Cryogenic Engineering Conference 1983
Colorado Springs CO
EB-4

COUPLING AND TERMINATION TECHNIQUE FOR FLEXIBLE CONCENTRIC MULTIPASS CRYOGENIC TRANSFER LINES

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INTRODUCTION

About 40 years ago the production of the Flexwell® tube, based on Kabelmetal's "Wellmantel"* process, was started in Germany. The Flexwell® principle calls for the application of a corrugation to a thin-walled tube to render it flexible. Flexwell® tubes are used as protective sheaths for electrical, district heating and safety cables and as special components for vacuum enclosures for the transport of virtually all liquid gases used in industrial and research applications.

The use of flexible transfer lines for cryogenic liquids is a relatively new development, in particular, for the transport of liquid helium. Flexwell® cryogenic lines can be produced in continuous lengths up to several hundred meters, without the need for elbow, joint or coupling. This has the advantage of minimum heat loss. In addition, they can be completely tested on the manufacturer's premises and the requirements for installation, test and commissioning on-site are minimal (Fig. 1). Furthermore, due to the line's flexibility, no sophisticated alignment procedures are called for and it is even possible to move components during supply operations. For applications in irradiated areas like DT-operated fusion devices, the simple replacement and reliability of cryogenic transfer lines is also very important.[1]

*"Wellmantel"is Kabelmetal's trade name for longitudinally welded and corrugated metallic tubes.

A key element in the implementation of flexible cryogenic multipass transfer lines is the design of the terminations and couplings. These determine not only the thermal losses but also the reliability and ease of installation of the line.

Fig. 1. Installation of a Flexwell® Transfer Line

FLEXWELL® TRANSFER LINES FOR CRYOGENIC LIQUIDS

Nitrogen Lines

Flexible nitrogen lines are standard products, consisting of two vacuum-insulated concentric tubes with heat inleaks of typically 1 W/m, depending on the size of the line. Liquid nitrogen lines are available in standard cross-sections for the liquid flow from 14 to 39 mm inner diameter and continuous length up to several hundred meters[2]. Other diameters are available to special request.

Helium Lines

While the nitrogen lines are standard products[2], the JET helium lines are of a unique design (Fig. 2) which guarantees low thermal losses for liquid helium transport over long distances (liquid helium supply line 5 mW/m, gaseous return line 150 mW/m). The core of the JET helium line is similar to the CERN line[3], except for the addition of a specially-designed liquid nitrogen cooled screen. With this configuration, minimum heat leak is guaranteed, as the entire helium circuit is shielded by liquid nitrogen. In addition, the liquid helium flow is shielded by 4 to 10 K boil-off helium which gives an optimum shielding to the inner supply line. The details of the JET helium line are shown together with the termination in Fig. 2. It consists of a five-fold coaxial configuration having the following components:

- an innermost pipe for the supply flow of liquid helium;
- a second and third concentric pipe for the helium return flow in the annular channel between these two pipes and with insulating vacuum between the innermost and the second pipe;
- a radiation shield, actively cooled by a liquid nitrogen loop and wrapped with several layers of super-insulation;
- a vacuum enclosure.

COUPLINGS

To minimize the heat load on the ends of the transfer line, Johnson type couplings are used for all connections to the distribution valve box and to the load. While this is a standard design for the nitrogen line, the multi-tube coaxial transfer line for liquid helium called for a special design of the termination.

The coupling for the helium flow is concentric. This ensures minimum heat inleak into the liquid supply line and provides for a simple and compact line termination, as illustrated in Figs. 2 and 3. This concentric design minimizes all requirements for alignment and it even allows the connected cryostats to rotate.

LINE TERMINATION TECHNIQUE

Each corrugated tube is manufactured to its full length without intermediate welding connection. A threaded interface piece at the end of the corrugated tube (Fig. 2) provides for the transition between the tubes and the termination. This piece is screwed into the helical corrugation and welded to the flexible tube in order to relieve the weld seam from the mechanical forces due to thermal contraction. All welds on the termination are TIG-(Tungsten Inert Gas) welds, without filler material. Each weld is thoroughly leak-tested before a new weld is made. This minimizes the risk for repair upon completion of the termination.

The male Johnson couplings are made of thin-walled (0.2 mm) corrugated stainless steel tubes which are reinforced with glass epoxy in order to provide for low thermal conductivity with high mechanical strength. Moreover, the glass epoxy cover provides

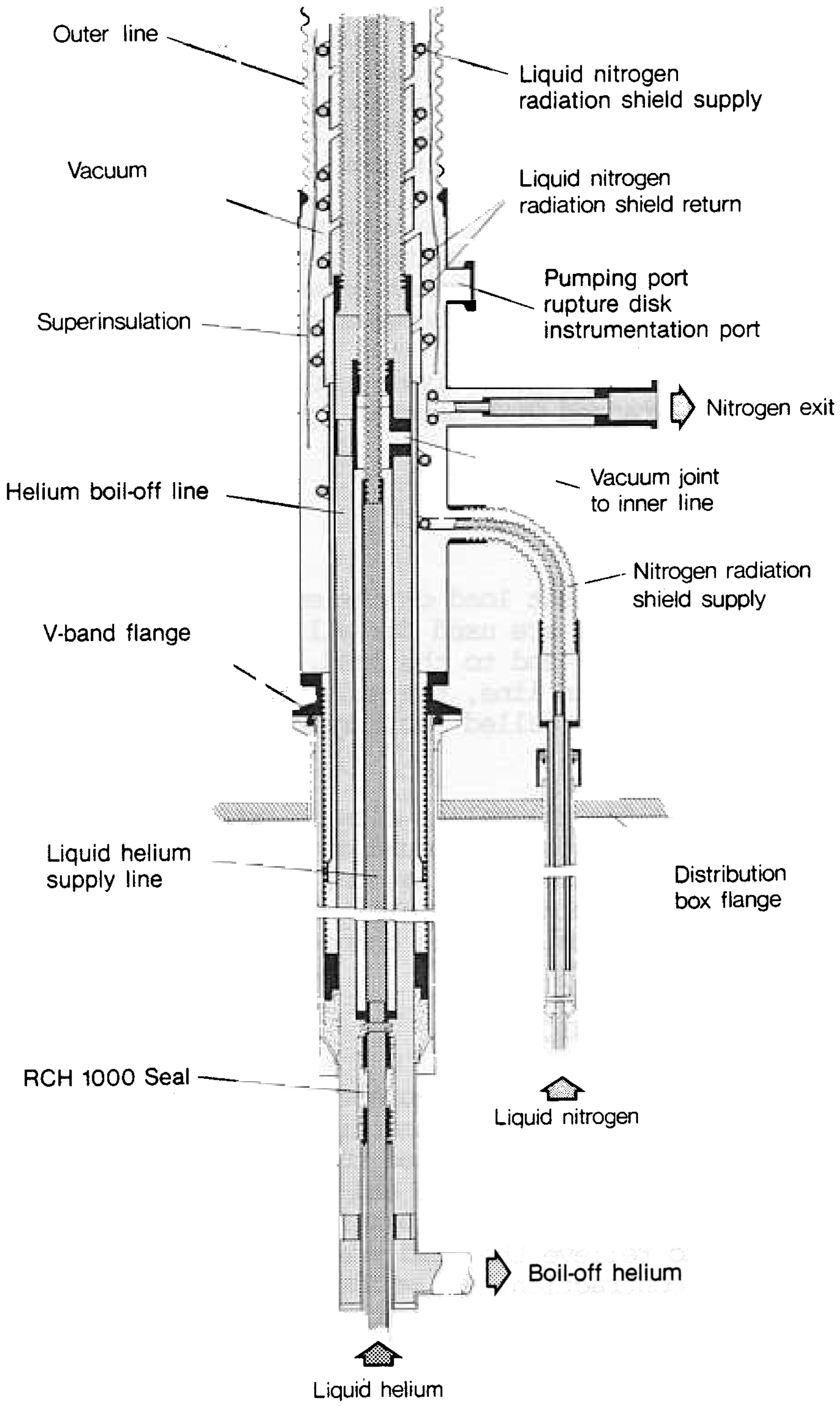

Fig. 2. Termination of multipass flexible helium transfer line for JET, including distribution box end with nitrogen shield inlet and outlet.

for the required electrical insulation between the supply and the cryostat.

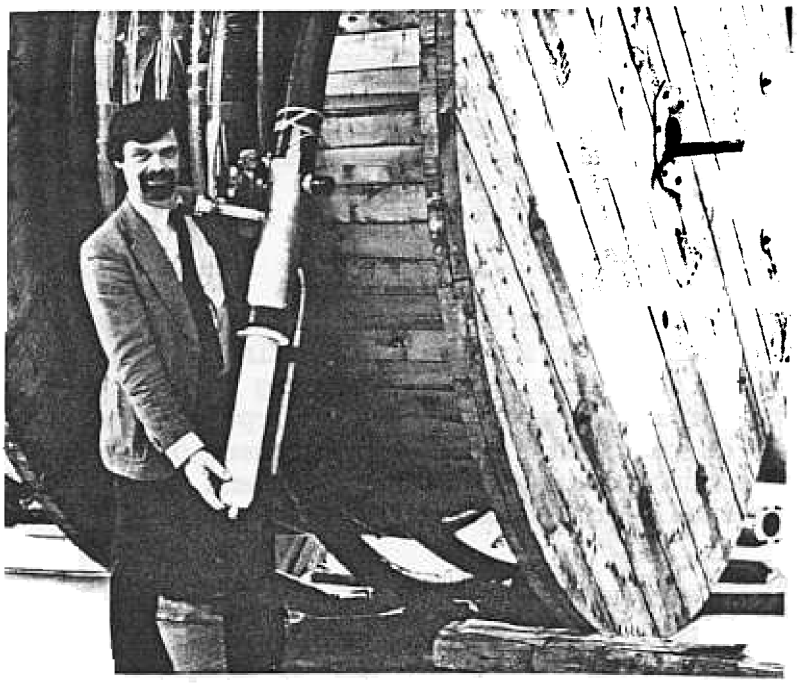

Fig. 3. 80 m flexible JET helium transfer line, with termination, on its shipping reel.

Internal Coupling

The concentric arrangement requires an internal seal for the inner supply line. This seal is not accessible during installation of the line. Any leak from this seal during operation acts as an additional heat load, as the amount of liquid which leads directly to the boil-off is missing in the supply balance of the system to be fed. Fortunately, however, the sealing requirements are not very stringent

For the internal coupling two different solutions have been developed, both avoiding spring-loaded seals. One seal consists of a RCH 1000 cover which slides smoothly over the corresponding stainless steel coupling tube and provides a seal due to the thermal contraction differential when cooled down. Tests with these RCH 1000 seals showed leak rates of less than 10^{-9} mbar L/s below 100 K and at pressure differentials of up to 10 bar between inside and outside. The RCH 1000 coupling is held by a bellows in order to ease the installation and to allow for minor misalignment. An alternative system consists of a set of highly polished ceramic disks which are sealed by adhesive forces. This seal allows rotation of the coupling, even when cold.

Counter-piece

A well-aligned counter-piece for each termination is included among the deliverable hardware for each line. The concentric counter-piece is to be welded to the appropriate cryostat at the distribution or load end. It provides for the separation of the two concentric supply and return flows, as shown in the white outline in Fig. 2.

Termination Components

The termination at the distribution end contains the liquid nitrogen inlet and outlet for the line radiation shield. Also installed at the same line end is a pumping port with vacuum lock, feed-throughs for instrumentation and adsorption heaters, and the rupture disk, as required for safety. For ease of installation there are no outcropping ports at the load end and the nitrogen supply is internally connected to the return flow pipe.

Thermal Load and Flow Restrictions due to the Termination

Pressure Drop. The cross-sections of the termination were sized such that they mate perfectly with the tubes of the transfer line. Thus, no additional pressure drop is caused by the termination.

Heat Load. The heat load on the line end is caused by the following contributing factors:

- the return flow is affected by the Johnson coupling. The effect has been minimized by the extension of the liquid nitrogen screen which maintains the temperature of the heat conducting pipe to that of liquid nitrogen. This loss is rated to be less than 0.5 W per coupling;

  by the heat loss to the supply flow which is the result of limited insulation to the return flow in the internal coupling. It has been diminished by going to a heavier RCH 1000 coupling of 10 mm thickness. Also, the 10 K max. temperature gradient between the supply and return flows during operation contributes to restrict this loss which is rated to be less than 0.1 W per coupling.

Remote Handling

In order to be able to disconnect the cryogenic lines while under radiation, remote handling capability must be provided. Here, the flexibility of the line is of great advantage, as only a single connection must be opened. The Johnson coupling is sealed at room temperature with radiation-resistant polyurethane O-rings and provided with a JET standard (V-band) remote handling flange connector[4]. This connector can be opened with ease by a single-arm manipulator (Fig. 4). The tolerance of the internal polyethylene spacer (about 0.1 mm at ambient temperature) provides for easy assembly during installation. All components of the line are resistant to a maximum radiation exposure of 10^9 rad during their lifetime.

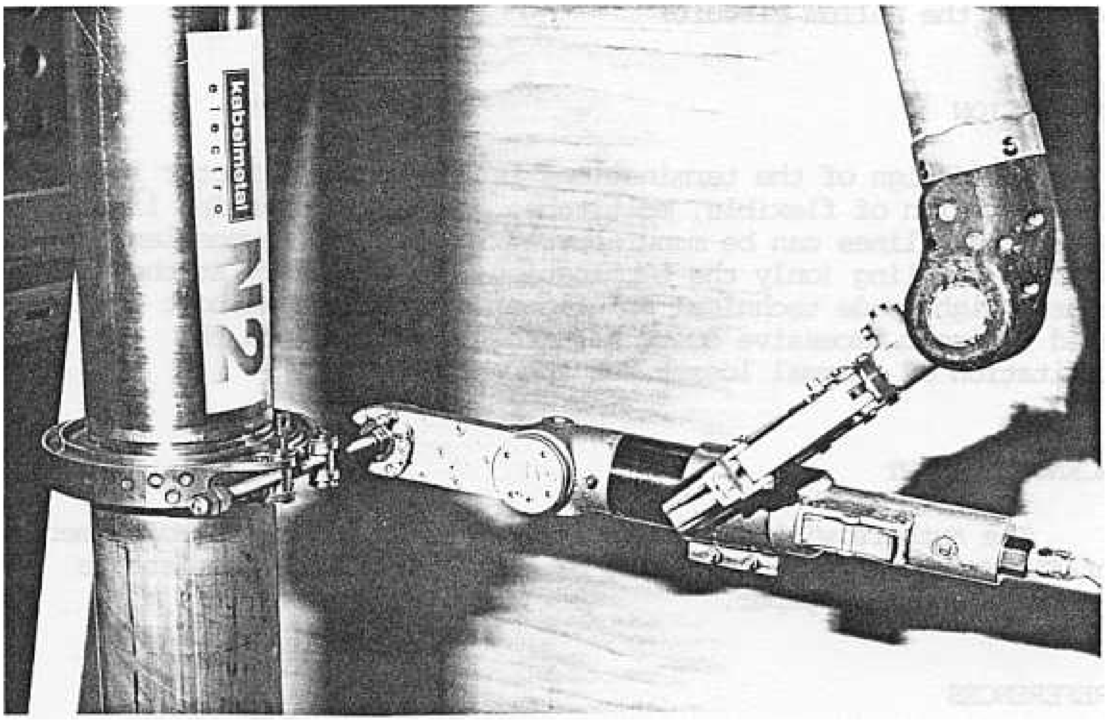

Fig. 4. Remote handling device for cryogenic transfer line coupling.

<u>Electrical Insulation</u>

In order to provide for galvanic decoupling between the cryogenic supply system and the experimental device, electrical insulation is built into the ends of the line. At the Johnson coupling this is accomplished through the application of the radiation-resistant glass epoxy cover over the thin-walled corrugated tube. For the inner tube, the polyethylene coupling and also the ceramic disks provide for sufficient electrical insulation. In addition, all coupling flanges are enamel-coated, thus providing the necessary electrical insulation and the required sealing surface quality.

The insulation breakdown is rated for 4 kV DC. A minimum of 4 cm insulation length ensures freedom from arc-overs.

Rotation of the Cryogenic Coupling

A special design feature of the cryogenic coupling is the ability to rotate the cryostat with respect to the cryogenic transfer line. Thanks to the flexibility and concentricity of the line the cryostat can be moved, and even rotated, without breaking the helium circuit.

CONCLUSION

The design of the terminations is an important factor in the operation of flexible, multitube, concentric transfer lines. Since these lines can be manufactured in long continuous lengths without coupling (only the terminations are necessary at the ends), high-grade technical solutions are possible without the need to incur excessive cost. A further benefit is in the limitation of thermal losses for the whole system.

ACKNOWLEDGMENT

The authors wish to express their thanks to Mr. H. Hofheimer of ELTEK Corporation, Larchmont NY, for his valuable assistance in preparing this paper.

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