EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN LEP-MA/89-38

VERY LOW-LOSS LIQUID HELIUM TRANSFER WITH LONG FLEXIBLE CRYOGENIC LINES

by

H. Blessing, Ph. Lebrun, K. Schippl*

Presented at Cryogenic Engineering Conference-
International Cryogenic Materials Conference, Los Angeles
24-28 July 1989

* kabelmetal electro GmbH, Hannover, F.R.G.

Geneva, Switzerland
July 1989

VERY LOW-LOSS LIQUID HELIUM TRANSFER WITH LONG FLEXIBLE CRYOGENIC LINES

H. Blessing, Ph. Lebrun, K. Schippl*

CERN, Geneva, Switzerland

*kabelmetal electro GmbH, Hannover, Federal Republic of Germany

ABSTRACT

The four underground areas of LEP, the large electron-positron collider now operating at CERN, are equipped with helium cryogenic plants continuously feeding superconducting magnets over distances of up to 92 m, with differences in elevation reaching 25 m. For this purpose, 500 m of vapour-shielded flexible cryogenic lines, of coaxial corrugated tube construction, have been manufactured in industry and performance tested in the laboratory prior to site installation. Several improvements in design with respect to earlier lines of similar construction, as well as systematic quality-control procedures, made it possible to achieve reproducibly linear heat inleaks of about 30 mW m^{-1} , in self-sustained vapour shielding operation. We describe the main design principles and constructional features of the lines, and report on methods and results of their performance tests.

INTRODUCTION

Transfer losses find their origin in several concomitant, yet independent processes, such as boiling of liquid by the residual heat inleak to the supply pipe, flashing due to isenthalpic expansion across the transfer pressure difference or cooldown of the vessels and transfer equipment. The occurrence and relative importance of these well-known phenomena are determined by the geometry, transferred quantities and operational requirements of the user device. In the case of devices operating in bath cryostats, with a small or moderate liquid cryogen consumption, helium economy tends to favour intermittent supply. This mode of operation, however, implies some drawbacks, among which

- the need for a sufficient buffer storage of liquid in the device cryostat resulting in a larger helium inventory,
- the periodic manipulation of transfer equipment and adjustment of control parameters by skilled operators,
- nonlinear response of any level control system due to increased vaporization upon restart of transfer and line cooldown,
- consequently, the upsetting of pressure and flow conditions in the cryostat, which is particularly annoying when the escaping cold vapour is further used for heat interception and thermal shielding.

When the transfer distances are large, the drawbacks of intermittent transfer may inhibit proper operation of the device; at best, the perturbations will result in long down-times, strongly affecting the device's availability and operational cost. In such a case, an efficient, continuous transfer system is required.

OPERATIONAL REQUIREMENTS

The LEP collider, which has recently started operation at CERN, provides four areas for high-energy physics experiments, located in deep underground caverns. In each area, two superconducting quadrupole magnets of high focusing strength[1], housed in liquid bath cryostats[2], require a continuously controlled supply of gaseous or liquid helium (for cooldown or normal operation, respectively) from a cryogenic plant installed at some distance in the cavern[3]. Eight transfer lines connect the magnets to the cryogenic plants, spanning over lengths ranging from 50 to 92 m, and across differences in elevation of up to 25 m [4]. The transfer lines must be flexible in order to make their installation possible along complex routing in an equipment-crowded environment, match tight installation schedules minimizing interference with other activities, and allow for occasional travel of the cold superconducting magnets without disconnecting the helium circuits.

In order to minimize the heat inleak to the liquid helium, both for reasons of economy and to achieve smooth two-phase flow (an essential condition for precise level control in the cryostats), the supply channels require integral thermal shielding over their entire length using the enthalpic content of the cold helium vapour escaping from the liquid baths, eventually recovered at ambient temperature. Besides the liquid transfer mode of operation, the supply and return channels have been dimensioned so as to provide sufficient hydraulic conductance for the forced flow of gaseous helium at gradually decreasing temperature used for magnet cooldown. Other requirements to be met by the lines include radiation resistance of constituent materials, as well as compliance to general safety rules, particularly those concerning pressurized pipe-lines and fire safety in underground areas.

DESIGN AND CONSTRUCTION

The transfer lines are based on the four-fold coaxial corrugated tube design, jointly developed more than a decade ago by CERN and kabelmetal[5]. Several hundred meters of such lines have been manufactured according to this design and satisfactorily operated at CERN since then[6,7].

Each line consists of four corrugated tubes, made of austenitic stainless steel and assembled coaxially (Fig. 1) to provide an inner channel for the supply of liquid or gaseous helium, an annular channel acting as a shield for the return of cold vapour, and a common vacuum enclosure for thermal insulation. A protective sheath of halogen-free, flame retardant metal-oxyde loaded copolymer is extruded around the outer corrugated tube. The main characteristics of these tubes are given in Table 1.

Solid conduction between the outer tube, return channel (shield) and supply pipe is limited by low-conductivity spacers made of four-strand braids of PTFE, helically wound around the tubes to ensure proper spacing with only occasional point contacts. The outer surface of the return channel is wrapped with 12 layers of a superinsulation tape made of double-aluminized polyester and polypropylene spacer material. In the previous lines, a stiffer solid polyethylene helical spacer was used in combination with a larger number of superinsulation layers, too densely

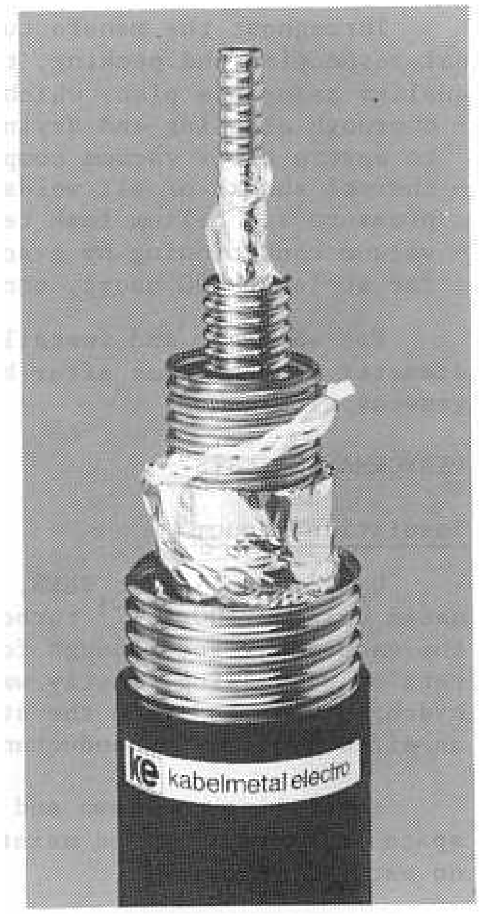


Fig. 1. Cross-section of a flexible transfer line showing the four corrugated stainless-steel pipes, helical braid spacers, metallized film insulation and external protective sheath.

packed and probably crushed upon bending of the lines, which eventually proved detrimental to thermal insulation.

Detailed analysis of the sources of residual heat inleak to the supply channel of earlier lines[6,7] revealed that radiation from the shield was the dominant contribution; consequently, any reduction in the effective emissivity of the stainless-steel surface of the corrugated tubes should result in an appreciable improvement in insulation performance. A measurement by boil-off calorimetry of the effective emissivity at 4.2 K, with respect to 290 K quasi-blackbody radiation, yielded a value of 0.19 for the bare corrugated tube; wrapping it with a foil of aluminium reduced this figure to 0.09. Following this result, the supply pipe of the lines was wrapped with 0.05 mm aluminium tape, held in place under the inner helical spacer.

Table 1. Main characteristics of the corrugated stainless-steel tubes

Tube No.	Inner diameter (mm)	Outer diameter (mm)	Wall thickness (mm)	Material
1	10	13	0.3	AISI 304L
2	21	25	0.3	AISI 304L
3	39	44	0.4	AISI 304L
4	60	66	0.5	AISI 304L
sheath	66	73	3.5	Polymer

Throughout the manufacturing sequence, from material reception to final inspection and packing, the transfer lines were subject to a detailed quality assurance plan, which included

- thorough cleaning and drying of the corrugated tubes and machined parts to ensure their vacuum compatibility,
- thermal shocks of all welds at liquid nitrogen temperature, followed by pressure and helium leak tests to better than 10^{-9} mbar l s^{-1},
- vacuum conditioning by evacuating the insulation space down to 10^{-6} mbar for at least 100 hours, concomitant with a bake-out at 100 °C.

For shipment and installation, the transfer lines were wound on 2.8 m diameter wooden drums after having their insulation spaces filled with dry gaseous nitrogen.

PERFORMANCE TESTS

Insulation vacuum

Upon reception at CERN, the insulation spaces of the lines were evacuated using a 100 l s^{-1} turbomolecular pumping unit. Within a few hours, the vacuum was good enough for efficient thermal insulation (Fig. 2). The rate of outgassing, mostly water vapour trapped in the superinsulation and hydrogen desorbed from the stainless-steel surfaces, permitted to estimate an effective vacuum conductance of 10 l s^{-1}.

After line cooldown and during liquid helium transfer, the insulation space is cryopumped and maintains a residual pressure below 10^{-6} mbar with no external pumping.

Figure 3 shows the pressure rise in the sealed insulation space for a period of one month following interruption of helium transfer. After an initial plateau, the pressure steadily rises with a rate of 8×10^{-7} mbar l s^{-1}. No trace of helium was found in the residual gas so that upon restart of operation, three months later, cryopumping restored excellent vacuum with no loss of insulation performance.

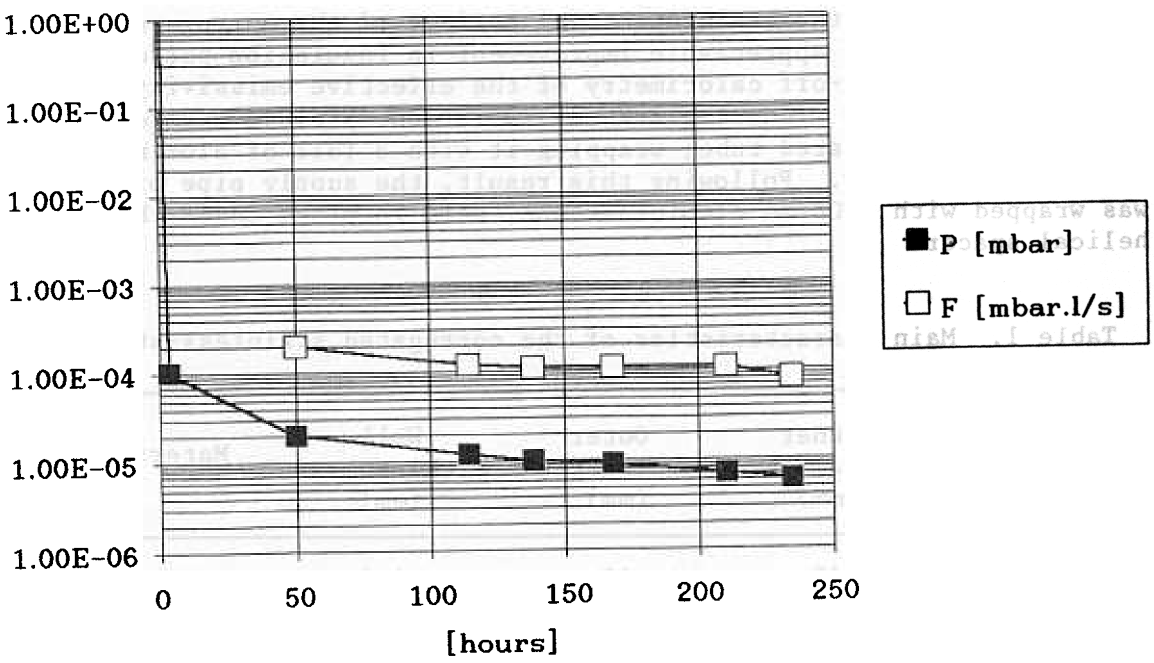


Fig. 2. Evacuation of insulation space of 54 m line
P = residual pressure
F = outgassing rate in insulation space.

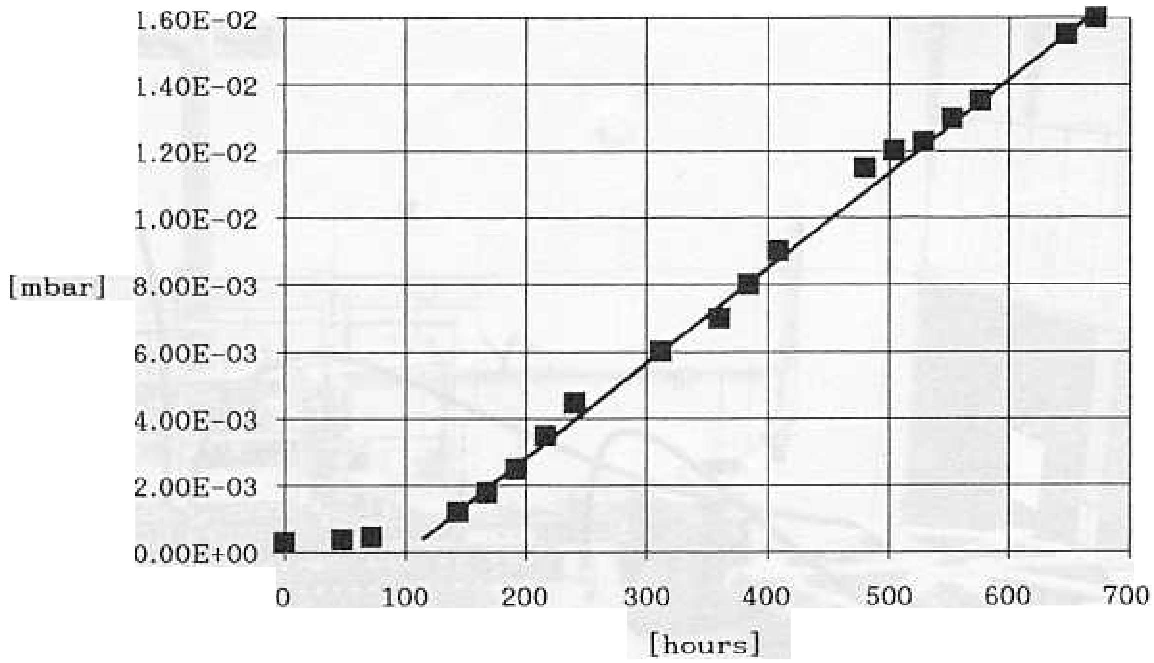


Fig. 3. Pressure rise in sealed insulation space of 54 m line following interruption of helium transfer.

Thermal performance

All eight transfer lines have undergone cryogenic tests and had their thermal performance measured in real operating conditions. For this purpose, the same method and test equipment were used as for earlier lines[5]: liquid helium was transferred through the line under test, from a buffer storage into a cryostat, in which the level was kept constant by vaporizing the liquid fraction remaining at the line outlet. The mass flow-rates out of the cryostat and through the line shield, as well as the heater power and screen outlet temperature, were monitored. Measurement runs were taken in quasi-steady conditions, established by controlling the transfer pressure difference. Major improvements on the test set-up concerned the automatic refill of the liquid buffer by a dedicated helium liquefier and automatic data acquisition every few seconds on a microcomputer controlling an IEEE-488 data bus. This permitted uninterrupted, unattended long-term operation and integration of physical variables, which proved essential to obtain precise and reproducible measurements despite the long thermal time constants and unavoidable pressure and flow oscillations in the system. After six to eight hours to establish steady conditions, a typical measurement run integrated data over two to three hours, during which the liquid level in the test cryostat was controlled within a few millimeters, while the temperature profile along the shield remained constant to a few degrees. A general view of the test set-up in operation is shown in Fig. 4.

The measured heat inleaks to the supply channel of the transfer lines are shown in Fig. 5 as a function of the shield cooling flow; the intersection of the experimental curve with the straight line indicates self-sustained vapour-shielding, i.e. the operating condition in which the heat inleak to the supply channel exactly generates the cold vapour flow returned in the thermal shield. In this mode, the measured heat inleaks, which also include a maximum of 0.3 W due to the test cryostat, are low; still, they can be further reduced if excess cold vapour, generated by the user device, is available to cool the shields to lower temperatures.

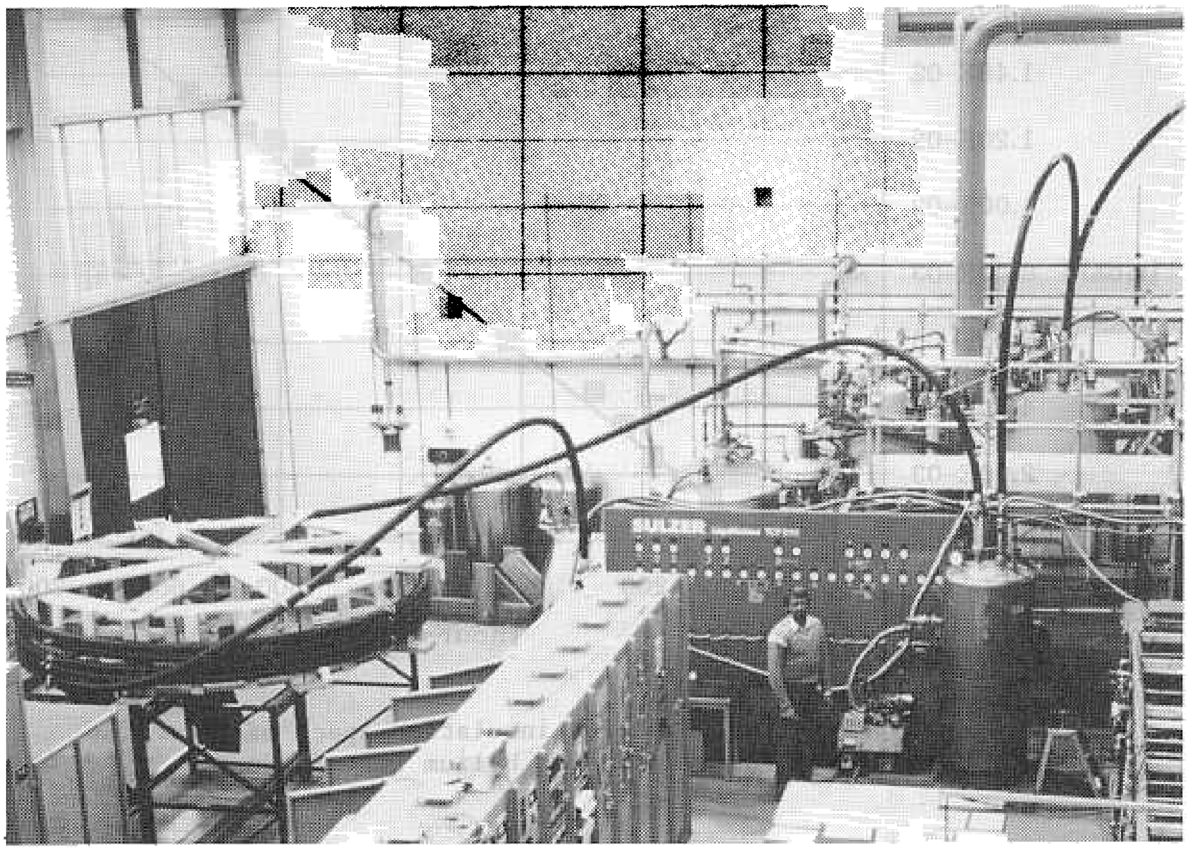
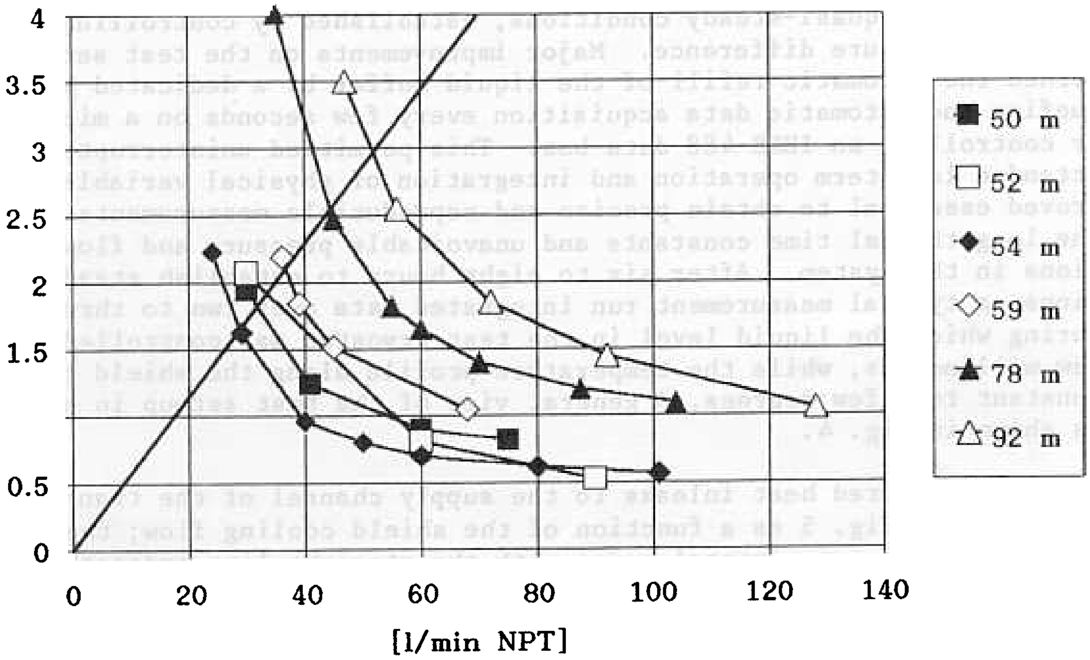


Fig. 4. General view of the transfer line test set-up at CERN

The heat inleaks to the return channel (shield) of the transfer lines appear in Fig. 6 and show a moderate dependence on the shield outlet temperature. Their absolute values are 30 to 40 times higher than those to the supply channels, demonstrating the efficiency of the vapour shielding.



5. Measured heat inleaks to supply channel of transfer lines vs. shield cooling flow; the straight line correspond to self-sustained vapour shielding.

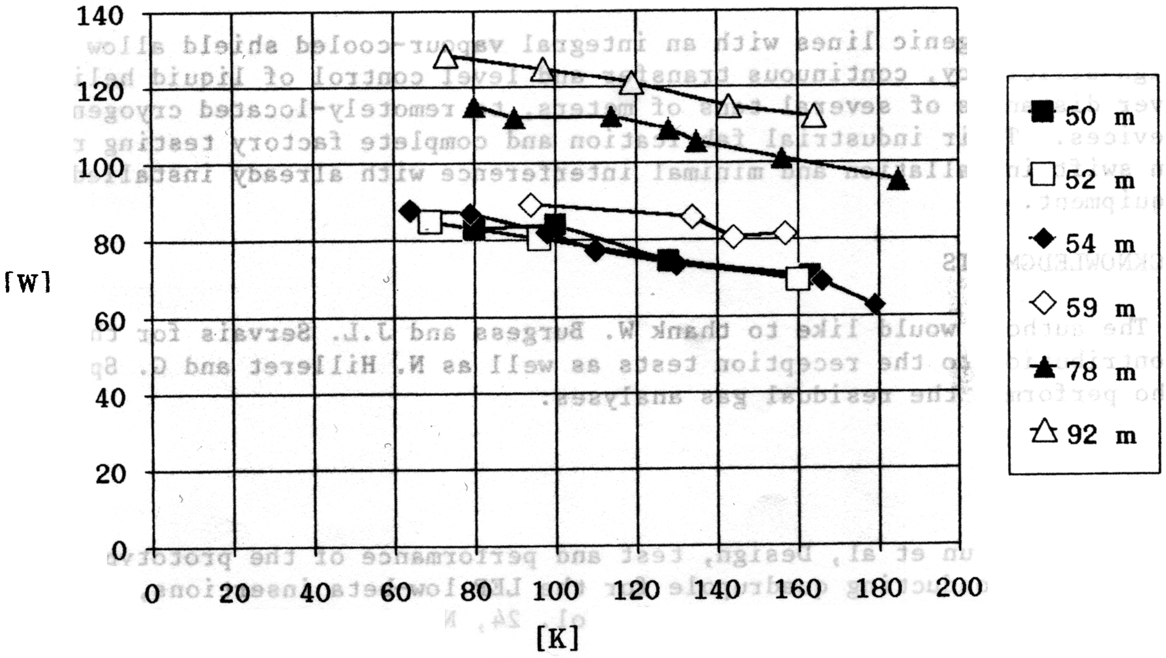


Fig. 6. Measured heat inleaks to return channel (shield) of transfer lines vs. outlet temperature.

The variations of the heat inleaks with length of the transfer lines are shown in Fig. 7 in self-sustained vapour shielding; the intercepts of the linear fits with the ordinate axis yields the lumped contribution of the terminations, while their slopes indicate the marginal heat inleaks per unit length. Typical values are 28 mW m^{-1} plus 0.4 W in the terminations for the supply channel, and 1 W m^{-1} plus 25 W in the terminations for the return channel (shield). In comparison with earlier lines[6,7], and scaling with transverse dimensions, this represents a two-fold increase in insulation, both on the supply and return channels.

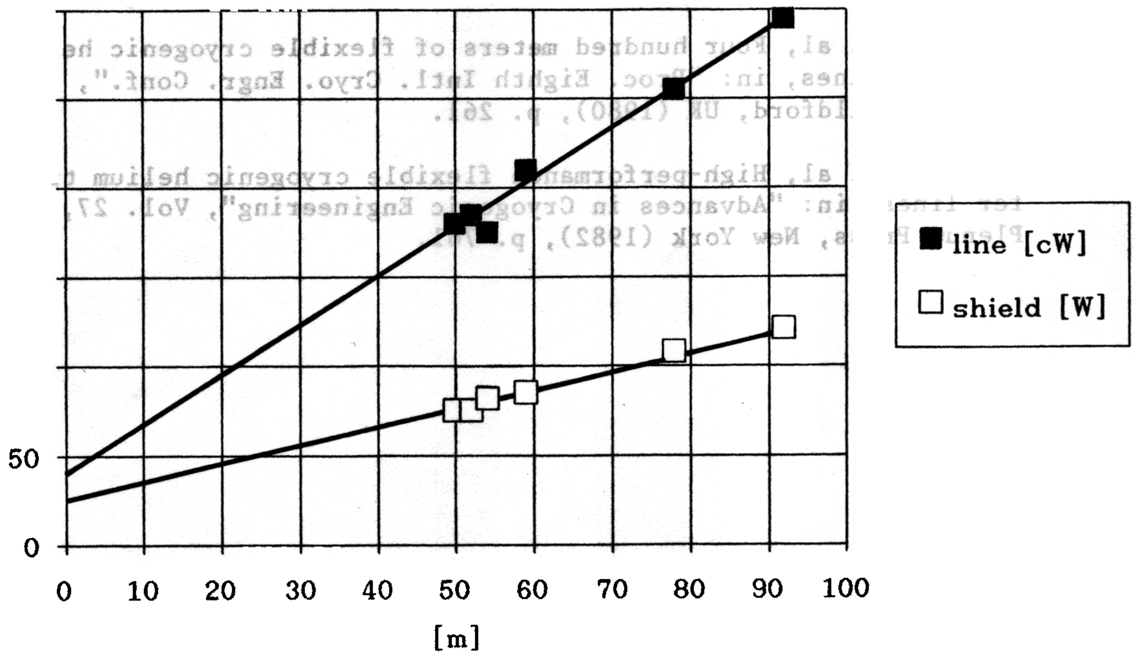


Fig. 7. Variations of heat inleaks with length of transfer lines.

CONCLUSION

Flexible cryogenic lines with an integral vapour-cooled shield allow high-efficiency, continuous transfer and level control of liquid helium over distances of several tens of meters, to remotely-located cryogenic devices. Their industrial fabrication and complete factory testing result in swift installation and minimal interference with already installed equipment.

ACKNOWLEDGMENTS

The authors would like to thank W. Burgess and J.L. Servais for their contribution to the reception tests as well as N. Hilleret and G. Speidel who performed the residual gas analyses.

REFERENCES

1. Ph. Lebrun et al, Design, test and performance of the prototype superconducting quadrupole for the LEP low-beta insertions, in: "IEEE Trans. on Magnetics", Vol. 24, No. 2, IEEE Magnetics Society (1988) p. 1361.

2. H. Blessing et al, Design, test and performance of the liquid helium cryostats for the LEP superconducting quadrupole magnets, in: "Proc. Twelfth Intl. Cryo. Engr. Conf.", Butterworth, Guildford, UK (1988), p. 112.

3. J.P. Dauvergne et al, Helium cryogenics at the LEP experimental areas, paper presented at this Conference.

4. H. Blessing et al, Controlled downward transfer of saturated liquid helium across large differences in elevation, in: "Proc. Twelfth Intl. Cryo. Engr. Conf.", Butterworth, Guildford, UK (1988), p. 222.

5. H. Laeger et al, Long flexible transfer lines for gaseous and liquid helium, in: "Cryogenics", Vol. 18 (1978), p. 659.

6. H. Blessing et al, Four hundred meters of flexible cryogenic helium transfer lines, in: "Proc. Eighth Intl. Cryo. Engr. Conf.", I.P.C., Guildford, UK (1980), p. 261.

   H. Blessing et al, High-performance flexible cryogenic helium transfer lines, in: "Advances in Cryogenic Engineering", Vol. 27, Plenum Press, New York (1982), p. 761.