Repairing and Welding Experience of LN_2 Cryogenic Transfer Line of 80 K Distribution System Of SST-1

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ABSTRACT

The 80 K liquid nitrogen distribution system is one of the essential sub-systems of SST-1 cryogenics system. It consists of 80 K Thermal shields, current feeders system, integrated flow distribution and control system, pre-cooling heat exchanges and purifier of helium plant system. The maximum operating pressure of liquid nitrogen is 1.9 bar (a) from the source storage tanks. Preliminary, authors observed the frosting in one of the section of return LN_2 cryo line near the phase separator interface. Due to this problem, they were unable to collect the phase separated LN_2 in the sub-cooler back. Appropriate investigation of leaks, reason for the leaks identified. Welding protocols (ASME section IX) and replacement of Bellows (as per EJMA standards) were carried out under satisfying the flexibility criteria. The evacuation of transfer lines, insulation wrapping, welding and assembly in congested space and safety aspect at 12 m height were the challenges experienced during repairing task. Due to this activity, the huge amount of LN_2 fluid has been saved.

In this paper, authors will mainly focus on the identification of weld leaks, welding and repairing process, vacuum evacuation process, design of sealing set up, NDT testing of weld joints and helium leak testing at operating condition of cryogenic transfer lines after welding task.

Keywords: Transfer line, Vacuum, Helium leak, Welding, Testing

1.0 INTRODUCTION

One mainly uses liquid nitrogen and liquid helium cryogens at IPR for SST-1 Tokamak cooling application. Specific to liquid nitrogen storage and distribution consists of three numbers of 35 m^3 (each) capacity vacuum and perlite insulated storage tanks installed in warm gas management area, which is about 300 m far from the main application of SST-1 and Cryo installation. Vacuum and super insulation (MLI) jacketed cryo line is connected between internal cryo distribution and storage tanks as shown in **Fig.1**.

There are different sizes of LN_2 cryogenic transfer lines installed of standard DN15, DN 25, DN 40, and DN 50. The LN_2 fluid flowed in sub-cooled condition through specific designed copper heat exchanger, auto control valve mechanisms of level, pressure, flow and temperature in sub-cooler vessel with minimum heat leak to cool to 80 K system and returned via phase separator of gas and liquid separation process of 15 litres and 25 litres capacity respectively to sub-cooler vessel. The LN_2 vapour out from the equipped Cryo grade P2 PUF insulated vent lines to atmosphere.

2.0 LIQUID NITROGEN TRANSFER LINES

The basic structure of the transfer line that consists of two tubes, inner process tube in which fluid flow which is fixed inside the outer pipe jacket supported inside the G-10 insulation material spacer. The straight part of transfer line is 6

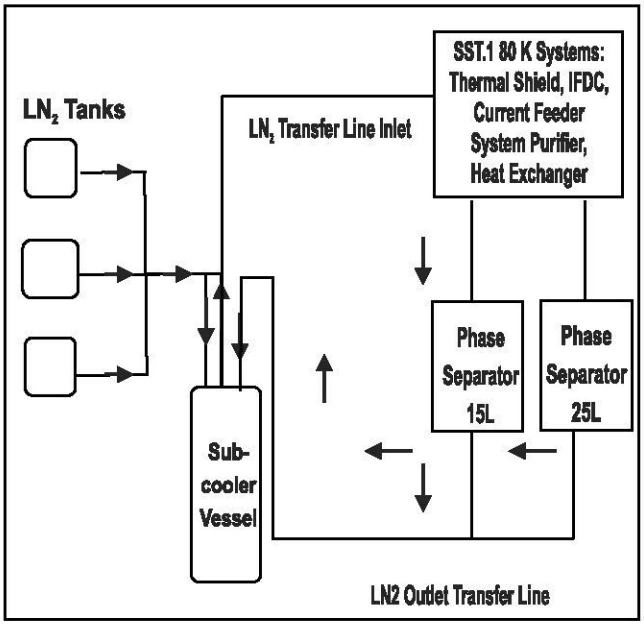

Fig.1 : Schematic of 80 K distribution system network

meter with inbuilt of vacuum barrier which divide the vacuum portion into two sections of line. The evacuation port is the inbuilt part of the transfer line for the vacuum of line through a puppet valve assembly. Cryogenic bellows and circular joint expansion joint unreinforced installed as per EJMA standard in the transfer line to take care of thermal contraction and induced thermal stresses due to temperature variation. The schematic and photo of DN25 size LN_2 transfer line as shown in **Fig.2** and **Fig. 3** and the technical details is summarized in **Table 1.**

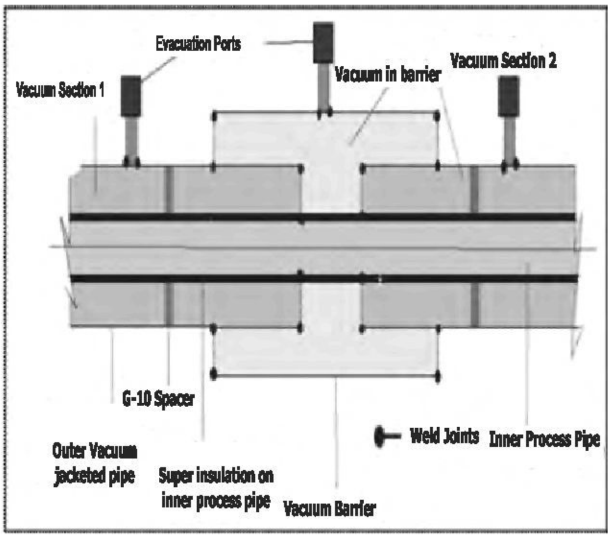

Fig.2 : Schematic of LN2 transfer line

Table 1 : Technical details of LN_2 transfer line

LN_2 transfer line Assembly	Technical Details	Remarks
Size: DN25	Process inner tube OD: 33.4 mm, thickness: 1.65 mm Outer jacketed pipe OD: 76.0 mm, 1.65 mm thick	Material: SS 1.4301/1
Type	Vacuum jacketed super insulation	≤ 10^{-3} m bar vacuum level
Pressure	2 bar (a)	Maximum safe operation pressure : 20 bar
Temperature	300 to 77 K	
Flow rate	1 l /s (14 g/s)	
Heat leak	0.38 W/m	
Material	SS 1.4301/1	
Length	~ 300 meter	
Bellows material	AISI 321	
Weld ends	AISI 304	
Bellows axial movement	± 20 mm/grad	
Spacer material	G-10 (Cryo grade insulation material	Thermal conductivity at 77K : 0.2 W/m-k
Insulation	Fiber glass paper and metal foil	10 layer

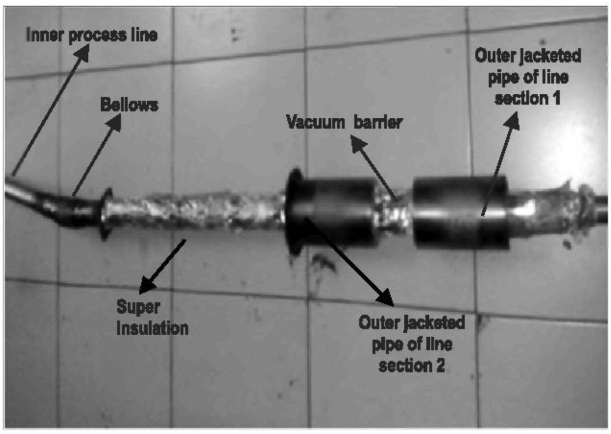

Fig.3 : Actual internal structure of LN2 line

2.1 Leaks observations and analysis of LN_2 Cryo transfer line

During the experiment, authors observed the huge frosting and condensation over some sections of main LN_2 line and return lines of 80 K system. LN_2 was dripping out from main LN_2 line evacuation port section and it covers around 2-3 meter area. They identified and eliminated the leaks in the frosted sections. Possible reasons behinds the leaks and condensation may be summarized as follows :

(i) Room temperature leak failure due to liquid metal embrittlement

(ii) Due to welding weakness as inclusion, root porosity or poor penetration remain vulnerable to the induced stresses and strains during cool down and warm-up cycle from 300 K to 80 K and reverse.

(iii) Excessive thermal fatigue cycle value of cryogenic bellows

(iv) Aging effect of materials

(v) Degradation of vacuum in space between two lines

(vi) Pressure rise due to a high suspected air leak

(vii) Due to low temperature inner cryogenic bellows pipe contracts and exert force on the outer jacketed pipe since both the pipes are welded together. [2]

(viii) Cryogenic bellows leakage [1] in its convolutions as shown in the **Fig. 4**, due to suspected solidified air blocked the undulation movement.

It was very mandatory to stop and warm up the operation of 80 K LN_2 system and in-house repairing was carried out for safety of manpower working in plant and to protect the equipments from damage and prevent the fluid losses.

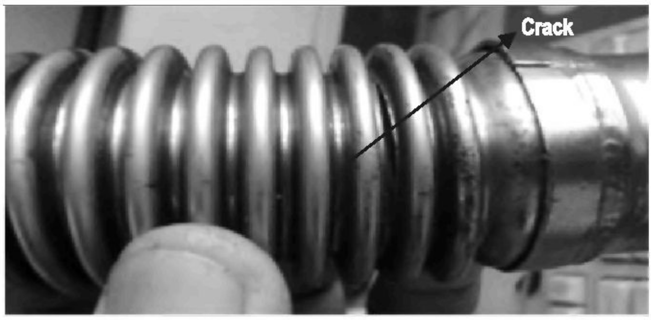

Fig.4 : Crack in cryogenic bellows of inner process line

2.2 Investigation and Repairing of LN_2 Cryogenic transfer lines

First these authors identified the location of the sections of transfer line where the huge frosting and condensation occurred, there were three locations (i) in main cryogenic transfer line (ii) in return line to sub-cooler vessel and (iii) at the sub-cooler vessel piping connection as shown in **Fig. 5(a), 5(b), 5(c)** and **5(d)**.

The repairing procedure was followed as

(i) In frosted sections of 4 meter main line DN25 size were to suspected to high air leaks, the evacuation process was carried out by a Root pump (1000 m^3/hr capacity) to check the vacuum level up to < $5x10^{-3}$ m bar and holding upto < 10^{-2} m bar in 24 hours. The vacuum level was observed up to 1 m bar pressure for continuous pumping 3 hours. The LN_2 line was pressurized by GN_2 at 2 bar from LN_2 plant, the puppet valve assembly port came out from the transfer line section that ensured and confirmed the leaks in the inner process pipe. In the helium leak test, it was found that the leaks occurred in convolution of the cryogenic bellows in inner process line.

(ii) Same process was carried out in another 6 meter section of transfer line size DN15. It is the return line from 80 K system through LN_2 phase separator to sub-cooler vessel. The frosted section was evacuated up to 8 m bar pressure and no vacuum improvement was observed by continuous pumping of 4 hours. In the test, authors identified the leaks at the outer jacket pipe weld as shown in **Fig. 5 (b)**. All weld joints seams of that frosted section were temporary sealed with 'Apiezone' make cryogenic 'N' grade vacuum grease. By this process, the vacuum level was improved to <10^{-2} m bar from 8 m bar in 5 minutes, that confirms the weld seam joint leaks.

(iii) After re-welding process of identified leaks of above section, the line was again tried to evacuateand the vacuum level could not to be achieved to 1 mbar, then they traced the network of that line section by removing the PUF insulation portion of sub-cooler vessel. The dish end plate was found separated from the outer jacket pipe of transfer line. This atmospheric air leaks which solidify the air inside in the transfer line and degraded the vacuum and condensed over the multi-layer insulation and outer jacket pipe due to the flowing LN_2 in the inner process line.

(iv) To remove the water moisture in the transfer line, 1 kW electrical heaters were wrapped over outer jacketed pipe of transfer line. This process extracts the water moisture from the insulation surface which wrapped over inner process line.

Both the sections mentioned in (a) and (b) were taken to ground by cutting at actual location of 12 meter height for welding and testing. The third section (c), the repairing, testing and welding job were performed at that actual location. The cutting job of a particular section of a transfer line is a specific technique and sequence of operation.

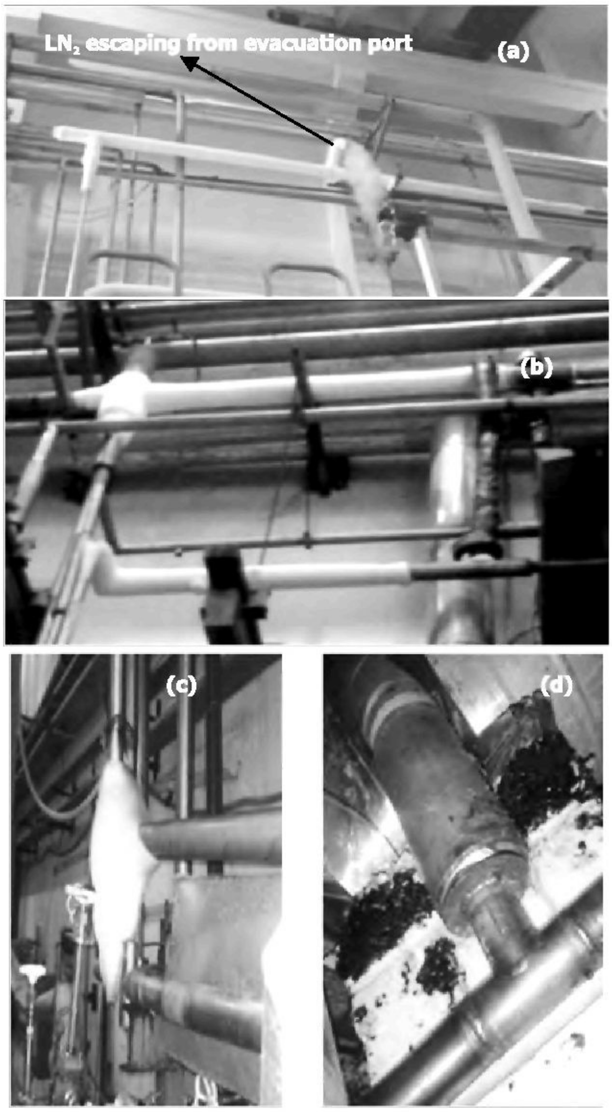

Fig. : 5 (a) LN2 dripping from main transfer line (b) Return line frosting from phase separator (c)Weld leakage in outer jacket T-joint in return lines (d) Dish end welding crack of main return line to sub-cooler vessel

3.0 WELDING OF CRYOGENIC LN_2 TRANSFER LINE

After helium leak tests of transfer line sections, the leakages were found in the following sections:

(i) In cryogenic bellows of process line of DN25 size of main LN_2 transfer line

(ii) In 2 number of weld seams of outer jacket of return line of DN15 size.

(iii) 1 no. of dish end plate of DN 25 size inner process pipe

3.1 Assembly procedure and welding parameters and weld test

Before welding the vacuum jacketed pipe sections together, slide the two sections over the inner process pipe which separate the vacuum in transfer line called vacuum barrier. The vacuum barrier pipe sections pre welded dish plate with both ends; the assembly is shown in the **Fig. 6**

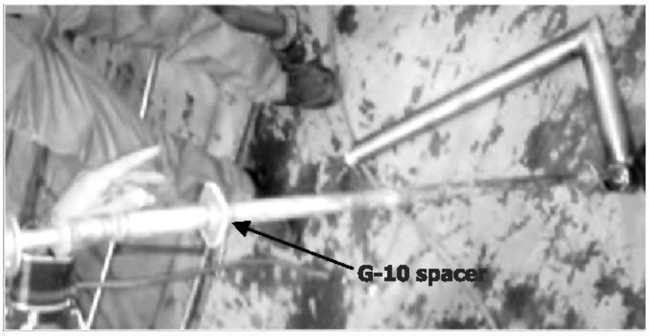

Fig. 6 : Assembly of LN_2 transfer Cryo line

(i) Tested cryogenic bellows [4] welded in the inner process line as shown in **Fig. 7**

(ii) Test the sections for helium leak rate in vacuum and pressure condition as

(iii) Apply multilayer of super insulation on inner process pipe.

(iv) Move the two sections together engaging the inner line weld socket and weld the weld socket

(v) Weld the one end of vacuum barrier pipe section with inner process line with dish end plate

(vi) The outer pipe section of vacuum barrier welded with both end dish plate

(vii) Slide the outer jacket pipe sections of both side of vacuum barrier and weld with dish end plate at actual location of transfer line as shown in **Fig. 8** (viii)The leaky sections were cut in two halves for ease the re-assembly and welding process.

(ix) The joints which are to be welded clean with petroleum ether and cotton cloth. The TIG welding process as per ASME section IX procedure was adopted in pulse mode method to avoid burning of insulation material wrapped over inner pipe. The heat control during welding reduces the risk of hot cracking and distortion of cryogenic bellows.

(x) The temperature was monitored ~70 °C by the digital thermometer, maximum 30 A current and 15 l/min purging with pure argon gas at 2 bar pressure were the desired/ optimized parameters for welding of cryogenic transfer line. The welding joint preparation job was carried out in stress free condition of transfer line to prevent the generating of induced thermal stresses when line cooled is to 80 K.

(xi) The weld joints were examined for any weld defects as surface flaws, cracks, etc. by liquid penetrant test using 'ORION'[R] 115D make cleaner, penetrant and developer. It confirms to ASME Boiler and Pressure Vessel code Sec 5 and ASTM E-165. For final examination all the weld joints helium leak were carried out in vacuum and pressure conditions confirms to helium leak tightness of < 10^{-8} m bar l/s. No indication of any weld defects and leakages were observed in any weld joints.

Fig. 7 : Welding of Bellows with transfer line

Fig. 8 : Welding of main LN_2 transfer line at 12 meter height

4.0 PERFORMANCE TEST RESULT OF REPAIRED CRYOGENIC LN_2 TRANSFER LINE

To ensure the complete leak tightness at cryogenic temperature 80 K, leak testing of transfer line are carried out at the following stages:

(i) Leak testing of individual process pipe and cryogenic bellows [4] shown in **Fig. 9**, this assures elimination of any leaks in components before it is welded to the assembly as shown in **Fig. 10**.

(ii) After welding of inner pipe and outer pipe, test of each welded and repaired joint

(iii) After acceptable preliminary leak testing, the transfer line assembly is leak tested at 80 K.

(iv) The inner pipe is filled with LN2 and annular space is connected to MSLD leak detector through the puppet evacuation port. Helium is sprayed externally on all outer surfaces of the outer jacket pipe including welded joints to check the failure of pipe/joint due to thermal stresses developed as a result of large temperature difference. Any drop in vacuum level of annular space indicates the failure of inner process pipe. The repaired line was validated by operating at 80 K as shown in **Fig. 11**.

(v) Masking and unmasking technique were used to localize the helium leaks.

The test parameters and its results are presented in **Table 2.**

Fig. 9 : Helium leak test of cryogenic bellows

Fig. 10 : Vacuum and helium leak test of LN_2 transfer line

Fig. 11 : Repaired LN_2 line at 80 K

Table 2 : Transfer line test parameters and results

Test Parameters	Parts/Section details	Helium Leak rate (mbarl/s)
Helium Gas pressure 1.5 bar, 3.5 bar at 300 K	Inner Process line along with bellows of main transfer line	3.1 x 10^{-6} mbar l/s in sniffer condition test
Helium Gas pressure 1.5 bar, 3.5 bar at 300 K	Inner and outer pipe line, dish end and vacuum barrier weld joints	5.0x10^{-6} mbar l/s in sniffer condition test
LN_2 pressure 2 bar, 80 K	Repaired main, return transfer lines	<1.0 x 10^{-8} mbar l/s in vacuum mode
Vacuum level achieved in 3 hours	Repaired main and return transfer line	<2.0x10^{-3} mbar and <1.3x10^{-2} mbar vacuum was hold in 24 hrs

5.0 CHALLENGES AND LESSONS LEARNT DURING THIS TASK

During the repairing of LN_2 transfer line, authors have experienced many critical issues summarized below:

(i) The welding job was carried out by the qualified welder and leak testing of transfer line in each stages were done to prevent the repetition of welding.

(ii) The cutting, evacuation, assembly in congested space as very less gaps between the transfer lines network, super insulation, testing and welding process at 12 meter height was the challenges faced. The safety aspects were considered used during the task under the supervision of safety officer of Institute.

(iii) The design and fabricated of 1" size puppet valve

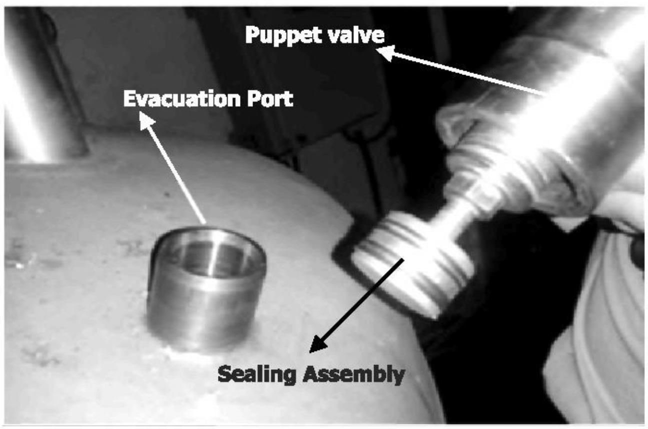

Fig. 12 : Evacuation port along with puppet valve assembly

evacuation port assembly which has specific feature of sealing contact 'O' ring at 8 points as shown in **Fig. 12**.

(iv) The testing of transfer line at operating condition 80 K, the manpower, helium leak detector, pumping unit, pressure measuring equipments, etc. were taken to actual location (12 meter height) of transfer line.

CONCLUSION

The in-house repaired LN_2 cryogenic transfer line has been validated by operating at 80 K for long duration operation, no indication of vacuum degradation; condensation and frosting were observed on any locations of transfer line. Authors replaced the entire evacuation puppet sealing port of leaked sections of transfer line which was the main factor of air leakage in annular space. Due to this activity, huge amount of LN_2 fluid have been saved. The most important aspects of preventing of equip-ments damage and safe to manpower by the LN_2 fluid dripping out from transfer line in the laboratory. The overall thermal performance of 80 K distribution system of SST-1 machine has been improved to satisfactory level. This practice results the safe long working conditions in cryogenic environment without meeting any emergency condition.

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APPENDIX

ASME : American Society of Mechanical Engineers

NDT : Non-destructive test

EJMA : Expansion Joint Manufacturer Association

LN2 : Liquid Nitrogen, GN2: Gaseous Nitrogen

MSLD : Mass Spectrometer Leak Detector

G-10 : Cryo grade glass fibre insulation material