IOP Conf. Series: Journal of Physics: Conf. Series **823** (2017) 012042 doi:10.1088/1742-6596/823/1/012042

Comparative analysis on flexibility requirements of typical Cryogenic Transfer lines

Mohit Jadon[1], Uday Kumar[1], Ketan Choukekar[1], Nitin Shah[1] and Biswanath Sarkar[1]

[1]ITER-India, Institute for Plasma Research, Sangath Skyz, Bhat – Koteshwar Road, Koteshwar - 380005, Gujarat, India.

E-mail: mohit.jadon@iter-india.org

Abstract. The cryogenic systems and their applications; primarily in large Fusion devices, utilize multiple cryogen transfer lines of various sizes and complexities to transfer cryogenic fluids from plant to the various user/ applications. These transfer lines are composed of various critical sections i.e. tee section, elbows, flexible components etc. The mechanical sustainability (under failure circumstances) of these transfer lines are primary requirement for safe operation of the system and applications. The transfer lines need to be designed for multiple design constraints conditions like line layout, support locations and space restrictions. The transfer lines are subjected to single load and multiple load combinations, such as operational loads, seismic loads, leak in insulation vacuum loads etc. [1]. The analytical calculations and flexibility analysis using professional software are performed for the typical transfer lines without any flexible component, the results were analysed for functional and mechanical load conditions. The failure modes were identified along the critical sections. The same transfer line was then refurbished with the flexible components and analysed for failure modes. The flexible components provide additional flexibility to the transfer line system and make it safe. The results obtained from the analytical calculations were compared with those obtained from the flexibility analysis software calculations. The optimization of the flexible component's size and selection was performed and components were selected to meet the design requirements as per code.

1. Introduction

The cryogenic systems and their applications, primarily in large Fusion devices, utilize multiple cryogen transfer lines of various sizes and complexities in terms of layout to transfer cryogenic fluids from plant to various user/ applications. The mechanical sustainability (under failure circumstances) of these transfer lines are primary requirement for safe operation of system and applications.

The Liquid Nitrogen carrying transfer line has been considered for the following study and analysed for 2 cases as follows:
case-1: without using flexible components
case-2: with flexible components

2. Design Criteria and constraints

The transfer lines need to be designed for multiple design constraint conditions, which are explained below:

i) Diameter constraint; the space restriction alongside the transfer line shall be complied.
ii) Flow rate constraint; the mass flow rates shall not be exceeded for line design.
iii) Routing constraint; the transfer line routing shall be complied in order to avoid clashes or interference with the very close adjacent equipment.
iv) Pressure drop constraints; the pressure drop values shall be within allowable limits.
v) Support locations; the external supports are available at limited locations and no scope is there for additional supports.

3. Analysis approach

i) Selection of segment of Liquid nitrogen cryogenic transfer line and modeling performed on CAESAR-II software.
ii) Finalization of applicable loads.
iii) Flexibility analysis performed based on loads without considering any thermal compensation device.
iv) Failure zones identified with respective stress values.
v) Flexible components such as metallic hoses and bellows placed at various locations.
vi) Flexibility analysis performed based on similar loads with flexible components.
vii) The number of flexible components were finalized based on the obtained stress values and allowable pressure drop values.

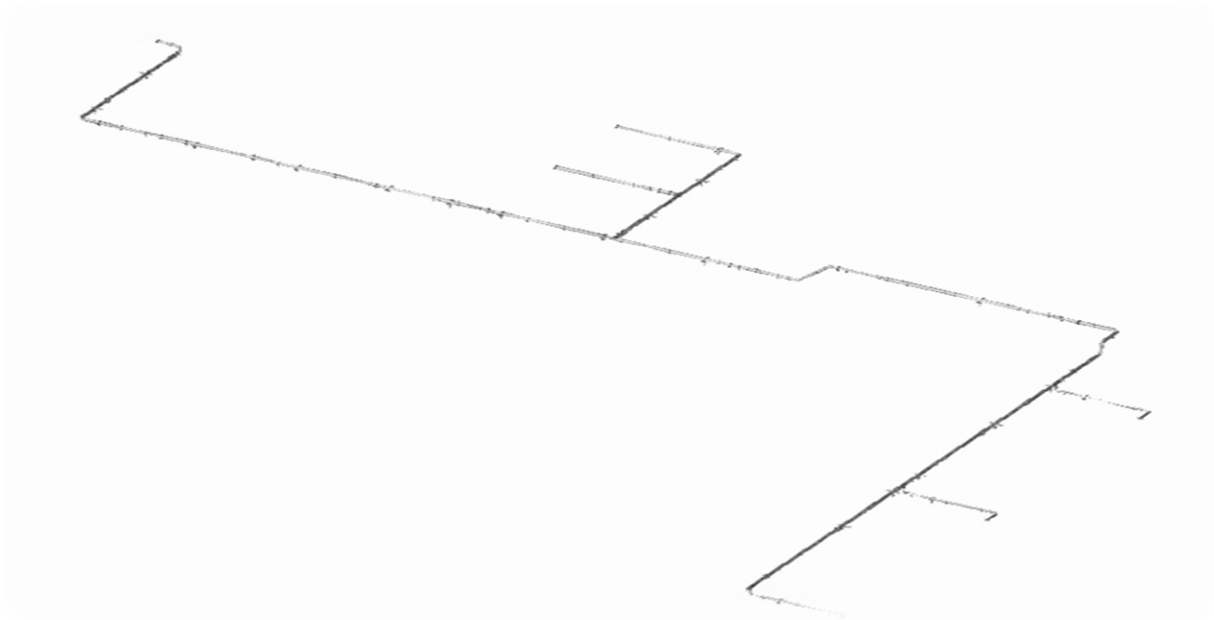

Figure 1. The layout and parameters of cryogenics transfer line.

4. Significance of load cases

i) LIV-2 is a failure case of ingress of atmospheric air due to rupture of outer vacuum jacket (OVJ).
ii) Seismic event non-nuclear (SL) may lead to operational failure of the system.
iii) The above cases along with normal operation and test conditions are considered for the safe design of transfer line.

IOP Conf. Series: Journal of Physics: Conf. Series **823** (2017) 012042 doi:10.1088/1742-6596/823/1/012042

5. Assumptions and specifications

i) Piping network is considered to be located in controlled environment, hence Snow and Wind loads are exempted.
ii) Bellows used in analysis are untied type bellows with internal sleeves, hence pressure drop is not considered in calculations.
iii) Factor of safety is taken as 1.5.
iv) OVJ Diameter: DN150, Process Pipe Main line Diameter: DN 80, Process Pipe Branch line Diameter: DN 50.
v) Material of pipe: ASTM A312.
vi) Design Code: EN 13480.

Table 1. Boundary conditions.

Load Case		T (K)	P (MPa)
G+NT+LIV-2	Process Pipe	80	1.1
	OVJ	252.1	0.01
G+NO	Process Pipe	80	0.39
	OVJ	323	0 (vacuum)
G+TP+TT	Process Pipe	323	1.573
	OVJ	323	0 (vacuum)
G+NT+LIV-2+SL	Process Pipe	80	1.1
	OVJ	252.1	0.05

where,
i) G : Gravity load
ii) NT : Nominal Temperature
iii) NP : Nominal Pressure
iv) LIV-2 : Loss of insulation vacuum
v) NO : Nominal operation (NT + NP)
vi) TP : Test Pressure
vii) TT : Test Temperature
viii) SL : Seismic Load

The spectrum for the Seismic case (SL) have been extracted from EN 1998-4 code (Design of Structures for Earthquake Resistance) .

6. Analysis Result

The frictional pressure drop across the pipe assembly has been estimated based on the following correlations:

i) Pressure drop through straight pipe [3], $\Delta P_{pipe} = \frac{\rho f l v^2}{2D}$ Pa (1)
ii) Friction factor for turbulent flow [4], $\frac{1}{\sqrt{f}} = -2log\left(\frac{Ra}{3.7d} + \frac{2.51}{Re\sqrt{f}}\right)$ (2)
iii) Pressure drop through pipe bends and fittings [3], $\Delta P_{bend} = \frac{K\rho v^2}{2}$ Pa (3)
iv) Pressure drop due to flexible elements [5], $\Delta P_f = \left(\lambda \frac{l_h}{d_h} + \xi_h\right)\rho v^2$ Pa (4)
v) Total pressure drop without flexible elements $\Delta P = \Delta P_{pipe} + \Delta P_{bend}$ Pa (5)
vi) Total pressure drop with flexible elements $\Delta P = \Delta P_{pipe} + \Delta P_{bend} + \Delta P_f$ Pa (6)

Table 2. Pressure Drop results.

Line description	Process pipe diameter	Mass flow rate (kg/s)	Operating Pressure (bar)	Operating Temperature (K)	Pressure drop without flexible elements (mbar)	Pressure drop with flexible elements (mbar)	Allowable pressure drop (mbar)
Main line	DN 80	2.5	3.6	81	252	302	450
Branch line	DN 50	2.5	3.6	81	197	250	300

Table 3. Analysis results.

Load Case	Allowable stress (MPa)	Maximum stress without flexible elements (MPa)	Maximum stress with flexible elements (MPa)	Maximum Deflection (mm)		
				X	Y	Z
G+NT+LIV-2	258	1201	198.6	-31.30	-11.75	20.66
G+NO	143.33	573	113	-37.20	-16.64	-16.90
G+TP+TT	204.25	29	142	1.44	-2.11	2.92
G+NT+LIV-2+SL	258	838.3	198.5	-0.15	-2.11	-0.11

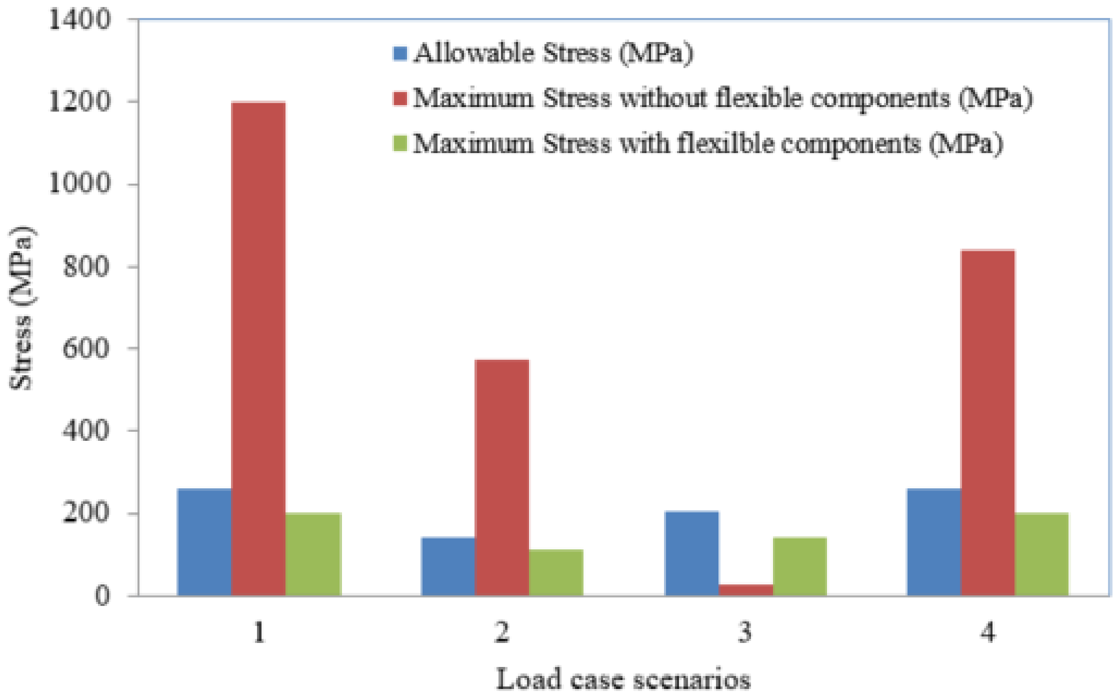

Figure 2. Graphical comparison of Maximum stress under conditions of usage of flexible components.

IOP Conf. Series: Journal of Physics: Conf. Series **823** (2017) 012042 doi:10.1088/1742-6596/823/1/012042

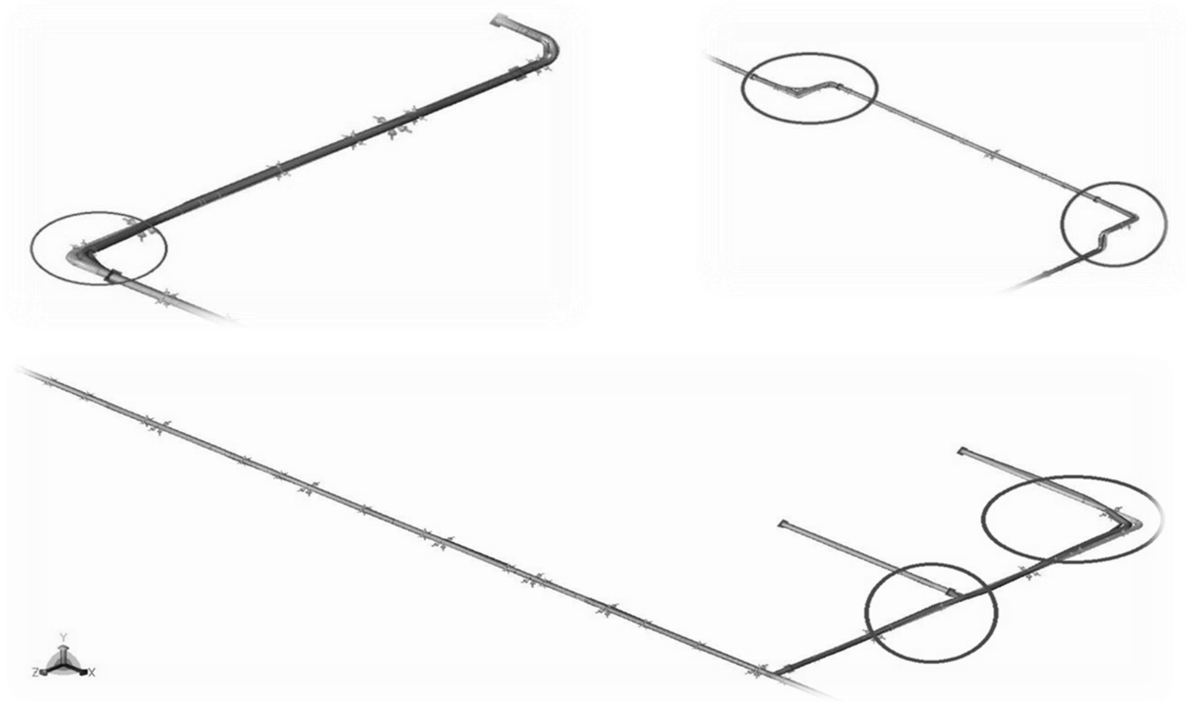

Figure 3. CAESAR II snapshots of the displacements in the critical sections of cryolines without use of flexible elements.

The following flexible components were selected after optimization of analysis:

i) No. of hoses on process pipe : 11
ii) No. of bellows on process pipe : 16
iii) No. of bellows on OVJ : 9

Table 4. Hose and bellows specifications.

		No. of component	Axial stiffness (n/mm)	Transitional stiffness (n/mm)	Eff. Id (mm)	Length (mm)	Dia. (mm)
Hose		2	10000	59	N/A	500	88.9
		9	10000	31.9	N/A	500	73
Bellow	PP	16	151.2	10000	105	168	88.9
			134	10000	75.5	140	60
			144	10000	93.2	165	73
	OVJ	9	96.5	10000	183	78	168.3

7. Conclusion

The Transfer line was designed based on the constraints. The flexibility of the line can be improved either by providing loop/ bend in the network if space permits or by introducing flexible components such as hoses and bellows. The flexible components are primarily avoided in order to respect pressure drop values and because of the higher maintenance required by them. The study concludes that it is important to achieve fine balance between the allowable pressure drop values and space constraints in order to select the flexible components.

Acknowledgement
We are sincerely thankful to Mr. Vikalp Sri Bachahan for his valuable contribution during the course of this work.

References

[1] Badgujar S, Benkheira L, Chalifour M, Forgeas A, Shah N, Vaghela H, and Sarkar B, "*Loads specification and embedded plate definition for the ITER cryoline system*", Cryogenic Engineering Conference and International Cryogenic Materials Conference, Tucson, Arizona; (2015)
[2] EN 10217-5 : 2004; *Seamless steel tubes for pressure purposes, technical delivery condition*
[3] *Flow of fluids through valves, fittings and pipe* – CRANE (Publication 410M (Metric edition))
[4] Colebrook C F "*Turbulent Flow in Pipes, with particular reference to the Transition Region between the smooth and Rough Pipe Laws*"
[5] WITZENMANN metal hoses manual (Section 7.2 Page 246-257)