Design and Development of a Cryogenic Chamber for Machining

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ABSTRACT

Man has still not quenched his inquisitiveness about outer space which has led to constant advancements in the materials used in space-crafts. Composite materials exhibit properties which makes them suitable for uses at cryogenic temperatures. In the present world scenario, where space exploration and research are of great relevance to every nation, it is the need of the hour for science congregants to take the next big leap in design and manufacturing of space-crafts and the materials used in different parts.

Keywords: Machining, Cryogenic condition, Composite material, Cryogenic temperature, Cryogenic chamber.

1. INTRODUCTION

In order to achieve this efficiently, there is a need to explore new materials which can cater to the specific requirements. This is followed by the meticulous testing of these materials, as a failure at that altitude can be fatal. The present work focuses on testing the composite materials in cryogenic environment, which resemble outer space temperatures created using liquid nitrogen. In a double walled vacuum chamber used as an attachment to the torsion-testing machine.

E.D. Marquardt et al. [1] suggested materials which included oxygen free copper. These materials are commonly utilized for cryogenic applications. A. Hima Bindu [2] found that a cylindrical vessel with a length –to diameter ratio of unity has only 21 percent greater surface area than a sphere of the same volume, so the heat in-leak penalty is not excessive for cylindrical vessel compared with a spherical vessel.

Duna-Corradini [3] studied polyurethane foam has the maximum advantages in cryogenic insulation as it can withstand with temperatures ranging from -200°C to +130°C. The foam is made of little bubbles filled with the blowing agent that provides the good insulation properties. J. E. Fesmire [4] performed fourteen tests using the cryogenic insulation test apparatus for cylindrical specimens, Cryostat-1. The test conditions were representative of the actual-use conditions for cryogenic insulation. The glass bubbles had much better thermal performance than perlite for all vacuum levels. The glass bubbles were also better than aerogel beads at high vacuum up to about 300 milli-torr. Vincent Grillo [5] suggested stainless steel is the best suitable material for cryogenic application. We supply liquid nitrogen containers (Dewar flasks) made of stainless steel 304.

2. Design of Cryogenic Chamber

The figure below shows the inner chamber and the inner chamber and outer chamber in creo parametric 2.0

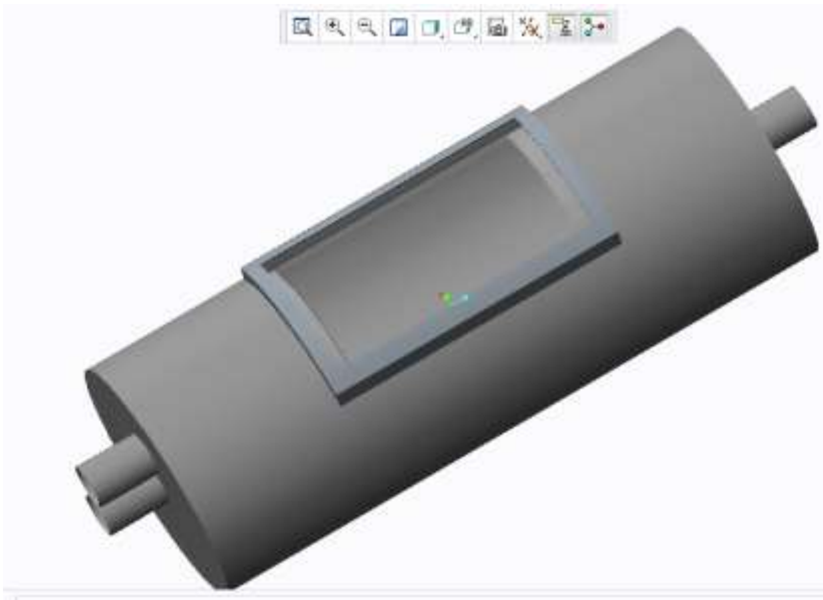

Figure 1 Design of inner chamber [12]

The figure below shows the insulation material design and vacuum valve design.

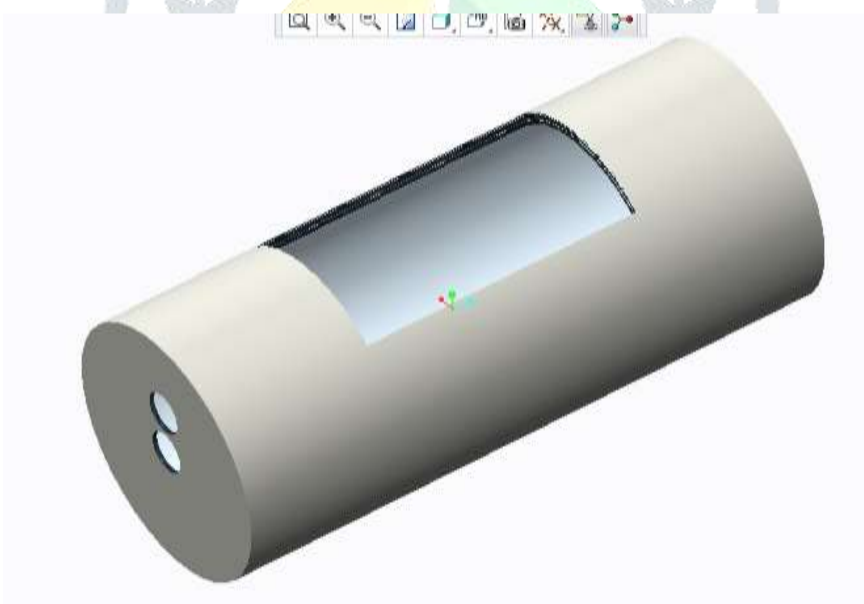

Figure 2 Design of insulation layers [12]

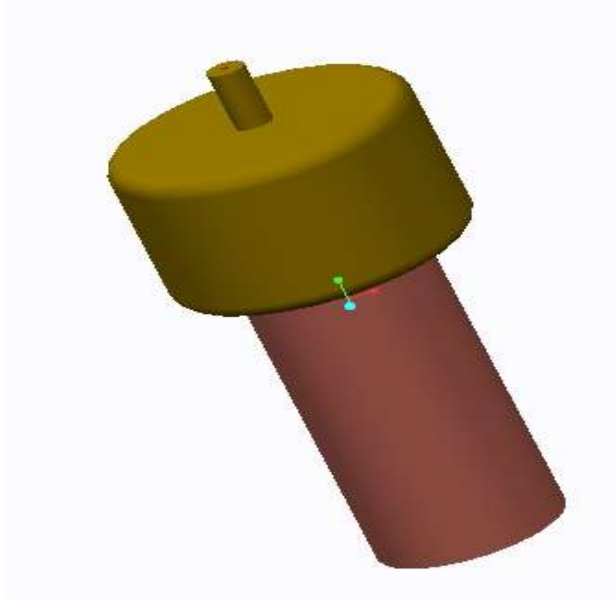

Figure 3 Design of vacuum valve [12]

The figure below shows the assembly of all three parts and its exploded view the process of design of the cryogenic chamber and associated insulation required in cryogenic have been studied. The whole chamber consists of the insulated environmental enclosure and vacuum pump.

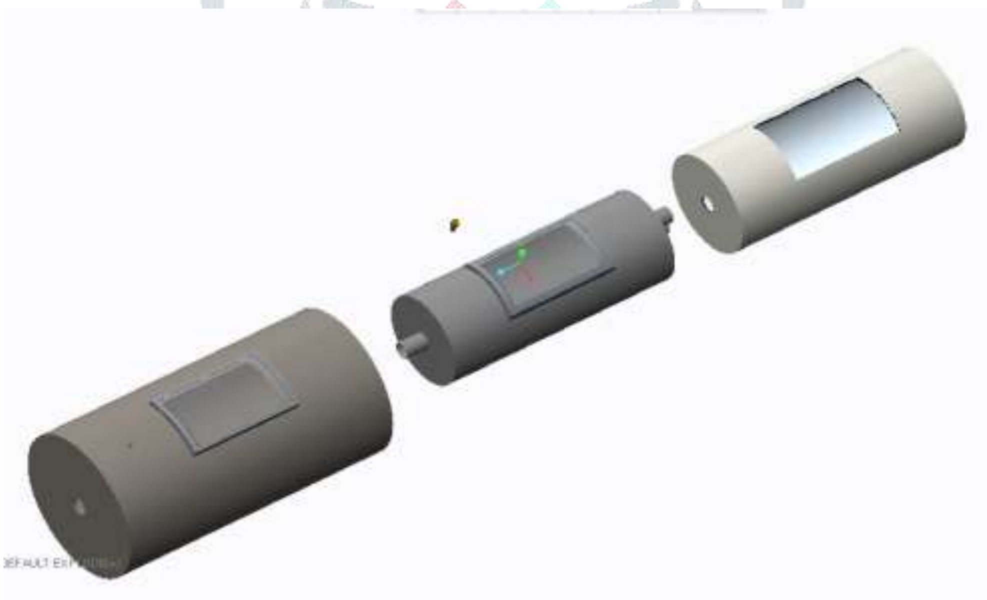

Figure 4 Exploded assembly [12]

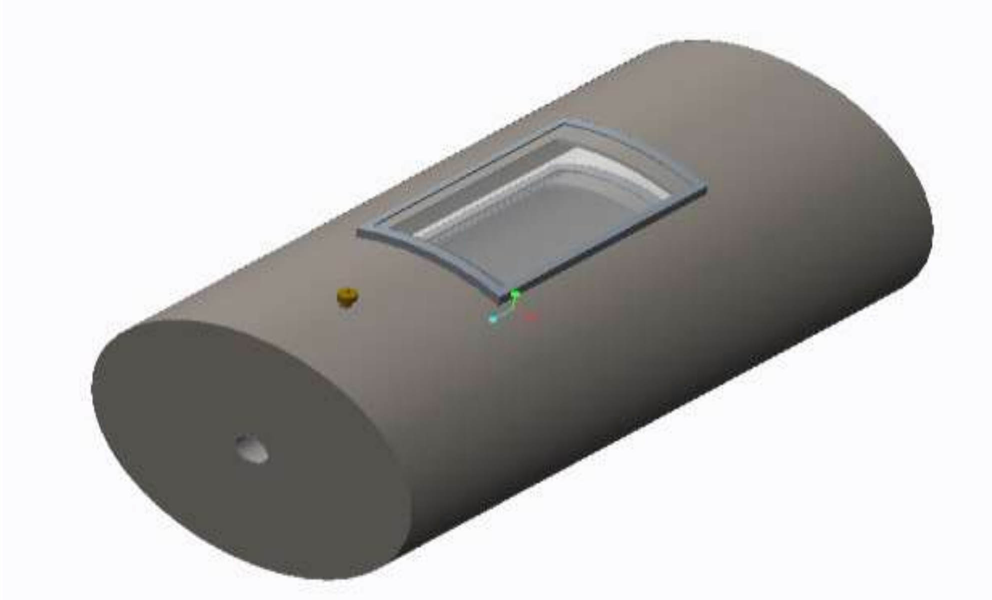

Figure 5 Assembled view [12]

The design procedure of the cryogenic chamber depends on spraying fluid, flow rate, sealing conditions and insulating material. The procedure created in this chapter shows my design considerations as per literature and materials which can sustain cryogenic temperature and insulation to be made for maintaining the temperature.

The design process is illustrated with figures. The present design procedure is more systematic and lucid than available in open literature. The design methodology of the environmental chamber consists of the following units, which are described in the subsequent sections.

- Design of main chamber
- Design of window
- Selection of material

Cryogenic chamber provides a means of carrying out materials tests in an accurately controlled air temperature environment. Minimum temperature that can controlled and maintained by this chamber is -196^{0}C. Chamber consists of a rigid stainless steel double walled cylinder, with inspection window and it is attached to the torsion testing machine. It consists of four ports. One port for liquid nitrogen, one for vacuum and two ports for testing materials inlet are incorporated. Chamber will be fix on stationary shaft of testing, that will be fixed in the jaws of the torsion testing machine and one jaw will be rotated through an electric motor for torsion testing. The specifications have been made by the requirements of Torsion Testing Machine. The basic dimensions for the system are shown in the table:

Table 1:-Dimensions of cryogenic chamber

PARTICULARS	DIMENSIONS(mm)
External Cylinder Length	306
Internal Cylinder Length	256
External Cylinder Thickness	3
Internal Cylinder Thickness	3
Connecting Pipe Length	25
External Cylinder Outer Diameter	160
Internal Cylinder Outer Diameter	100
LN_2 Port Diameter	18
Shaft Port Diameter	18

The chamber is constructed using a stainless steel of grade 304 with a wall thickness of 3cm, which can withstand the cryogenic conditions. Vacuum is created between inner and outer chamber. Filling of LN_2 is done by a cylinder.

Window is specially designed to inspect the inner testing, therefore acrylic sheet is used as a transparent window in both inner and outer chambers.

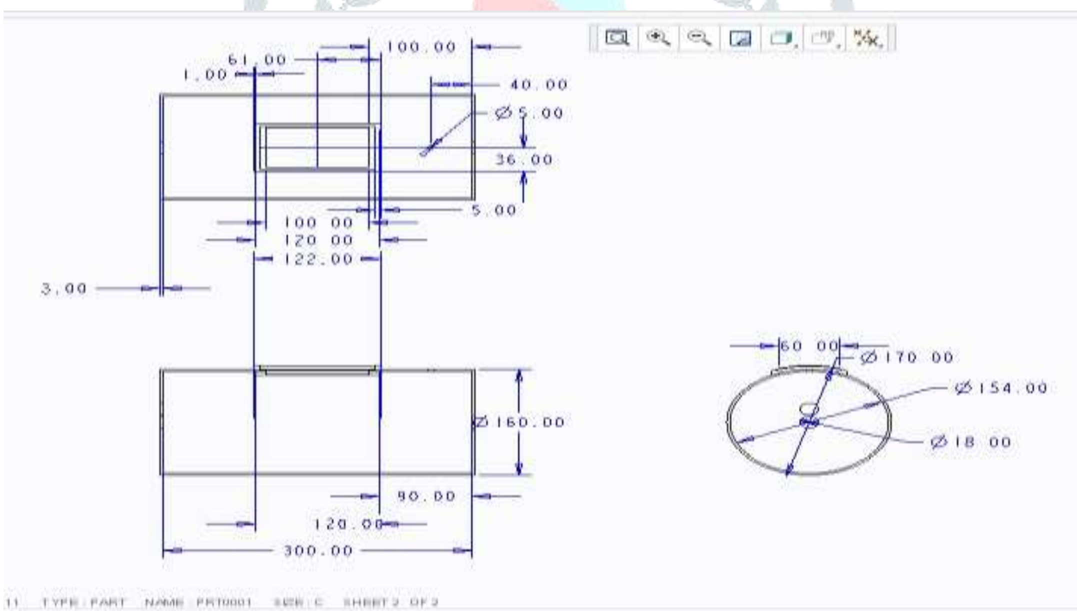

Figure 6:-dimensions of outer chamber [12]

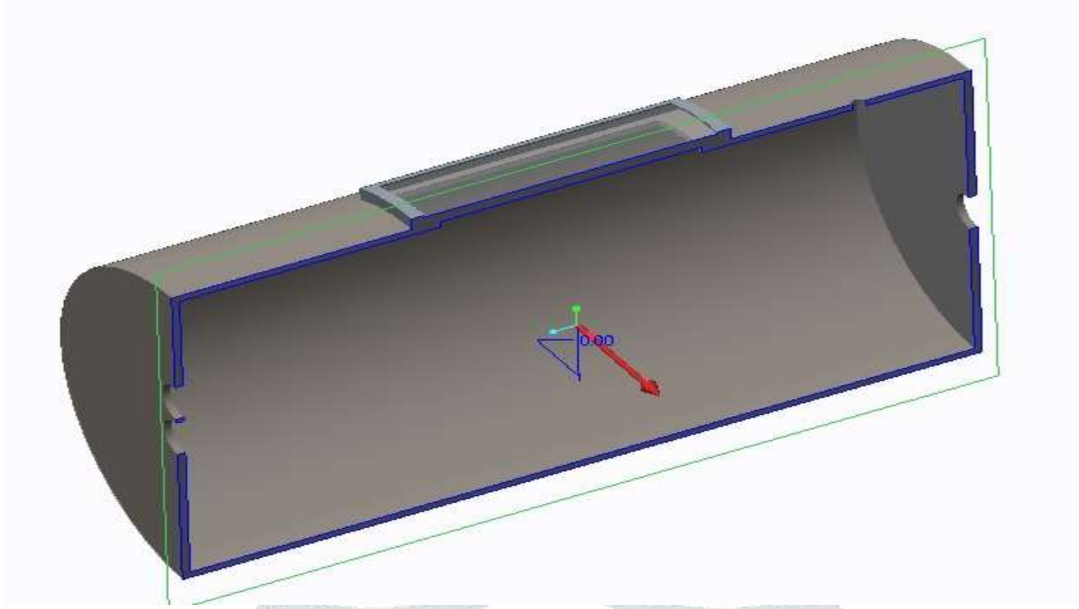

Figure 7:-section view of outer chamber [12]

The ports on top and bottom of the chamber are provided for testing material inlet. These ports are the connecting pipes between inner and outer chamber. These pipes acts as a support for inner chamber inside outer chamber so as to get the minimum contact surface from outer chamber. This chamber is also made up of SS 304.

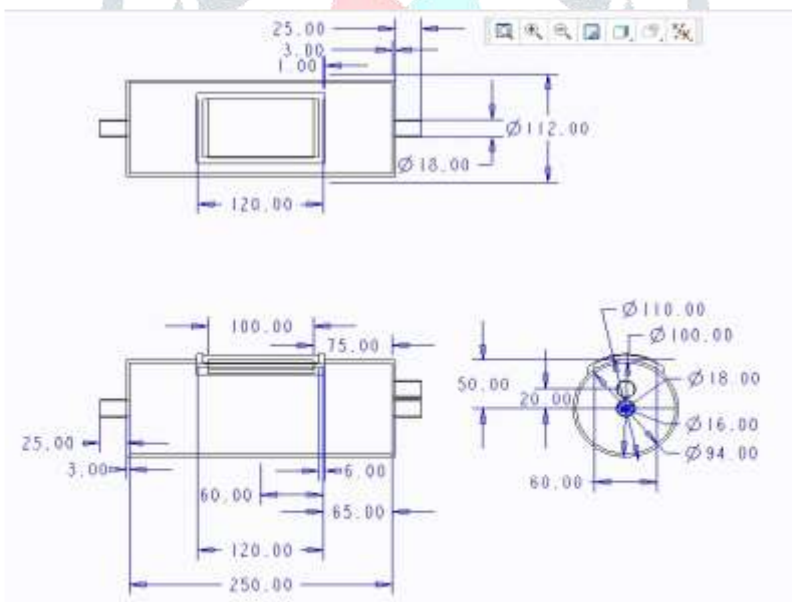

Figure 8:-dimensions of inner chamber [12]

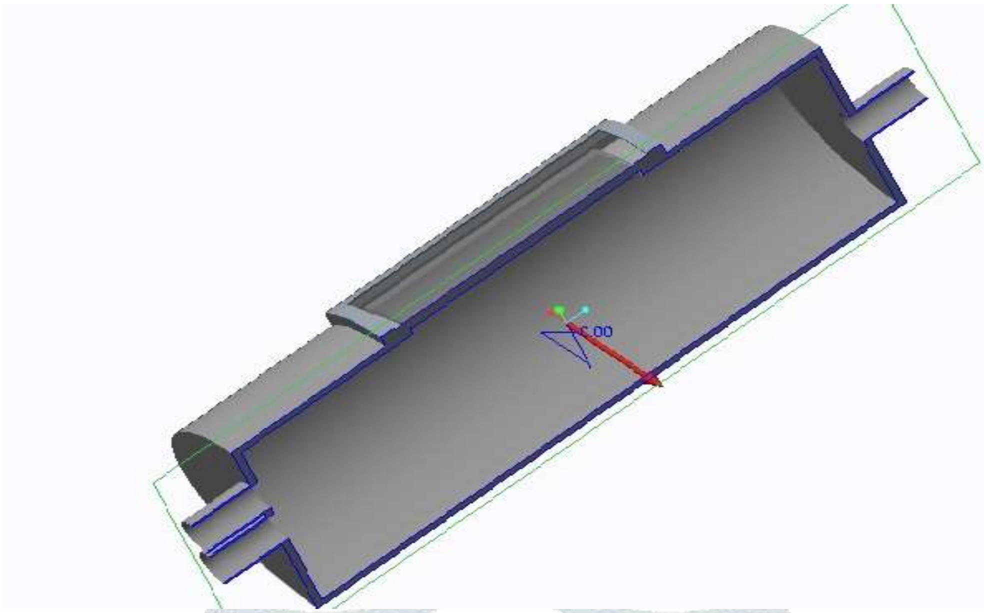

Figure 9:-section view of inner chamber [12]

Thermal insulation consists of three layers. Here two layers are of polyurethane foam and one layer of aluminium foil for the silvering of inner chamber. To make the window section these three layers are trimmed from the designed window section of inner chamber.

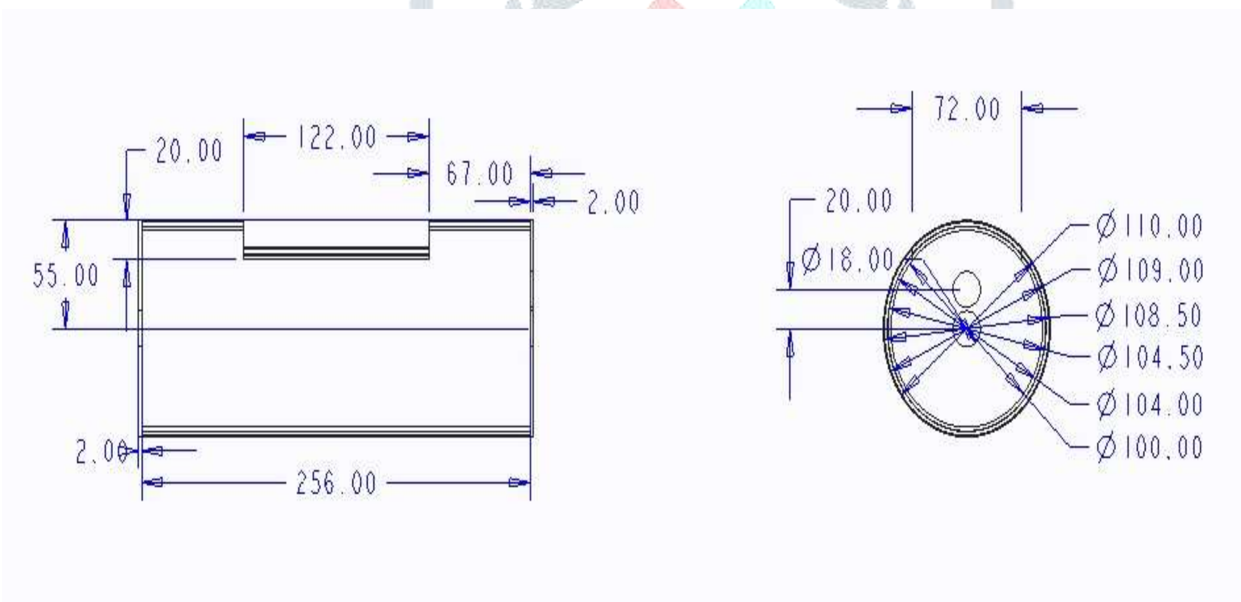

Figure 10:-dimensions of insulation [12]

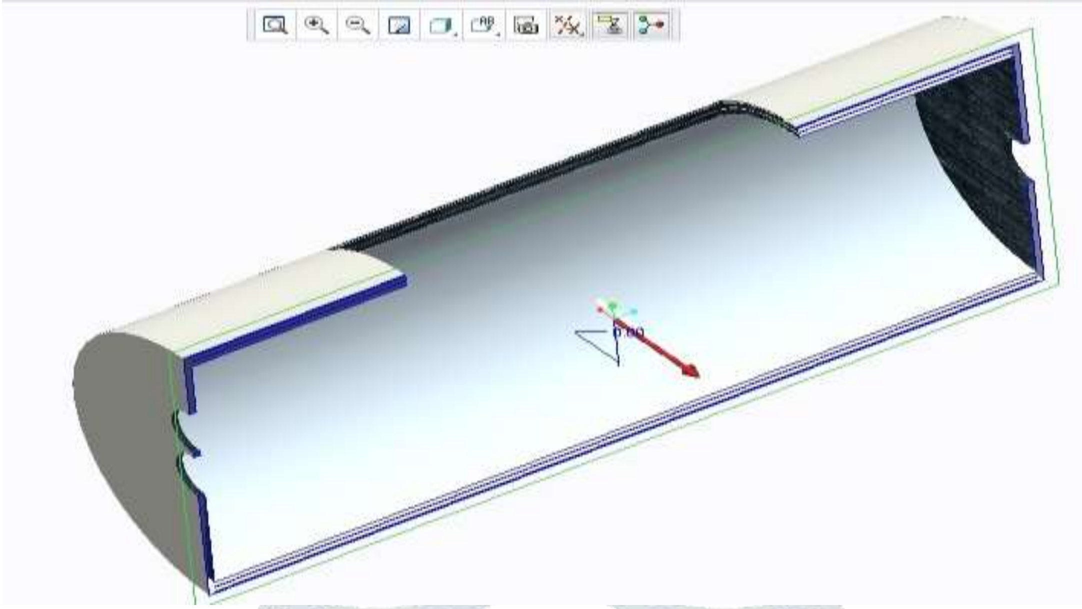

Figure 11:-section view of insulation [12]

Vacuum valve design is made by approximations as it may varies from the actual design. Vacuum valve is suitable according to the charging line used in the vacuum pump.

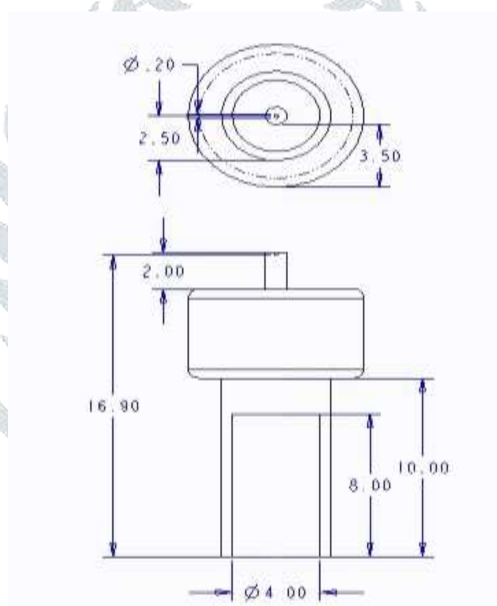

Figure 12:-dimensions of vacuum valve [12]

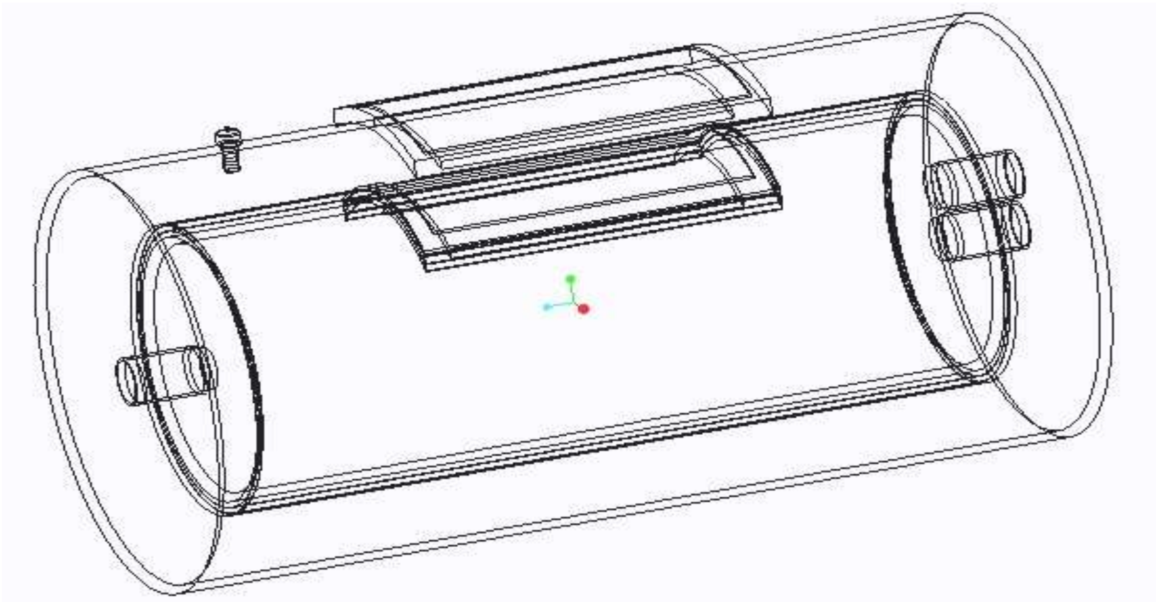

Figure 13:-wired frame assembly view [12]

Table 2:- properties of SS-304

PROPERTY	VALUE
Density	8 g/cm³
Specific Heat (0-100^{0}C)	490 J/Kg k
Modulus of elasticity	193 – 200 G pa
Electrical Resistivity	7.2 Ω/cm
Thermal conductivity	16.2 W/m K
Thermal Expansion	16 mm/m/˚C

Table 3:-properties of SS-304

PROPERTY	VALUE
Hardness, Brinell	123
Hardness, Knoop	138
Hardness, Rockwell B	70
Hardness, Vickers	129
Tensile Strength, Ultimate	505 MPa
Tensile Strength, Yield	215 MPa at 0.2% offset
Elongation at Break	70 % in 50 mm
Modulus of Elasticity	193 - 200 GPa
Poisson's Ratio	0.29
Charpy Impact	325 J
Shear Modulus	86 GPa

Materials typically come in three basic forms: bulk fill, foam and multi-layered. The heat or cold vacuum pressure (CVP), is the major cost driver for the design, fabrication of the system. After the actual operating conditions are considered, a module of the total heat leak of the mechanical system is needed to determine the insulation materials. Often only a common-sense thermal review of the system is needed to pertain the level of insulation material should be selected. The performance level will match the insulation materials and mechanical support structures or joining devices to be used.

References

[1] Gantt chart, https://app.smartsheet.com

[2] Jongmin Kim, Choonghyo Jang, Tae- Ho Song * School of Mechanical, Aerospace and Systems Engineering, Korea Advanced Institute of Science and Technology, Guseong-dong 373-1,Yuseong-gu, Daejeon, Republic of Korea

[3] J.E. Fesmire a, ⇑, B.E. Coffman a, B.J. Meneghelli b, K.W. Heckle ba Cryogenics Test Laboratory, NASA, Kennedy Space Center, FL, USAb Cryogenics Test Laboratory, ASRC Aerospace Kennedy Space Centre, F USA

[4] R.L.BARRON, Cryogenic Systems, McGraw-Hill Book Company, Inc., New York, 1984.

[5] Fesmire, J.E. and Augustynowicz, S.D., Advances in Cryogenic Engineering, 45, pp. 1683-1690, (2000).

[6] Vincent Grillo (Co-President), liquid nitrogen Dewar flasks, cryofab company, Kenilworth, NJ, USA, 1971, www.cryofab.com

[7] Fesmire, J.E. et al., "Equipment and Methods for Cryogenic Thermal Insulation Testing," in Cryogenic Engineering Conference, Anchorage, September 2003, to be published.

[8] Fesmire, J.E., Augustynowicz, S.D., and Rouanet, S., Advances in Cryogenic Engineering, 47, pp. 1541-1548 (2002).

[9] Cunnington and Tien, "Apparent Thermal Conductivity of Uncoated Microsphere Cryogenic Insulation," Advances in Cryogenic Engineering, 22, (1977).

[10] Duna-Corradini S.p.A. via Modena Carpi, 388 41019 Soliera, MODENA, Italy, www.dunagroup.com , info@dunacorradini.it

[11] CYRO Industries, Parsippany, New Jersey 07054, www.cyro.com

[12] PTC Creo Parametric 2.0, designing of project