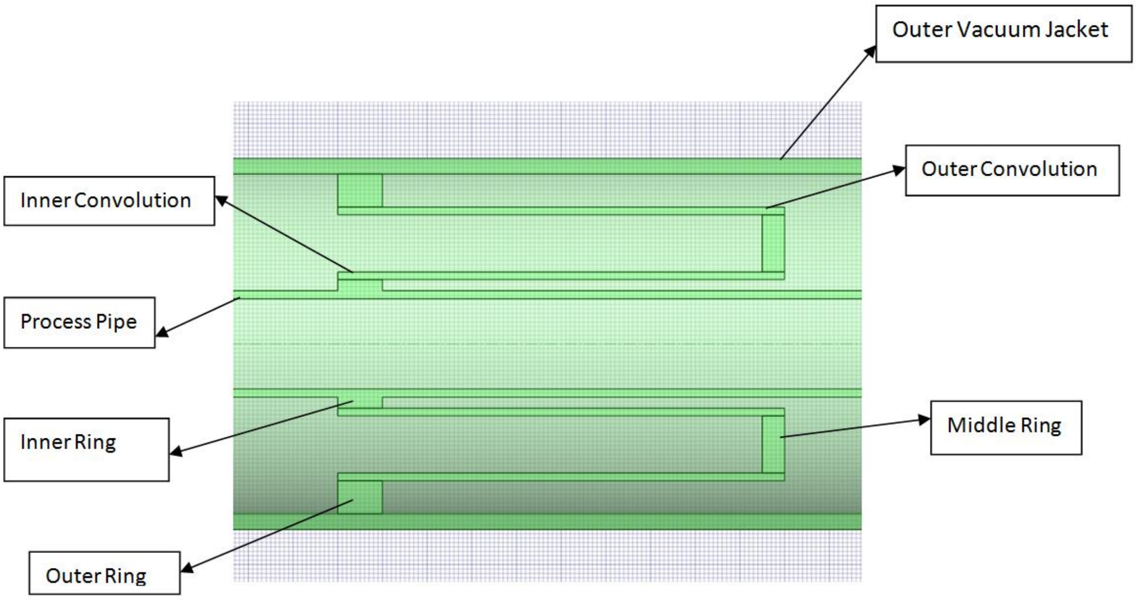


Components of Jacketed Piping System

Cryogenic transfer lines are typical components of almost all cryogenic systems. They are intended for transferring cryogenic fluids between two cryogenic devices. Since the value of the cryogenic fluids is essentially in the thermodynamic states of their molecules, the transferring should not cause significant changes in the thermodynamic states of the transferred cryogens. It means that either the temperature increase or, in case of liquids, the vapourquality and also pressure changes should be negligibly small.

The supports are important to ensure that the bellows absorbs the motion for which it is designed. The Fixed spacer/support has to withstand the static weight of the process pipes and its content. It also acts as the anchor or fixed point for the bellows. It has to take care the spring as well as the pressure thrust forces arising from the bellows. Inadequate design fixed support causes stress that reduces the life of the bellow,cause pipe bucking and system failure.

To understand the Design of Fixed Spacer & Initial Configuration.



There are Five Parts are in the Assembly the fig. shows in 1.2.1. The names are as under:

1. Inner Convolution
2. Outer Convolution
3. Middle Ring
4. Outer Ring
5. Inner Ring

Heat Load Path is from Process pip to inner ring, inner ring to inner convolution, inner convolution to middle ring, middle ring to outer convolution, outer convolution to outer ring and outer ring to outer vacuum jacket.

II. LITERATURE REVIEW

N. Shah and et al. The PTCL will be manufactured in 1:1 scale with a configuration of main line and branch line that includes vacuum barriers. It is being designed with four process pipes at temperature level 4.5 K and two process pipes at temperature level 80 K. To meet the test objectives, the necessary infrastructure as well as the control system have been designed, analyzed, and optimized within the constraints imposed. The PTCL will be tested to measure heat load at 4.5 K with scaled mass flow rate and a thermal shield at 80 K.

Sarkar et. al. Six process pipes, a thermal shield operating at 80 K, and an outer vacuum jacket constitute the topology of the torus and neutral beam cryoline. To foster trust in the idea and to lay out the elevated degree of science and assembling innovation, a model testing has been proposed. Mechanical way of behaving of cryoline because of warm anxieties will be contemplated while executing the examination. The trial of the model cryoline will approve the plan definitions and recreation results.

Vaghela et. al. these incorporate specialized risk evaluation, examination, relief plan and execution with the modern accomplices. The paper portrays the technique of specialized risk the board, esteem designing performed to guarantee satisfaction of permitting and administrative commitments, practical dependability, testing and manufacturability by standard modern cycles, with the goal that exceptionally solid incorporated circulation framework is conveyed for the task. Forages et. al.'s PTCL test was conducted at ITER-India cryogenics laboratory following its complete installation and integration with the existing test facility to confirm its mechanical integrity and thermal performance. The methodology and observed results of PTCL will be summarized in the paper.

Muralidhara and et. al. The approach for conceptual load estimation and selection of EPs for Toroidal Field (TF) Cryoline as an example by converting the load combinations into two main load categories is described in the paper, as are the single loads and load combinations considered in load specification; pressure and seismic.

Bhattacharya and co. al, the task has advanced from the calculated stage to the modern stage. the subsystems are at different phases of configuration as characterized by the task, in particular, primer plan, last plan and formal surveys. The current status of the task as far as specialized accomplishments, ramifications of the progressions and the specialized administration as well as the gamble appraisal and its moderation including way ahead towards acknowledgment is portrayed.

Badgujar et. al. the multi-process pipe vacuum jacketed cryolines for the ITER project are likely world's most mind boggling cryolines as far as design, load cases, quality, security and administrative necessities. Before the final design of ITER cryolines was approved, it was planned to design, manufacture, and test a prototype cryoline (PTCL) as a risk mitigation plan. The current paper portrays the warm and cold test consequences of model cryoline for Gathering X cryolines (PTCL-X) did during September-October 2016 at ITER-India Cryogenics Research center (IICL) in Gandhinagar, India.

Kapoor and et. al. The ITER CL system and the assembly and installation plan that was created taking into account the layout constraints and complexity of the integrated installation in the Tokamak building are described in this paper. The ITER cryoline (CL) framework comprises of a perplexing organization of vacuum protected multi and single interaction pipe (PP) lines dispersed north of three distinct regions at ITER site. The establishment of these CLs in the Tokamak building is an extremely provoking and exceptionally coordinated task because of the presence of numerous gear in their area.

Using thermal optimization criteria, Navion-Maillot et al.'s FS design has been optimized for thermal, structural, and combined loads; less than 1.5 Watt at 4.5 K and less than 8 Watt at 100 K, respectively. ANSYS 10.0 was used for the analysis, while CATIA V5 R16 was used for the modeling and optimization of the geometry. To bring the Von-Mises pressure inside the OK furthest reaches of 115 MPa, an itemized network responsiveness concentrate on has been done. alongside plan enhancement. The pressure examination has been done for upgraded network size. The analysis's findings, construction details, and design methodology will all be discussed in the paper.

Vaghela and everyone have realized that a back-up plan is necessary to guarantee that the measurements are accurate. The back-up strategies anticipated as Plan-B incorporates (I) filling the cycle pipes with low temperature helium gas and assessing time bound temperature increment and (ii) estimating temperature contrast for different radiator power utilizing existing electric warmers and extrapolating the outcomes. The plans for measuring heat load at temperatures of 4.5 K and 80 K, as well as a comparison of the two, are discussed in detail in this paper.

Bhattacharya and et. al. The specifications for the test infrastructure have been finalized by conducting a process study and a variety of analyses. The global thermo-hydraulic analysis of the PTCL test infrastructure is the subject of the current study. In order to investigate the 80K system's dynamic behavior, preliminary process simulation with ASPEN HYSYS® was carried out.

Bhattacharya and co. al. the idea for fixed and sliding help has been created alongside three ideas for warm safeguard. The conceptual design details of "MAG CL" are discussed, as are design difficulties, constraints, and analysis findings for fixed support, sliding support, and thermal shield. biggest and most confounded multi process pipe cryoline which upholds different working methods of magnet framework. Process pipe sizes have been finalized through hydraulic analysis.

S, Naik, and al. Taking into account the complex thermo-water power included, Microsoft Succeed, Hepak© and NIST material information has been coordinated to foster the static test system which performs itemized thermo-water driven

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computations for different info information to appraise strain and temperature profile of liquid along the cycle lines of PTCL as well as to gauge the cooldown/warmup term and absolute stock of helium during the test. The setup of the test, the major phases of the PTCL test, the background calculations that were done, the simulator's various built-in options, and the results for specific cases are all covered in this paper.

Kosek, and al. After the short depiction of the CL framework, the paper will portray the EcosimPro® model ready for the powerful review. The paper will also describe the results, such as the RL's minimum temperature, mass flow, and maximum pressure, which are primarily used to select the safety relief devices that will safeguard the CL process pipes and their locations. The ITER cryoline (CL) system is made up of 37 different kinds of vacuum-jacketed transfer lines. These lines are located inside the Tokamak building, on a special plant bridge, and in the Cryoplant building/area. Together, they make up a complicated, structured network that has a length of about 5 km.

Shah and al. The cryoline's functional operating scenario must be satisfied by the cryogenic system. cryoplant, circulation box including fluid the cryogenic framework for the taste. A commercially available refrigerator/liquidifier and a custom-designed housing cold compressor, cold circulator, phase separator, and submerge heat exchanger comprise the conceptual system architecture..

Ketan. et al. The helium screw compressor, liquid helium Dewar, liquid nitrogen Dewar, 80K cold box, and test valve boxes for distributing and controlling the flow of cold helium make up the majority of the test facility. The test office has been effectively introduced and as of late dispatched in 80K temperature level. In addition, the system was tested once more in a variety of modes to determine its operational adaptability for the PTCL test. The results of the test facility's commissioning and the operational experience gained during the system performance measurement tests are discussed in this article.

In order to enable a variety of ITER experiments, the cryogenic plant and cryo-distribution subsystem are designed to be robust and adaptable in operation. Mental images. The large pulsed heat load deposited in the ITER magnets can be reduced thanks to the cryogenic system's design. The key aspects of the ITER cryogenic system are highlighted in this publication, along with the findings. investigations to reduce the heat load from helium circulating pumps and attenuate pulsed heat loads on the helium refrigerator. Elsevier B.V. has all rights reserved as of 2006.

This paper deals with the theoretical and practical concepts to develop a SCADA System using CODAC Core Software. The work has been focused on developing the complete human machine interface The final application has been successfully developed to control the cryogenic test facility for PTCL. The analysis and results confirm that the objective of developing SCADA using CODAC Core software for the cryogenic test facility has been fulfilled is ready for actual experimental work.

The experimental and anticipated heat loads. Transverse radiation is quite important for the heat load at 80K, according to the study's findings. Only 2% separate the revised heat load value (220.67W) from the PTCL experimental heat load, which was determined through numerical analysis taking transverse radiation with conduction into account.

The PTCL experimental heat load at 80K and the impact of transverse radiation caused by the bare surface of fixed supports, vacuum barriers, and sliding supports are summarised in this paper.In order to reduce the refrigeration power, an algorithm has been devised to optimise the supercritical helium mass flow and the cold source temperature.

In this early design stage, the goal of such analysis is to help optimise the cryogenic system and the superconducting magnets in order to reduce the refrigeration power, a significant upfront cost and ongoing operating expense for the future tokamak.

The results of the thermohydraulic calculations to determine the transient heat loads at the interface between the magnet system cooling loops and the auxiliary cold box are presented in this study together with the static and variable heat loads of the various cooling loops.

The torus subsystem, composed of six torus cold valve boxes and associated cryopumps, is dynamically modelled in this article for both operational and 100 K regeneration situations. We'll discuss the preliminary simulation findings, which provide helpful details for fine-tuning factors including pressures, mass flow rates, and valve control. These findings can be used to improve the commissioning and final design of the distribution system.

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III. NUMERICAL ANALYSIS WORK

3.1 Introduction of Numerical Analysis.

The study of methods for mathematical analysis issues (as opposed to discrete mathematics) that use numerical approximation rather than symbolic manipulation is known as numerical analysis. The study of numerical methods aims to identify approximate rather than precise answers to issues.

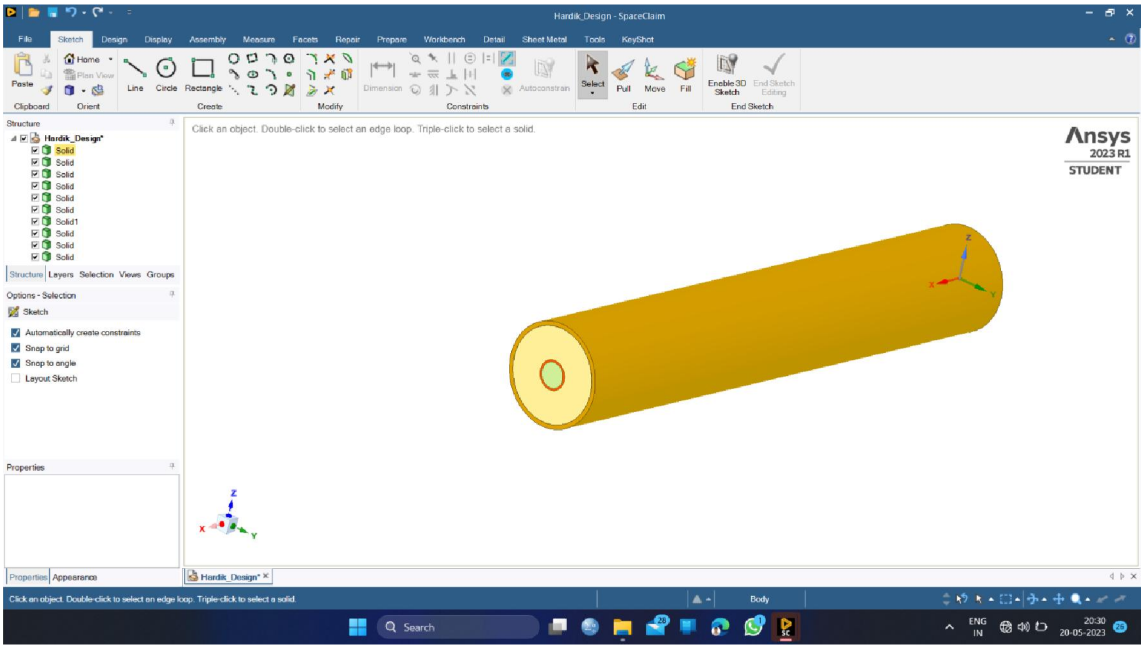
The study of methods for mathematical analysis issues (as opposed to discrete mathematics) that use numerical approximation rather than symbolic manipulation is known as numerical analysis. The study of numerical methods aims to identify approximate rather than precise answers to issues.The basic of using simulation in performing structural and thermal analysis.

Advantage of numerical analysis:

- Applicable to complex geometry.
- Applicable to arbitrary nonlinear physical problem.
- Allow a more accurate representation reality.

The fig. 3.1 shows the 3D Model develop in Space Claim 2023 R1 student Version. The fixed Spacer numerical analyzed in software of ANSYS 2023 R1.

3.2 Fixed Spacer Design & Parameters



In the present Study Fixed Spacer used in Cryoline is analysed using ANSYS Software. So, 3d model develop in design model in Space Claim 2023 R1. There are many parts designs are included in fixed spacer of 3d model. The design parameters of fixed Spacer is taken from the Research paper of Kumar et.al [20].

The dimensional drawing of the Fixed Spacer is shown in figure no. 3.2.1 & table no. 3.2.3The S.S. 304 L and G10 (Composite) Materials are used in this Case Study. Two Materials are selected for analysed work.For S.S. 304 L materials four cases are studies& Its dimension are shown in fig. 3.2.1 For G10 (Composite) Material six cases are studies & its dimensions are shown in fig.

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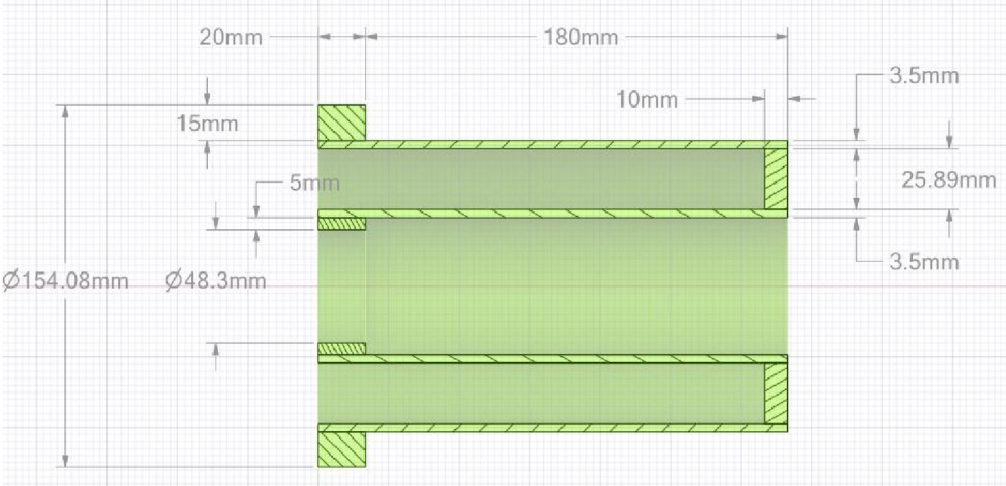
Design Parameters of Fixed Spacer



3.2.1 Dimensional with Figure of Fixed Spacer

3.2.2 3D Model

3.3 Design Parameters for S.S. 304 L Material.

Sr no.	Case Study	I.D of Inner Ring	O.D. of Middle Ring	O.D. of Outer Ring	Inner Ring (T)	Middle Ring (T)	Outer Ring (T)	Mass	Allowable Stress	Heat Load
1	Case Study 1	Ø53.3mm	Ø 117.08 mm	Ø154.8 mm	5mm	10 mm	20 mm	4.94 Kg	190 MPA	10.787W
2	Case Study 2	Ø53.3mm	Ø117.08 mm	Ø154.8 mm	5mm	10 mm	20 mm	3.65 Kg	190 MPA	6.32 W
3	Case Study 3	Ø53.3mm	Ø 118.08 mm	Ø 154.8 mm	5mm	5mm	20 mm	2.87 Kg	190 MPA	4.52 W
4	Case Study 4	Ø 38.3mm	Ø 119.08 mm	Ø 154.8 mm	5mm	5mm	5mm	1.55 Kg	190 MPA	2.79 W

3.2.4 Result of S.S. 304 L Material

The all four case studies dimension values are given in table no. 3.3. In Four case Studies, the Stress limit value is same. But, the mass values are changed in four case studies. This both values has been applied in four case studies.

In case study - 1, the given dimensions are use in case study 1 So, the Heat load value is Obtained 10.787 W. In case study - 2, the I.D. of inner ring diameter is to be changed in case study 2. So, the Heat load value is Obtained 4.52 W.In case study - 3, the O.D. of Middle Ring and Middle Ring (T) is to be changed. So, the Heat load value is Obtained 4.52 W. In case Study - 4, the I.D. of Middle Ring, O.D. Middle Ring and Middle Ring (T) is to be changed. So, The Heat load Value is Obtained 4.52 W.

According to the above table no. 3.3, We can knew the Heat Load values. In Four case studies the Minimum Optimum suitable heat load value is 2.79 W.

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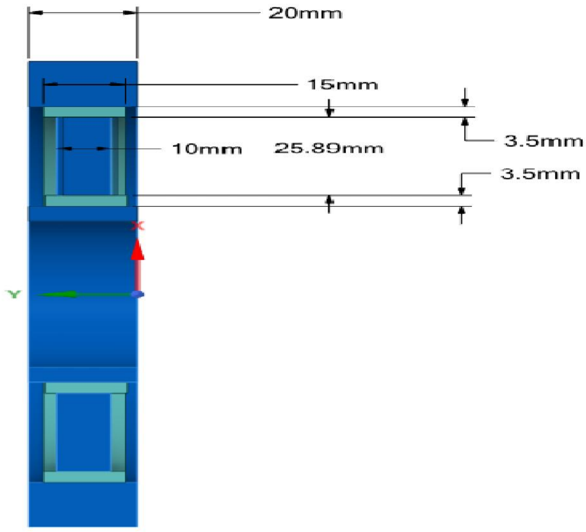
3.4 Design Parameters of Fixed Spacer with include Fixed support of G10 Material.



3.4. Dimensional Figure of fixed support between S.S. 304 L Parameters

3.4.1 Different Dimensions for G10 (Composite) material.

Sr No.	Outer Ring O.D.	Composite material ring O.D	Inner Ring (T)	Mass	Outer Ring (T)	Allowable Stress	Heat Load
1	154.08 mm	124.08mm	15 mm	1.79 Kg	20mm	148 MPA	36.68 W
2	154.08 mm	124.08 mm	10 mm	1.19 Kg	15 mm	148 MPA	21.64 W
3	154.08 mm	124.08 mm	15 mm	2.24 Kg	35 mm	148 MPA	13.23 W
4	154.08 mm	137.38mm	15 mm	0.768 Kg	20mm	148 MPA	9.58 W
5	154.08 mm	137.38mm	5 mm	0.368 Kg	10 mm	148 MPA	3.4 W
6	154.08 mm	147.11 mm	4 mm	0.267 Kg	10 mm	148 MPA	2.4 W

3.4.2 Result of Fixed Support G10 (Composite) Material between S.S. 304 L Material

The all six case studies dimension values are given in table no. 3.41. In Six case Studies, The Stress limits value is same. But, the mass values are changed in Six case studies. This both values has been applied in sixcase study.

In Case Study -1,the given dimensions are use in case study – 1 So, the Heat load Value is Obtained 36.68 W. In case Study -2, the Inner Ring (T)and Outer Ring (T)is to be changed So, the Heat load value is Obtained 13.23 W. In Case Study – 3, the Inner Ring (T)and Outer Ring (T)is to be changed So, the Heat load value is Obtained 13.23 W. In Case Study - 4, the Composite Material O.D. and Outer Ring (T)is to be changed So, the Heat load value is Obtained 9.58 W.In case study -5, the Inner ring (T) andOuter Ring (T)is to be changed So, the Heat load value is Obtained 3.4 W.In case study - 6, the O.D. of Composite Material and Inner ring (T) is to be changed So, The Heat load value is Obtained 2.4 W.

According to the above table no. 3.4, We can knew the Heat Load values. In Six case studies the Minimum Optimum suitable heat load value is obtained 2.4 W.

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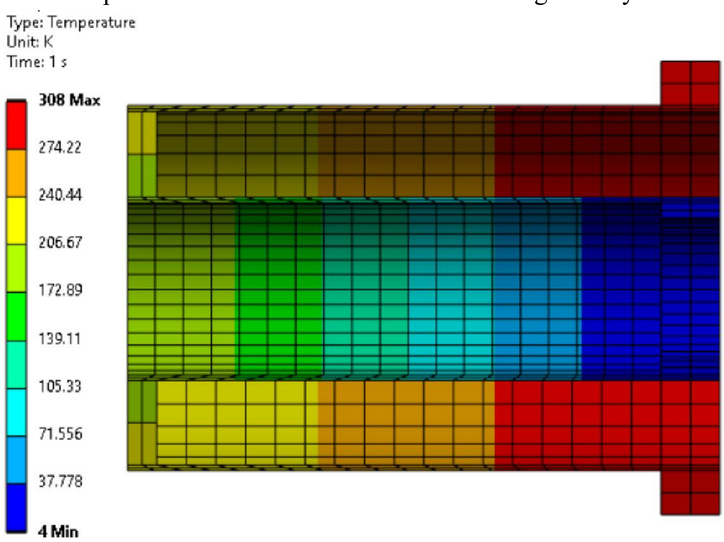
IV. RESULT & DISCUSSION

4.1 Results Simulations for S.S 304L Material.

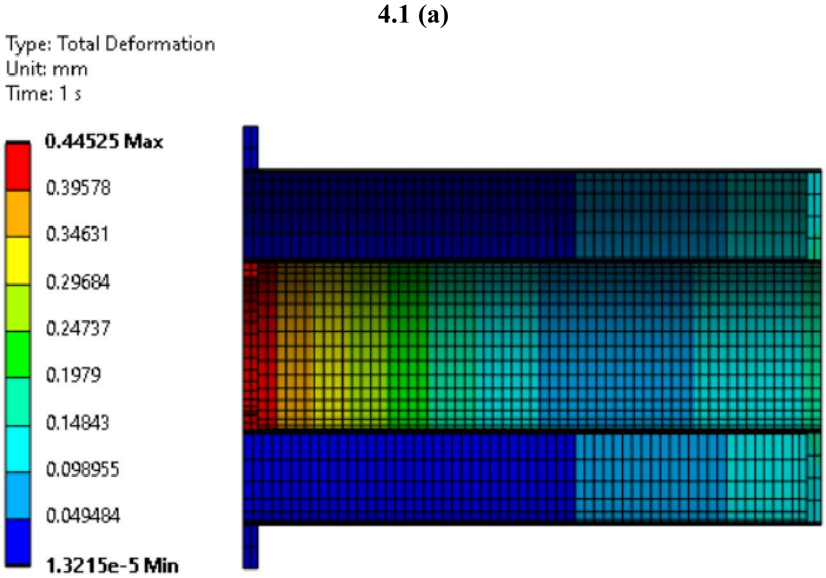
To Perform the FEM simulation on channel geometry for various Temperature and Deformation.The input data of the mass and allowable stress are applied in without Composite methods under the allowable stress limit.Heat Load is directly proportional to Mass of the Body, Specific Heat at Constant Pressure and Change in Temperature.As per the results obtained from the Design and Simulation of the Spacer, Heat Load reduces with reduction in the Mass through change in the dimensions / size of the Spacer.

In operation, the result Simulations for S.S. 304 L methods are obtained the minimum heat value is 2.79 W.As per the specified condition, in study cases the dimension has to be changed until a satisfactory result is obtained.

Hence, the more suitable S.S. 304 L method is case study 4.Because its result is satisfactory as per the other case study. Fig. 4.1 (a),(b),(c) represent the Temperature and Deformation simulation of geometry.



4.1 (a)



4.1 (b)

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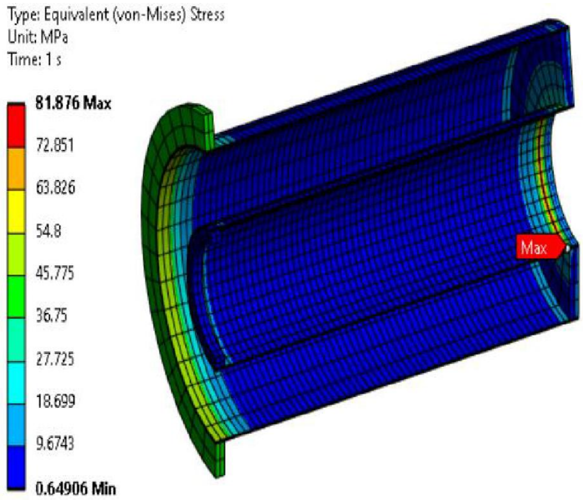
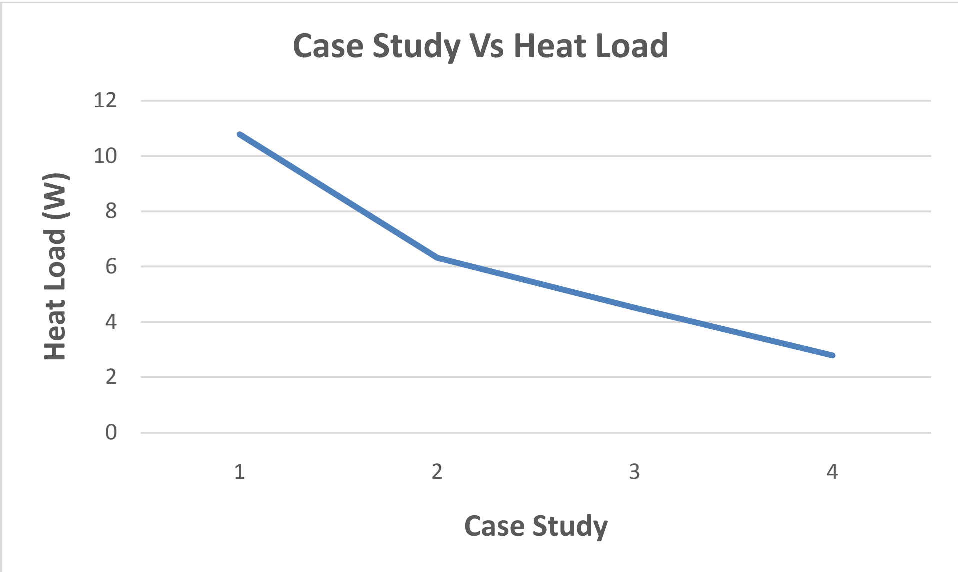


4.1 (c)

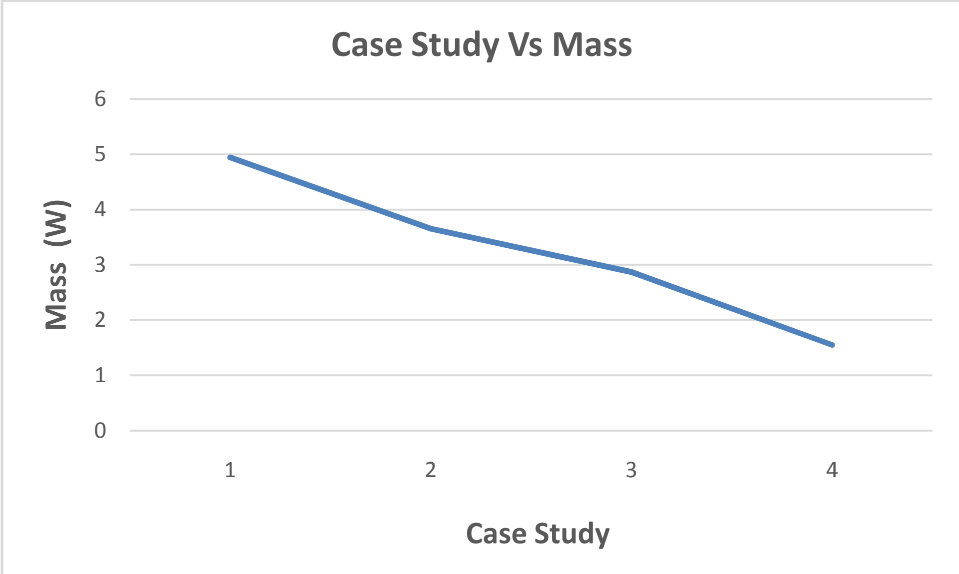
Basically, The four case study database results are shown. such as, Temperature profile, Deformation profile, Stress Profile. But, case study 1,2,3,4 database is shown in table no. 4.1.1.

4.1.1 Simulation result of different types of heat load for S.S.304 L.

Sr No.	Case Study	Mass	Allowable Stress	Heat Load
1	Case study -1	4.94 Kg	190 MPA	10.787 W
2	Case study -2	3.65 Kg	190 MPA	6.32 W
3	Case study -3	2.87 Kg	190 MPA	4.52 W
4	Case study -4	1.55 Kg	190 MPA	2.79 W



4.1.2 Case Study Vs Heat Load

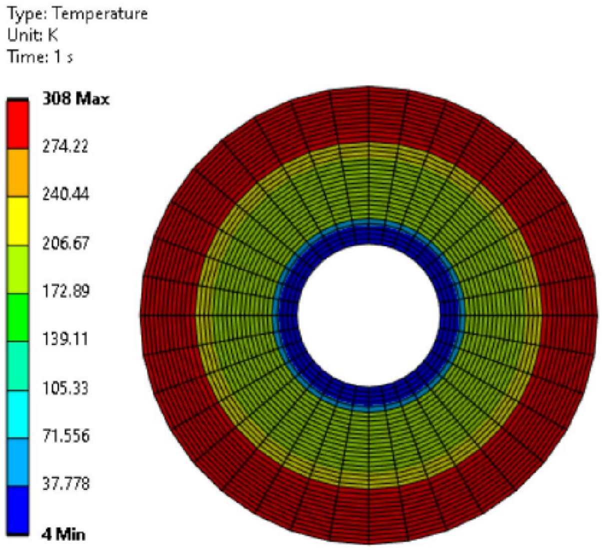


4.1.3 Case Study Vs Mass

4.2 Results Simulations of G10 (Composite) Material

To Perform the FEM simulation on channel geometry for various temp. and deformation.The input data of the mass and allowable stress are applied in Composite methods under the allowable stress limit. In study case Heat Load is directly proportional to Mass of the Body, Specific Heat at Constant Pressure and Change in Temperature.As per the results obtained from the Design and Simulation of the Spacer, Heat Load reduces with reduction in the Mass through change in the dimensions/size of the Spacer.

In operation, the result Simulation of G10 (composite) material methods are obtained the minimum heat value is 2.4 W. As per the specified condition, in study cases the dimension has to be changed until a satisfactory result is obtained.Hence, the more suitable G10 (Composite) material method is case study 6.Because its result is satisfactory as per the other case study. Fig. 4.2 (a),(b),(c) represent the Temperature and Deformation simulation of geometry.



4.2 (a)

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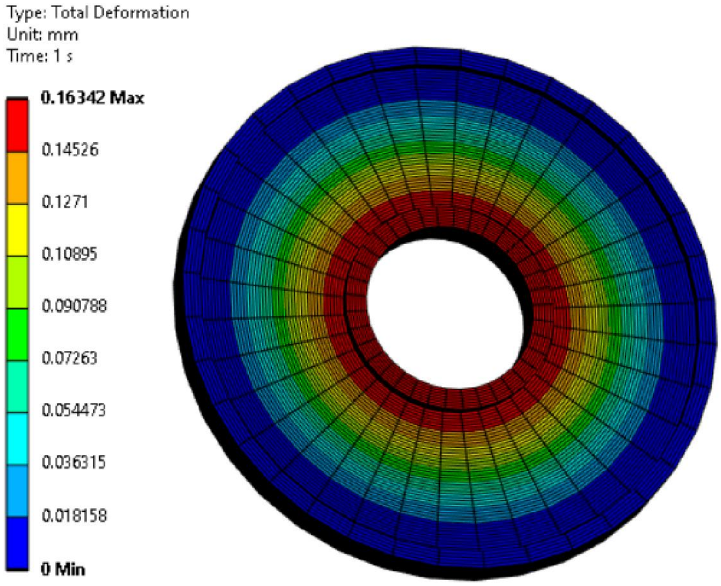
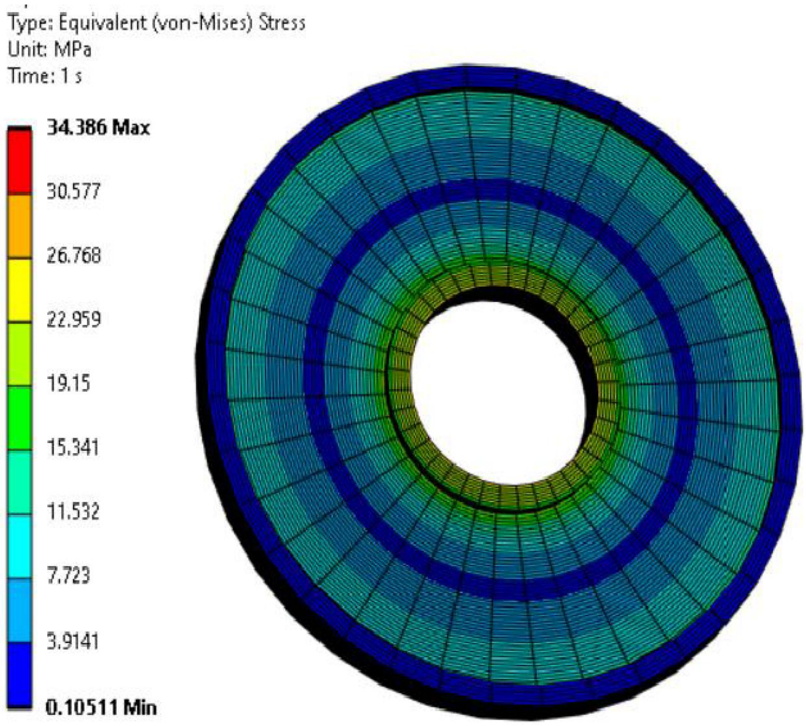


(b)



4.2 (c)

Basically, The Six case study database results are shown. such as, Temperature profile, Deformation profile, Stress Profile. But, case study 1,2,3,4,5,6 database is shown in table no. 4.2.1.

4.2.1Simulation result of different types of heat load for G10 (Composite) Material

Sr No.	Case Study	Mass	Allowable Stress	Heat Load
1	Case study -1	1.79 Kg	148 MPA	36.68 W
2	Case study -2	1.19 Kg	148 MPA	21.64 W

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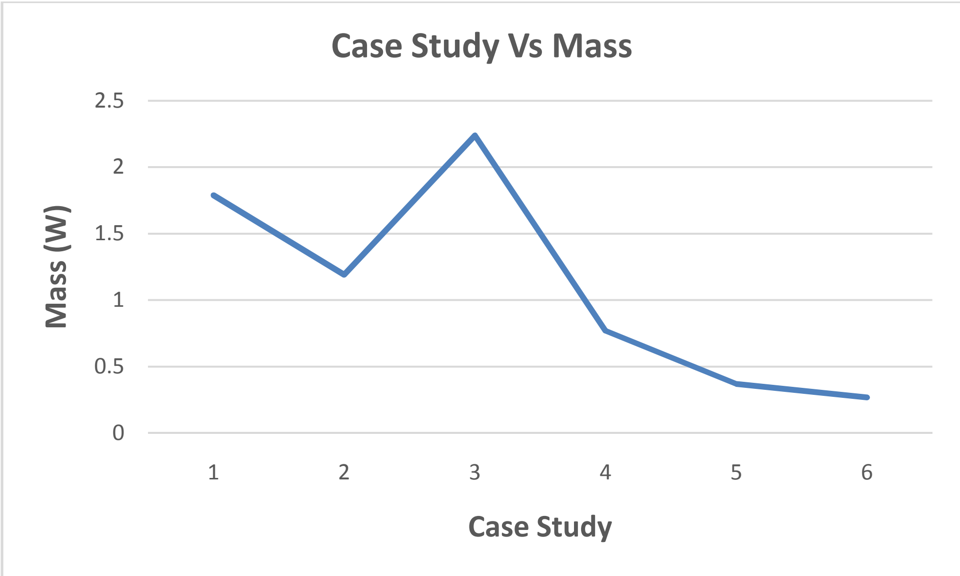
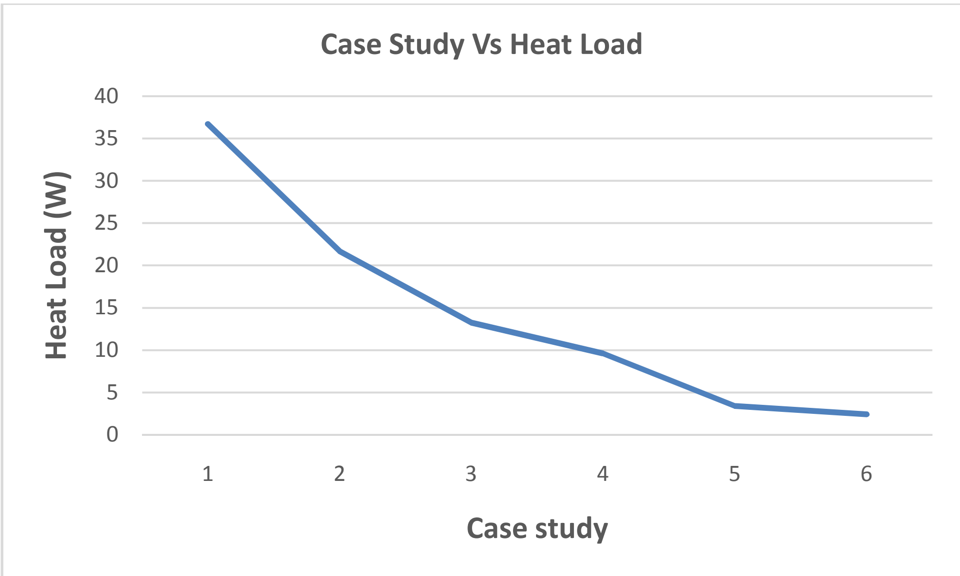
3	Case study -3	2.24 Kg	148 MPA	13.23 W
4	Case study -4	0.768 Kg	148 MPA	9.58 W
5	Case study -5	0.368 Kg	148 MPA	3.4 W
6	Case study -6	0.267 Kg	148 MPA	2.4 W



4.2.2 Case Study Vs Mass



4.2.3 Case Study Vs Heat Load

V. CONCLUSION

In this master thesis, an extensive investigation was conducted to enhance the design of fixed spacers for cryogenic systems. The primary focus was on optimizing heat load performance by examining the maximum temperature difference. Initially, various configurations were analyzed using stainless steel as the sole material. Subsequently, a second phase of simulations was carried out, incorporating a combination of stainless steel and G10 composite material to further refine the design.

Through this optimization process, a significant reduction in heat load was achieved, decreasing from 10 Watts to 2 Watts. Furthermore, space requirements were significantly minimized, shrinking from 500 mm to just 20 mm. Additionally, the mass of the fixed spacer design was optimized, resulting in a substantial reduction from 10 kg to a mere 200 grams, thanks to the incorporation of stainless steel and G10 material.

Overall, this research successfully demonstrated the efficacy of the optimized fixed spacer design in terms of heat load reduction, space utilization, and mass optimization. These findings hold considerable potential for enhancing the performance and efficiency of cryogenic systems.

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BIOGRAPHICAL NOTES

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