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Flexible Corrugated Cryotransferlines, Long Term Experience at JET and the Experience with Supercritical Helium Flow Conditions

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ABSTRACT

Long flexible corrugated cryotransferlines are widely used at JET for the supply of liquid nitrogen and liquid and supercritical helium. Their low thermal losses allow to use a central distribution system with individual lines to each user with line lengths of up to 90 m. The easy installation of the fully tested cryolines, their flexibility, high pressure stability and compatibility with the remote handling requirements of JET were important design specifications. Some of the cryolines have been in operation for over 15 years and the paper reports about their excellent reliability records and the main performance data.

INTRODUCTION

For the cryosupply of JET - the world's most advanced thermonuclear fusion experiment - the concept of a central distribution system with individual cryolines to a network of load assemblies taking liquid nitrogen and liquid/supercritical helium has been adopted. This concept was chosen in order to keep all control systems (in particular valves and instrumentation) in easily accessible areas, because the loads themselves cannot be accessed in the D-T phase of the project due to the expected radiation level in the vicinity of equipment inside the torus hall. This concept required, however, long transferlines and thus the development of the JET low loss cryolines.

The use of low loss long flexible JET cryolines for liquid helium has been first reported at the ICEC12 [1]. These line were a further development of flexible lines used for CERN [2] implementing as a new element a liquid nitrogen radiation shield as an integral part of the cryoline. JET has subsequently commissioned over 30 long (>50m) flexible corrugated cryolines which represent a total length exceeding 2 km. Individual lengths of the cryoline are up to 90 m. Some of the cryolines have been in use for over 15 years and JET gained considerable experience with these lines during this period. JET installed new flexible corrugated cryolines for the 1993-94 experimental campaign for the supply of supercritical helium (in contrast to the two phase liquid helium which is supplied to all other users).

CRYOLINE SPECIFICATION

Boundary conditions

The operation of the cryogenic loads which are mainly large scale cryopumps at various places at the experiment (for details see [3]) are located in a potential radiation area with high induced eddy currents. This requires that the cryolines:

- have low thermal losses
- have high pressure stability and small thermal mass for fast cooldown

- are radiation resistant and compatible with remote handling i.e. connection, disconnection and line exchange must be easily performed by a remote handling manipulator
- have an electrical break to separate the electrical potential of the load from that of the cryoplant
- are flexible in order to allow for the movement of cryo-loads
- can be easily rearranged to make space for new equipment
- can be used as vacuum line for pumping of vacuum spaces of the cryo-loads
- have minimum time requirement for on-site installation

Thermal losses:

The considerable length of the cryolines requires a system with low thermal losses. This could be achieved owing to the fact that the lines have no intermediate lossy joints and are fully thermally shielded by helium boil-off and liquid nitrogen.

Thus the thermal losses of the cryolines are small in the overall thermal balance despite of their length. The specific data are listed in table 1.

Table 1 Thermal loads to JET low loss Helium-cryotransferlines

Liquid helium go-line	< 10 mW/m
Gaseous helium return line	< 100 mW/m
Liquid nitrogen shield	< 2 W/m

Pressure stability

An important specification for the cryolines is their pressure stability. The cryosupply for the JET cryo-loads operates at pressures of up to 12 bars for special transient conditions such as cooldown by using the 12 bar high pressure outlet of the cryoplant. The cryolines have also to cope with large pressure excursions of up to 10 bars from unplanned regenerations (quench) of the cryopumps. Due to the special corrugations of the pipes high pressure stability is provided for internal pressure as shown in table 2.

Table 2: Pressure stability of corrugated pipes used for JET cryolines

corrugated line diameter, wall	burst pressure	elongation 5%	buckling
14/18 mm, 0.3mm	>300 bar	>50 bar	>160 bar
39/44 mm, 0.4mm	>130 bar	>22 bar	> 80 bar
60/66 mm, 0.5mm	>130 bar	>17 bar	> 70 bar

Line flexibility

Another important issue for the use of the cryolines is their flexibility under operation conditions as they have to cope with the movement of the cryoloads during the experiment which is in some places up to $\pm 100\text{mm}$ with a frequency of 2 Hz. For installation great care has to be taken to avoid torque during the movement as the line has no flexibility for torsion.

In this context it has to be noted that KEK/Japan which adopted later the JET cryolines uses them to pull their cryo-load completely out of the operation area without dismantling the cryoline.

Vacuum

One advantage of the concept of long flexible cryolines is that they can be fully tested cryogenically for thermal performance and vacuum leaks (leakrate $< 10^{-9}$ mbar l/s) at the manufacturers and installed within a short period of time (typically 1-2 days) by a cable pulling team. The vacuum of the cryolines is also used at JET as a vacuum pumping line for interspaces of the cryoloads.

Electrical break/ Radiation resistance

The cryoplant has to be electrically insulated from the cryoloads for a potential of up to 2 kV and the cryocouplings had to be designed accordingly. The interior shrink coupling is made of a cryogenically and radiation compatible polymer, the coupling itself coated with a radiation compatible glass epoxy sleeve and the connection flanges enamelled or equipped with a polymer spacer. For all the internal spacers of the cryoline and the superinsulation, radiation resistant material had to be used.

Material

The use of austenitic stainless steels AISI 304 or 316 (equivalent DIN 17440: 1.4541, 1.4301, 1.4435, 1.4306) is a prerequisite to be compatible with the weldability for vacuum leaktightness, ductility at cryogenic temperatures, low thermal conductivity, corrosion and good emissivity properties.

JET CRYOLINES

Over 30 long cryolines (with lengths between 45 and 90 m) are in use at JET. They originate from the central distribution area and are branched off to the various loads (see Figure 1). The inner liquid helium go lines have diameters between 10-20mm depending on the needs of the specific cryo-loads, the helium return lines have an annular gap of 3-5mm and are rated to

minimize the pressure drop on the return in order to guarantee stable operation of the users. The outer dimension of the helium cryolines are ~110 mm which gives a reasonable flexibility for installation. Two different types of liquid helium lines are used at JET. There is one type with an integrated go and return nitrogen shield loop and one with a single flow nitrogen loop which is used to supply a nitrogen user at the outlet of the cryoline (see figure 2).

Due to the installation requirements at JET the cryolines are installed with height differences of up to 10m and a bending radius of 1.5m for the large 110 mm LHe lines and less for smaller lines and have usually a loop which allows to accommodate a few metres spare length.

Figure 1: Bundles of JET cryolines leaving the main penetration into the JET basement.

Figure 2 Cryoline with integrated LN loop (Go and return)

Cryoline with single flow LN supply

Couplings/ Remote handling

A key element for the ease of handling and the performance of the cryolines are the terminations at the end of the lines. The termination of the cryolines provides an entire vacuum enclosure and no vacuum connections are required for installation. Using for the internal go line a simple shrinkage seal and for the external seal a JET standard Vacuum O-ring sealed V-band flange guarantees that the cryoconnection can be opened and closed with ease even by remote handling with a single-arm manipulator.

Figure 3: Remote handling tool for disconnecting cryoline by opening V-band clamp

EXPERIENCE AND LESSONS

In terms of long term performance the cryolines and the JET cryopumps are practically maintenance free [4]. A spare line which was procured at the beginning of the project is still waiting to be used - see Figure 4 which shows the way of delivery of a 90m long He-line on a simple cable drum.. In particular there were no detectable problems of fatigue, despite considerable thermal cycling, and no deterioration of the thermal performance of the lines over the years could be detected. The flexibility of the lines allowed rearrangement and even complete rerouteing of lines in order to accommodate the installation of new experimental equipment at JET in a short period of time with minimum efforts. No remedial work on the lines has been necessary over the last 15 years. However several design improvements have been made. These concern the details of the inner thermoplastic shrink seal and the electrical breaks. These can crack if overstressed, therefore clearances and tightening has to be followed carefully.

Flow of supercritical helium of up to 17 g/s through the corrugated pipes could be established without any problems or flow instabilities. The measured pressure drops were well

within the calculated values (< 50 mbar for 2.7 bar/4.5K and a Reynoldsnumber of 3×10^5). This fits well with a friction factor of 0.098.

Whilst there were no vacuum problems with the cryolines themselves problems were found with the feedthroughs for the instrumentation and heaters for the adsorber packages where the glass insulation developed cracks by the force from the sealing clamp. With improved clamps and feedthroughs the problems was solved. During operation with LHelium air leaks cannot be detected due to the large cryopumping of the helium lines and if the systems are operated for a considerable time a stoppage of the helium flow can cause a considerable pressure rise of the insulation vacuum which may cause a problem for the subsequent cooldown. This is in particular important when regular thermal cycling of the loads takes place such as at JET (daily to weekly).

Figure 4 Storage/delivery drum with spare 90m long JET liquid helium cryoline and single pass liquid nitrogen line.

CONCLUSION OUTLOOK

Long flexible cryolines at JET allow the easy transport of cryogens over long distances with minimum thermal loads into areas with restricted access. The long term experience with these lines shows that they can be regarded as practically maintenance free. The use of similar lines with integrated superconductors will be an ideal concept for a combined supply of electrical power and cryogens to the superconducting coils for future fusion devices such as ITER.

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