www.ijecs.in
International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 5 May 2015, Page No. 12181-12182

Flexibility Analysis of A Bare Pipe Line Used For Cryo Application

Vansylic Israel Pintu J[1] & Dr. Manivannan[2] Jeremiah JothiRaj [3]

[1&2]Department of Mechanical engineering, Regional centre of Anna University Tirunelveli
[3] Scientist 'E',Indian Space Research & Organisation, IPRC, Mahendregiri, Tirunelveli.

ABSTRACT

The cryogenic piping circuit is studied to design and to handle the Liquid hydrogen. It is one of the important piping circuit networks present in the fuel booster turbo pump which mainly comes under the cryogenic upper stage in Geo Synchronous Launch Vehicle of Indian Space Research Organisation at Mahendragiri.. It consists piping elements like expansion joints/loops with optimal placement of supports. This paper mainly discusses about the Thermal stresses induced in the piping circuits when liquid hydrogen flows through it and how these stresses can be reduced by incorporating various expansion loops. Cryogenic fluid servicing pipelines are tend to develop thermal stress due to contraction/ expansion of piping material during chilling/ warming from ambient to cryogenic temperature or vice versa. The present project is to design, analysis of cryogenic piping using Finite Element Method (FEM) tool and detailed engineering. Flexibility results can be determined by structural analysis by altering the elbow angles respectively.

***Keywords**:* Cryogenic piping circuits, Thermal stresses, Flexibility analysis

INTRODUCTION:

Subscale Engine Test facility (SET) is one of the cryogenic ground testing facility located at ISRO Propulsion Complex (IPRC), Mahendragiri, Tirunelveli District, Tamilnadu, India. This ground testing facility is used to test various sub-systems of cryogenic rocket engines such as Steering Engine, Fuel booster turbopump, LOX pressure regulator, etc at Cryogenic conditions. The core of my project is to study the flexibility of cryogenic circuits involved for the testing of Fuel booster turbopump. The above said circuits such as booster pump outlet circuit, bearing coolant disposal circuit & turbine outlet circuit are modelled using Finite element analysis software and the results are plotted and discussed in this paper.

Cryogenics

Cryogenics is defined as that branch of physics which deals with the production of very low temperatures[1]. In a more optional way, it is also defined as the science and Technology of temperatures below 123. A formulation which addresses both aspects of attaining low temperatures which do not naturally occur on Earth, and of using them for the study of nature or the human industry. The densification by condensation, and separation by distillation of gases was historically – and remains today - the main driving force for the cryogenic industry, exemplified not only by liquid oxygen and nitrogen used in chemical and metallurgical processes, but also by the cryogenic liquid propellants of rocket engines and the proposed use of hydrogen as a "clean" energy vector in transportation [2].

Table.1.Cryogenic fluids

Cryogen	Triple point	Normal boiling point	Critical point
Methane	90.7	111.6	190.5
Oxygen	54.4	90.2	154.6
Argon	83.8	87.3	150.9
Nitrogen	63.1	77.3	126.2
Neon	24.6	27.1	44.4
Hydrogen	13.8	20.4	33.2
Helium	2.2	4.2	5.2

Cryogenic Fluids

The simplest way of cooling equipment with a cryogenic fluid is to make use of its latent heat of vaporization, e.g. by immersion in a bath of boiling liquid. As a consequence, the useful temperature range of cryogenic fluids is that in which there exists latent heat of vaporization, i.e. between the triple point and the critical point, with a particular interest in the normal boiling point, i.e. the saturation temperature at atmospheric pressure. To develop a feeling about properties of these cryogenic fluids, it is instructive to compare them with those of water. As the critical temperature of cryogenic fluid is less than ambient temperature, it cannot be Liquified by the application of pressure alone at or above ambient Temperature. Helium, Hydrogen, Neon, Nitrogen, Fluorine, Argon, Oxygen, Methane and Krypton are some of the cryogenic fluids.

Table.2.Properties of cryo fluids

Property	Helium	Nitrogen	Water
Normal boiling point [K]	4.2	77	373
Critical temperature [K]	5.2	126	647
Critical pressure [bar]	2.3	34	221
Liquid density* [kg/m3]	125	808	960
Liquid/vapor density ratio*	7.4	175	1600
Heat of vaporization* [kJ/kg]	20.4	199	2260
Liquid viscosity* [μPl]	3.3	152	278

Turbo Pump

Turbo pump is rotating machinery used to pump the liquid propellants in a rocket engine, and driven by a turbine. The pressure in the liquid at the retreating surface of the vane is reduced, and it can be low enough to allow local boiling to take place. Bubbles of vapour are produced, and they then collapse when they enter a region of normal pressure. The tiny shock waves produced damage the surface of a vane. Severe cavitations can produce significant quantities of vapour at the inlet of the turbo pump.

In-order to validate the performance of Fuel Booster turbopump before integrating with rocket engine, it is mandatory to do ground level acceptance test. During testing, the fluid circuits are subject to low temperatures which in-turn produces thermal induced stresses. Therefore, these circuits are to be suitably designed to have minimum thermal stresses.

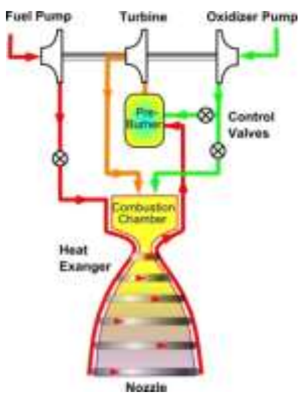


Fig. 1. Schematic diagram of FBTP and its circuits

Flexibility Analysis:

Flexibility is another important factor that needs to be addressed in design of the cryogenic piping circuits. This is achieved by incorporating flexibility metallic bellows or expansion loops. In case of complex fluid circuits involving number of branches, bends and associated flow components and piping stresses involves greater analytical computations. By using the hand calculations it may not be accurate and clear, so bringing it into the Finite element analysis for the clear accuracy.

Fuel Booster Turbo Pump:

Fuel booster turbo pump involves three circuits. They are as follows,

- Booster pump outlet circuit.
- Turbine outlet circuit.
- Bearing coolant disposal circuit.

The dimensions of the pipe line is chosen as follows

Booster pump outlet circuit:

Fuel booster pump outlet circuit was drawn in Auto-cad software package, which carries the cryogenic fuel throughout the line. This circuit carries two elbows with seven socket joints and seven butt joints, here flow rate is measured in the middle.

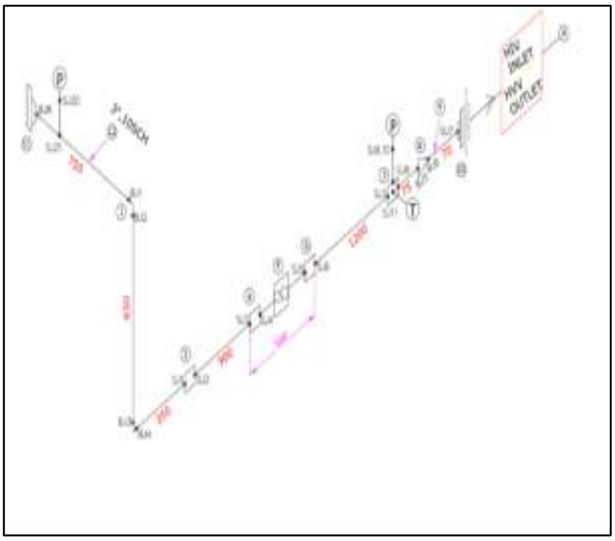


Fig. 2. Booster pump outlet circuit:

Table.3. Dimension:

Parameters	Outer diameter (mm)	Thickness (mm)	Inner diameter (mm)
80 NB, 10 SCH	88.9	3.05	82.8

Turbine outlet circuit:

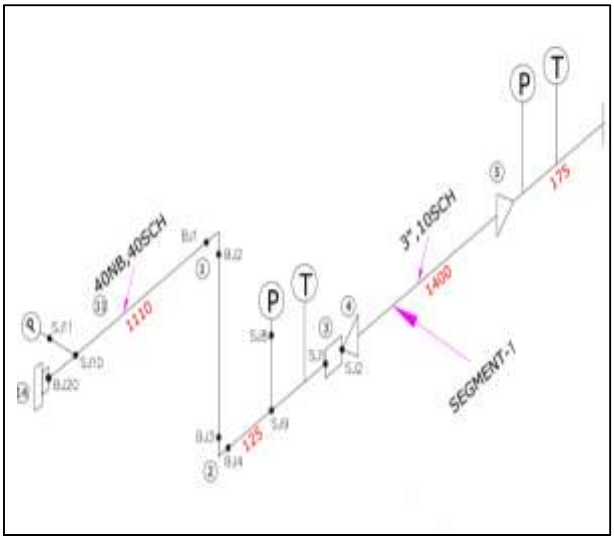


Fig. 3. Turbine outlet circuit.

Turbine outlet circuit was drawn in Auto-cad software package, its main function is to let out the cryo fluid from the turbine through the outlet circuit.. This circuit carries two elbows with two socket joints and four butt joints, here expander and reducer plays a vital role and its functions are measured in the Segment-1. Generally the turbine drives the pump

Table.4. Dimensions.

Bearing coolant disposal circuit:

Bearing Coolant Disposable Circuit was drawn in Auto-cad software package. Its main function is to cool down the fuel turbo pump which runs at 40,000 rpm. This circuit carries five elbows with eight socket joints and twelve butt joints.

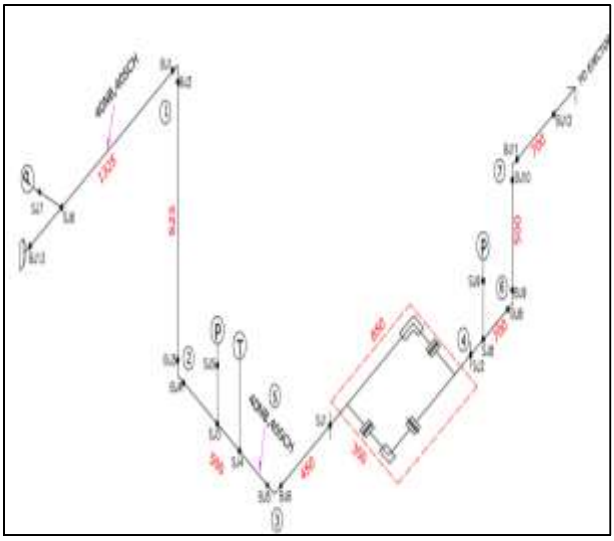


Fig.4.Bearing coolant disposal circuit.

Table.5. Dimensions

Parameters	Outer diameter (mm)	Thickness (mm)	Inner diameter (mm)
40NB, 40SCH	48.3	3.68	40.94

Tool for validation:

The vacuum insulated line may be used with any cryogenic fluid from liquid oxygen to liquid helium to attain low loss transfer. Vacuum jacketed lines are usually designed according to ASA code for Piping Pressure. The Thermal contraction problem can be solved in cryogenic transfer line design through the use of expansions bellows and U- bends. It is a good practice to locate the expansion bellows only in the outer line and to achieve the Flexibility of the inner line through the use of U- bends. If the bellows are used for inner line then the pressure thrust absorbed will be fairly heavy[2]

Flexibility of the inner line may be achieved through the use of a U- Bends Elastic energy theory is applied to determine the maximum stress induced by thermal contraction. The maximum

Pipe size	Outer diameter (mm)	Thickness (mm)	Inner diameter (mm)
40NB,40 SCH	48.3	3.68	40.94
80 NB, 10 SCH	88.9	3.05	82.8

thermal stress is given by :

1. For α = W/L > ½:

$$\frac{\sigma_{\max} L}{E\, e_t D_0} = \frac{\alpha+\beta}{B}\{1 + \frac{(1+2\beta)D_0}{4(\alpha+\beta)H}\}.$$

2. For α < ½:

$$\frac{\sigma_{\max} L}{E\, e_t D_0} = \frac{1-\alpha+\beta}{B}\{1 + \frac{(1+2\beta)D_0}{4(1-\alpha+\beta)H}\}.$$

Where $B = 2/3\,\beta[\beta(2+\beta] + 3\,\alpha(1-\alpha) + 3/8(1+2\beta)(D_0/H)^2]$.

α = W/L.

β = H/L.

$e_t = \int_{T_c}^{T_h} \lambda_t\, dt$ = unit thermal strain.

D_0 = Outside diameter of the line.

E = Young's modulus.

Theoretical calculation for an assumed pipelines with prescribed dimensions, Outside diameter D_0 = 168.3mm.

L = 12250 mm, W = 6125mm, H = 3500 mm.

Young's modulus E = 207E3.

S.no	Temperature (K)	Young's Modulus (GPa)	Linear Coefficient of Thermal Expansion, x E-6 (K^{-1})
1	20	199	0.5
2	75	190	7
3	240	170	15
4	260	165	15.5
5	300	161	16.1

Poissons ratio μ = 0.28.

Maximum thermal stresses for the given dimensions are calculated using the formulas which are stated above.

Fig..5. U- Bend Cryogenic pipeline.

SEQV- Von Mises Stress = **37.719 MPa.**

FINITE ELEMENT ANALYSIS:

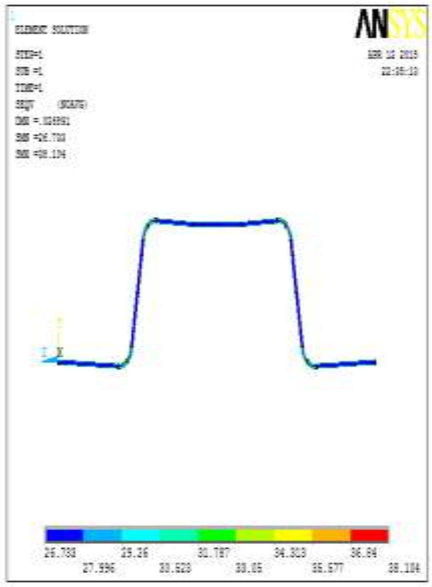


Fig..6. Elemental solution of Von mises stress

Here the von mises stress value is **38.104 MPa**.

The results are very much comparable with FEFrom this comparison, I can clearly validate the three circuits irrespective to the input datas available.They are as follows,

Booster pump outlet circuit:

The input available datas for simulation,

Table.6

Actual Stress calculation:

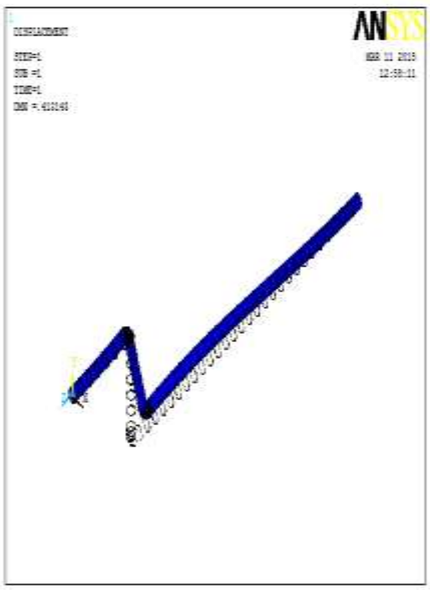


Fig.7.Displacement

Fig.8.Von Mises stress

Table.7

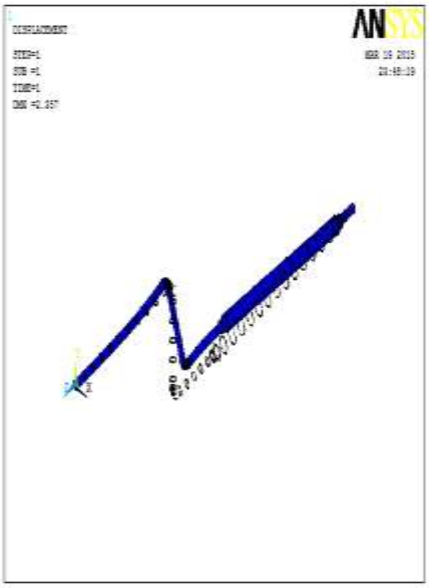
	DMX	SMN	SMX
SEQV	**0.43143**	**8.503**	**16.579**

Turbine outlet circuit

The input available datas for simulation,

Table.8

S.no	TEMP (K)	YOUNG'S MODULUS (GPa)	THERMAL EXPANSION x E -6 (K^{-1})
1	240	170	15
2	250	168	15.1
3	260	165	15.5
4	290	163	16
5	300	161	16.1



:

Fig.9.Displacement

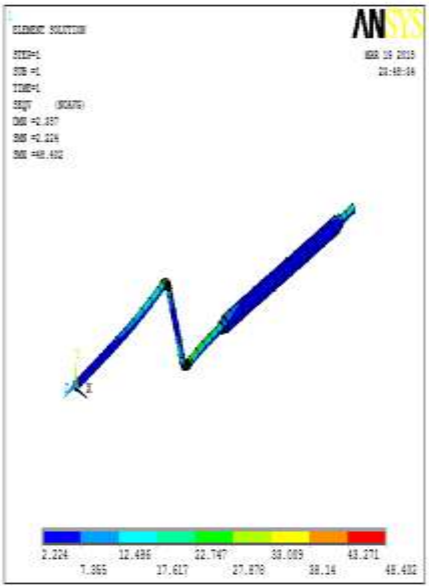


Fig.10.Von Mises stress

Table.9

TOC	DMX	SMN	SMX
SEQV	2.357	2.224	48.402

Bearing coolant disposal circuit:

The input datas available for simulation.

Table.10

S. No	TEMP (K)	YOUNG'S MODULUS (GPa)	THERMAL EXPANSION x E -6 (K^{-1})
1	33	197	1
2	75	190	7
3	240	170	15
4	260	165	15.5
5	300	161	16.1

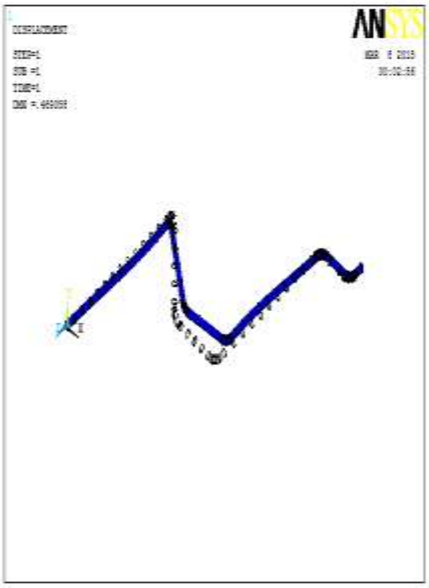


Fig.11.Displacement

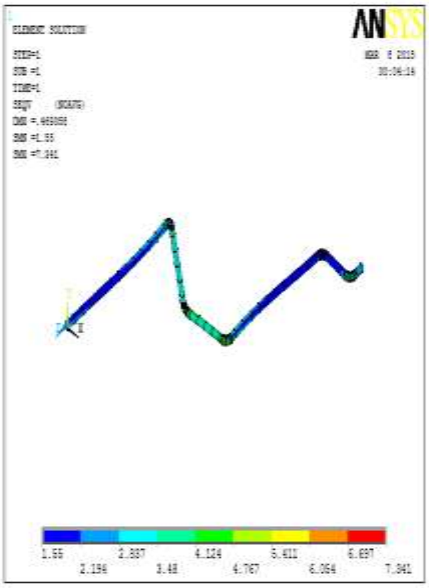


Fig..12.Von Mises stress

Table.11

BCDC	DMX	SMN	SMX
SEQV	0.4690	1.55	7.341

Graphical results:

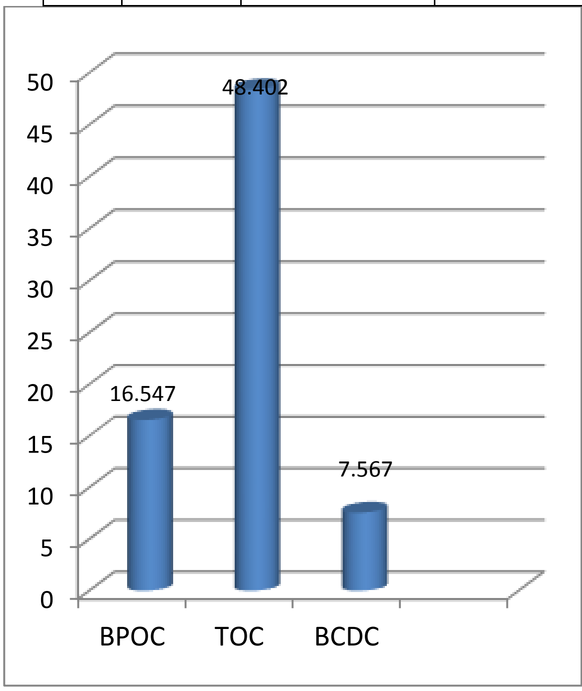


Fig.13. Structural Analysis: I

In this analysis, three circuits are brought into structural consideration, in the previous analysis, the circuits containing Elbows whose degree is 90 but here in this analysis ,these elbows are replaced by Elbow 45^0. It includes much more number of Elbows than the Previous Analysis. The main reason for this structural analysis I is just to fetch the improved results from the previous analysis, (i.e.) max thermal stress expected in this analysis has to be a meager sum.

Booster pump outlet circuit:

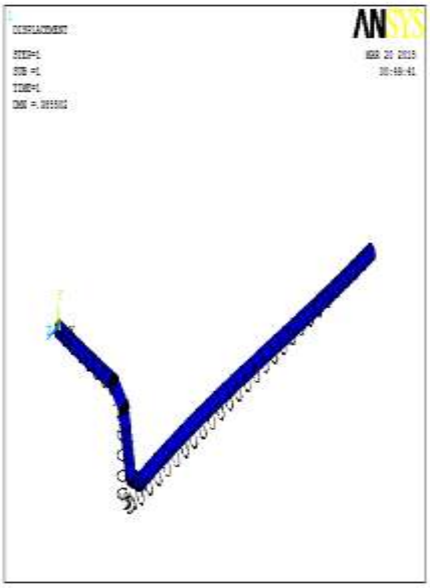


Fig.14.Displacement

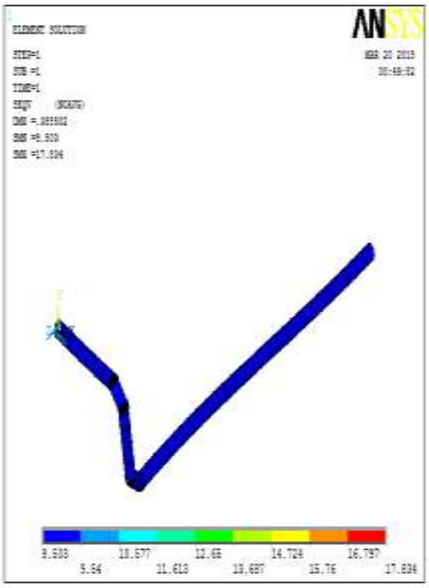


Fig.15.Von Mises stress

Table.12

BPOC	DMX	SMN	SMX
SEQV	0.388502	8.503	17.834

Turbine Outlet Circuit:

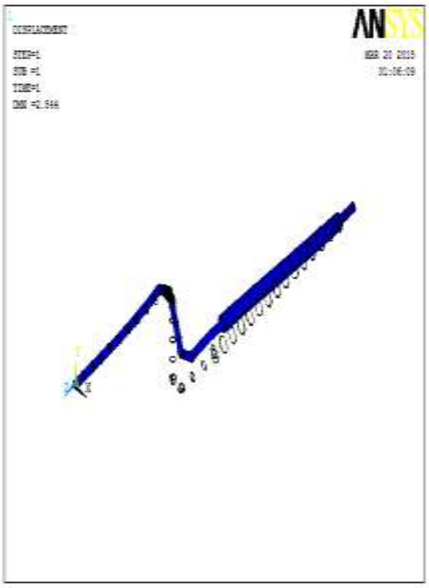


Fig.16.Displacement

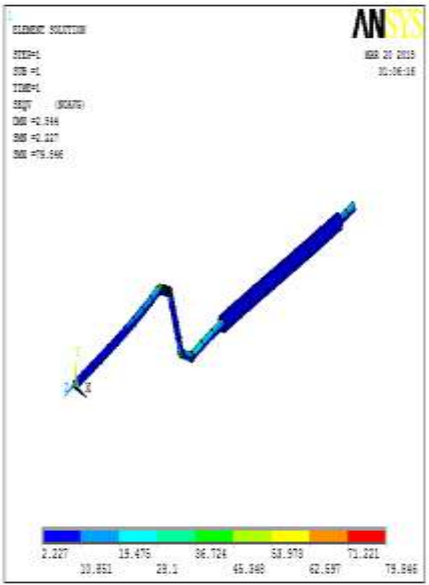


Fig.17.Von Mises stress

Table.13

TOC	DMX	SMN	SMX
SEQV	2.544	2.227	79.846

Bearing coolant disposal circuit:

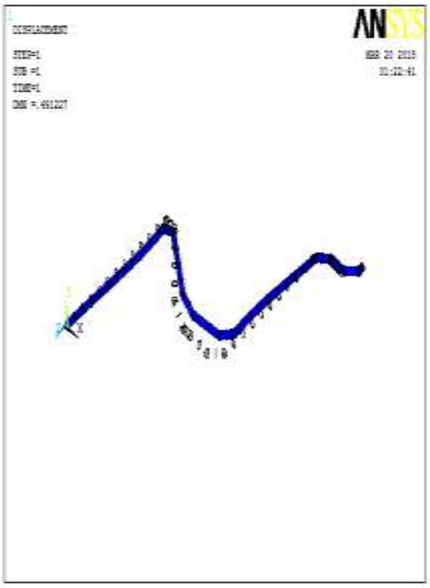
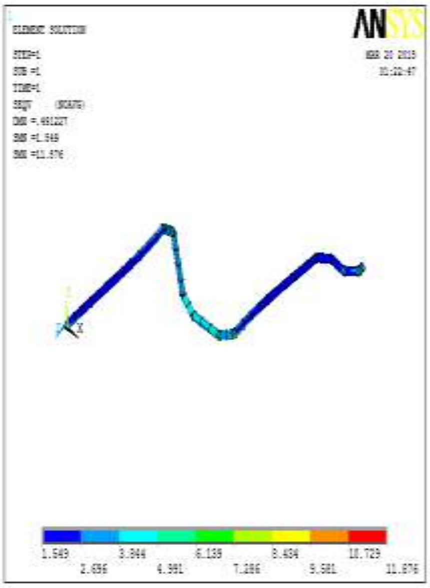


Fig.18.Displacement



8

Fig.19.Von Mises stress

Table.14

BCDC	DMX	SMN	SMX
SEQV	0.491227	1.549	11.876

Graphical results:

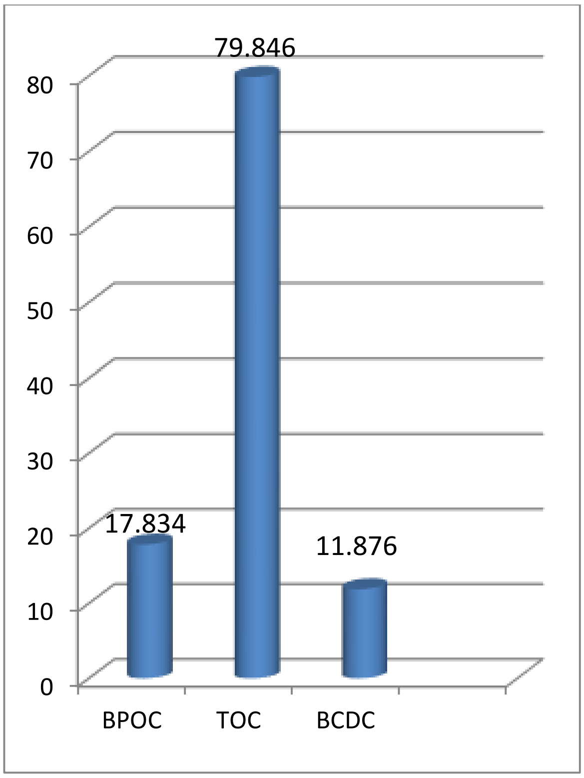


Fig.20.Von mises stress comparison

From the chart it clearly states that the von mises stress values or the structures elbow 45^0 fetches much more negative results than the elbow 90^0 structures.

Structural Analysis: II

From the previous analyses, it is clearly understood that there is no improved results. In order to get the improved results, structural analysis II comes into act to get a minimu thermal stress value for all the three circuits respectively

Here in this analysis, elbow 45^0 's are replaced by curvature contours. The bend radius involved here in this analysis are 270,300,330.

Booster pump outlet circuit:

Fig.21.Displacement

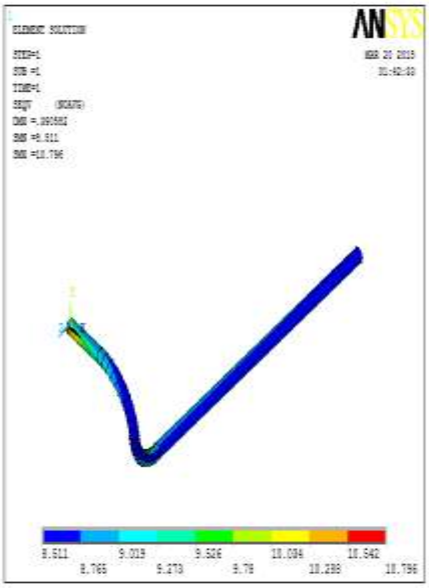


Fig.22.Von Mises stress

Table.15

BPOC	DMX	SMN	SMX
SEQV	0.390582	8.511	10.796

Turbine outlet circuit

:

Fig.23.Displacement

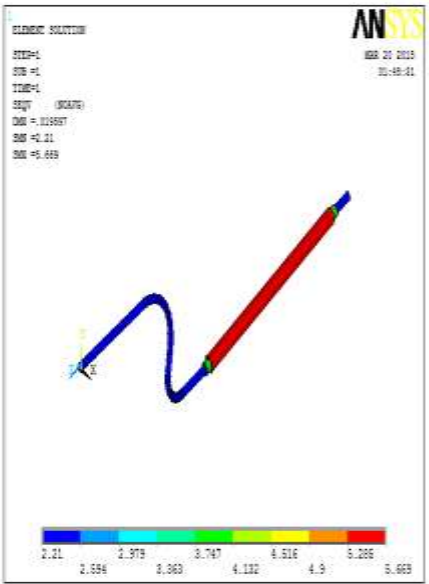


Fig.24.Von Mises stress

Table.16

TOC	DMX	SMN	SMX
SEQV	0.019597	2.21	5.669

Bearing coolant Disposal circuit:

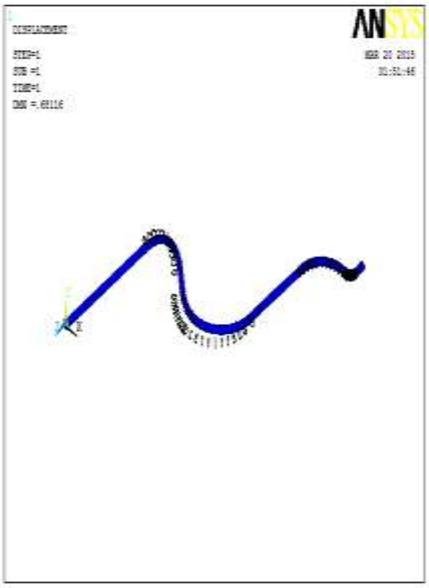


Fig.25.Displacement

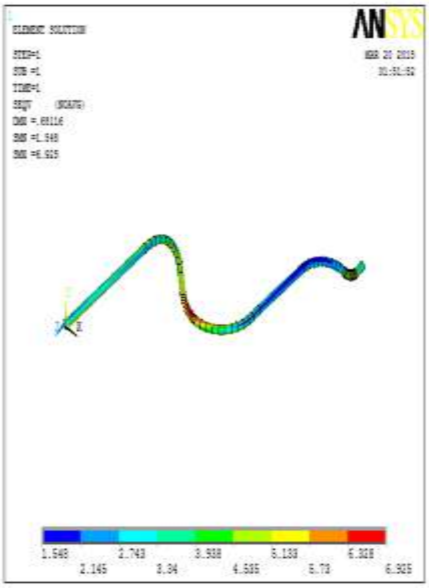


Fig.26.Von Mises stress

Table.17

BCDC	DMX	SMN	SMX
SEQV	0.68116	1.548	6.925

Graphical results:

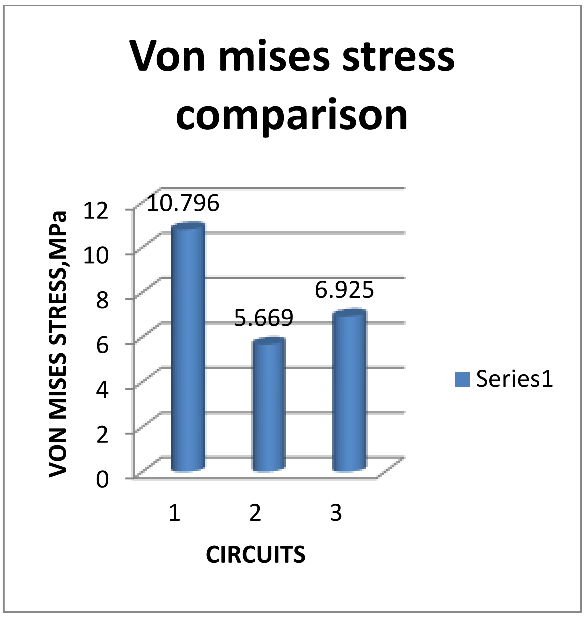


Fig.27.Von mises stress comparison

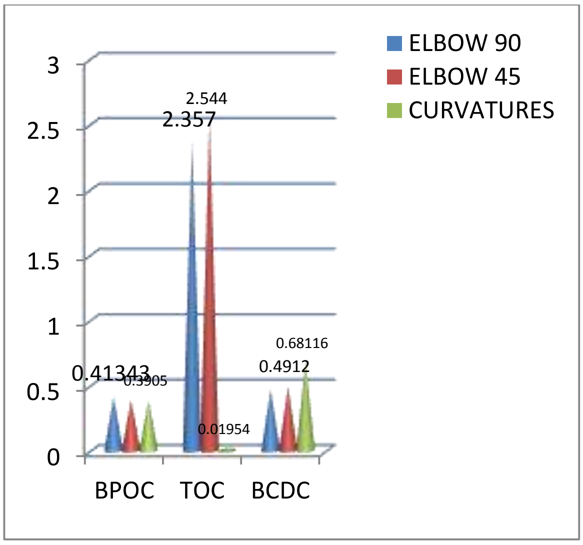


Fig.28.Comparison Between The Structural Displacements,mm

From the above two charts, it is clearly understood that the thermal stresses induced over there contour structures are much lower than the previous elbow used structures.

Booster Pump Outlet Circuit:

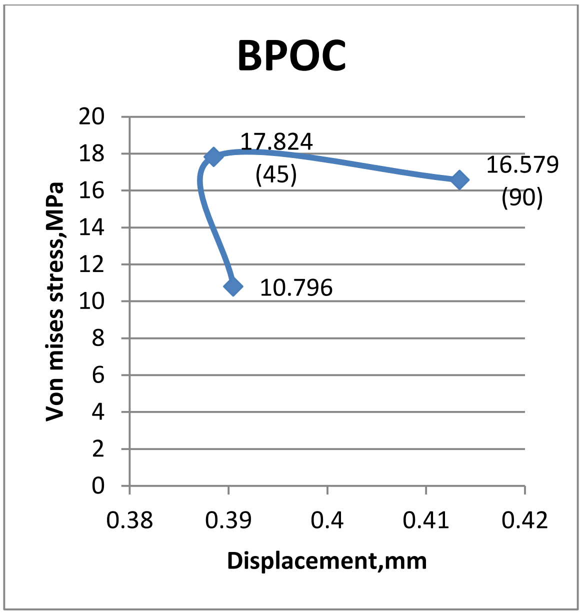


Fig.29.Von mises stress Relationship

From the above relationship, it is clearly defines that ,the structures of BPOC with contours has lower thermal stress value than the other two,(i.e.) the thermal stresses induced in this contour structures are low when compared with the two.

Turbine Outlet Circuit:

DISP- Von mises Relationship:

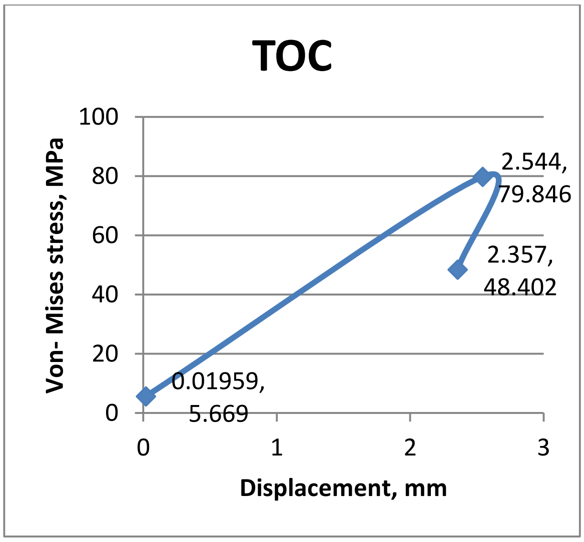


Fig.30.Von mises stress Relationship

From the above relationship, it is clearly defines that ,the structures of TOC with contours has lower thermal stress value than the other two,(i.e.) the thermal stresses induced in this contour structures are low when compared with the two

Bearing Coolant Disposal Circuit:

DISP- Von mises Relationship:

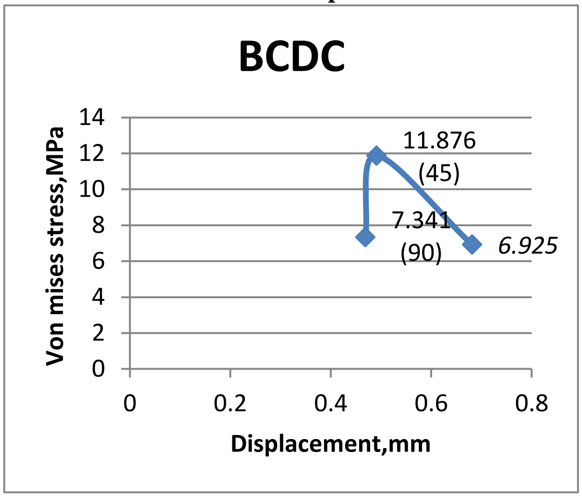


Fig.31.Von mises stress Relationship

From the above relationship, it is clearly defines that ,the structures of BCDC with contours has lower thermal stress value than the other two,(i.e.) the thermal stresses induced in this contour structures are low when compared with the other two.

RESULTS:

Thus the structural analysis provides some flexibility results. From the graphical results, it clearly gives the best suited structure among the three analysis. From the three pipelines with goose neck design gives the lowest stress value when compared with others

VON MISES STRESS:

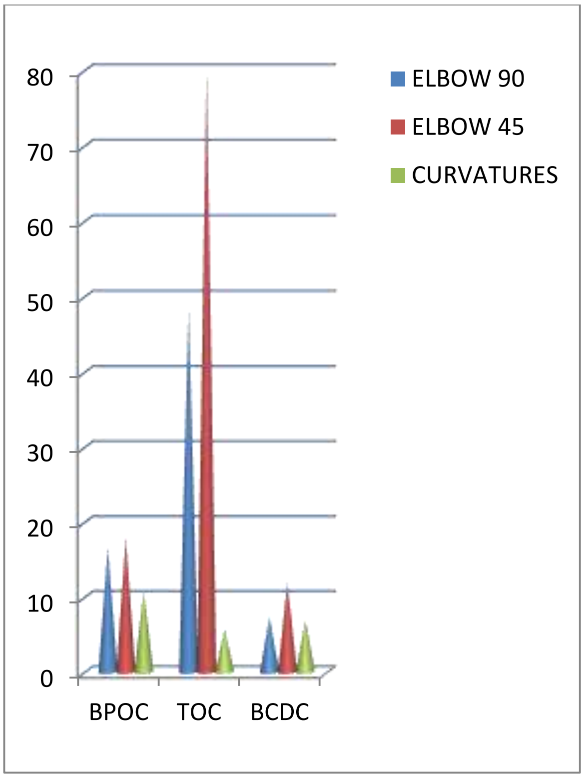


Fig.32.Von mises stresses comparison.

References

1. Thomas Flyn, (1990), Handbook of Cryogenics.
2. Randall F. Barron,(1985) Cryogenic systems.
3. S. Timoshenko and S. Woinowskey-Kreiger. *Theory of Plates and Shells*. McGraw-Hill. New York . 1959.
4. D. M. Tracey. *"Finite Elements for Three Dimensional Elastic Crack Analysis"*. *Nuclear Engineering and Design*. Vol. 26. 1973.
5. E. H. Vanmarcke. *"Structural Response to Earthquakes"*. *Seismic Risk and Engineering Decisions*. Elsvier Scientific Publishing Co.. Amsterdam-Oxford, New York. edited by C. Lomnitz and E. Rosemblueth. pp. 287-337. 1976.
6. K. J. Bathe. *Finite Element Procedures*. Prentice-Hall. Englewood Cliffs. 1996.
7. L. H. Chen. *"Piping Flexibility Analysis by Stiffness Matrix"*. *ASME, Journal of Applied Mechanics*. December 1959
8. Lebrun H,, The technology of super fluid helium, CERN-2004-008, Geneva
9. (2004) 375.
10. Maria Grazia De Giorgio G., "Emissivity measurements of metallic surfaces used in cryogenic applications", Adv. Cryo. Eng. 27 (2006) 293.
11. Demyanenko R, A. R. C. Markl, H. H. George (2007), Fatigue Test on Flanged assemblies. Transaction of the ASME, Vol 72, pp. 77-87.
12. George P, et al., Rued, L., "Counter-Rotating Turbine designed for Turbopump Rocket Engine," AIAA paper 2008-4768, June 2008
13. Makoto Kojima H., Huber, F. W., Barnstorm, B. R., Finke, A. K., Johnson, P. d., Rowley, R. J., and Veres, J. P., "Design and Test of a small two-Stage Counter-Rotating Turbine for Rocket Applications," 2011.

Nomenclature:

Symbol	**Name**	**Units**
E	Young's modulus	N/m^2
σ_{max}	Max stress	MPa
μ	Poisson's ratio	No units
D_0	Outer diameter	mm
t	thickness	mm
p	Inside pressure	MPa
σ_i	Inner stress	MPa