DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, January 17, 2005

Note: **CR-1**

DAFNE Superconducting Compensator Magnets Commissioning. New flexible LHe Coaxial Transfer Line: a 4.4 K "auto" Screened Solution

G.O. Delle Monache

Abstract

The four DAFNE solenoid magnets, called "compensators" since their function is to "compensate the main solenoidal field of the magnet detector, (CMs) commissioning and the design of four innovative "coaxial auto shielded" Transfer Lines (TLs) for Liquid Helium (LHe) is analyzed in this technical note. The new TLs overcome the mismatch between the original TLs and the Joule Thomson valves (JT).

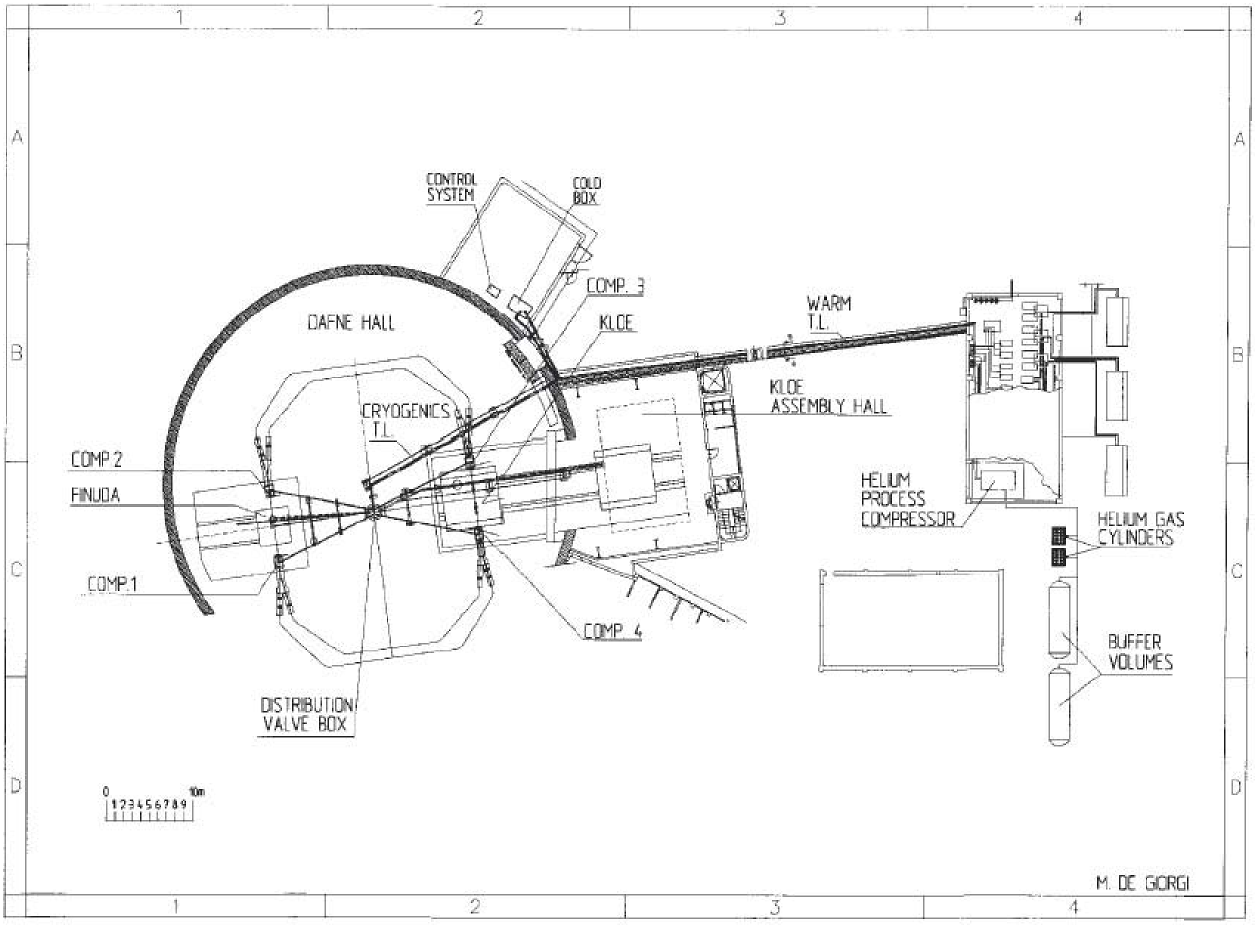

Figure 1: DAFNE cryogenic system lay-out.

General

The DAFNE accelerator is a e^+ e^- collider at 500 MeV. In the experimental zones six superconductive magnet are cooled down to 4.4 K @ 1.2 bar, they are:

- KLOE experiment magnet;
- Finuda experiment magnet;
- 4 “Compensator” magnets.

The CMs have to be energized in pairs to compensate the bunch rotation due to the solenoidal magnetic field of the detector magnet. Since the DAFNE optics doesn’t allow to operate contemporarily the two experiments, the CMs are energized two at a time.

The refrigerator plant is a LINDE TCF 50 with a nominal compressor power of 250 kW, which deliver two cold He lines:

- 4.4 K @ 3.0 bar (100 W nominal power + 1.14 g/s LHe);
- 77 K @ 10 bar (900 W nominal power).

The cold transfer lines are collected in the Valve Box (VB) and then to each magnet with dedicated TLs.

The two detector magnets are similar with respect to their cryogenic lay-out. Separate lines for 4.4 K and 77 K supply He to respectively to the superconducting coil and to the shields in a continuous filling mode.

Only the 4.4 K He is supplied to the compensator magnet in a discontinuous filling mode. The shields are cooled by LHe evaporated from the coil itself.

The cold gas from the magnet is warmed in a natural convection evaporator up to 300 K before coming back to the compressor. Thus, the cryogenic load is a pure liquefaction one.

The CMs are derived by standard NMR apparata produced by Oxford Instruments (OI). Usually this magnets are filled with liquid He from Dewar and run in a *persistent mode*. For DAFNE, these magnets have been modified adding a JT valve inserted in the magnet turret.

Compensators first cool down

Due to the short available time to install the cryogenic plant in the 1996, only the KLOE magnet was commissioned by means of the cryogenic plant at that time[1].

The compensator TLs were tested without having been connected to the CMs. Only the cryogenic power of the plant was tested, connecting one TL to a Dewar with a heater inside.

After the tests in 1997 the TCF 50 was put temporary out of order, because the initial running modality of the accelerator did not contemplate superconducting magnets.

In February 1999, after the roll in of the KLOE experiment, the CMs and the TLs were finally installed.

The procedure provided by the manufacturer for the cool down of such small magnets is really simple, since due to their small dimensions there is no risk for the coil and shields to undergo to critical temperature gradient during the cool down.

The JT can be opened at 100% (3 turns of the needle) from the beginning of the cool down [2]; The cold gas is diverted initially to the bottom part of the magnet by the top/bottom valve (T/B) (put in series with the JT).

When the coil temperature sensor is approaching 10 K, the T/B is set to “top” position to start collecting liquid in the turret [3].

After 2 days of attempts, the maximum level collected in the turret was 40%. This was not evidence of the presence of some liquid in the magnet, but just the effect of the level probe cooling [4]. Several tricks were tryed to fill the CM.

First of all the JT was opened to more than 100% (up to 370%).

Then, we try to fill the magnet by holding the by pass flow regulating valve (for the TL cool down) opened during the filling of the magnet. This to lower the temperature before the JT and try to obtain more favorauble thermodinamcs condition for the iso hentalpic expansion.

All the attempts to fill the magnets failed, and in the meantime the CMs were the last magnets to be switched on to let the DAFNE accelerator running.

For this reason the decision to fill the CMs by Dewar with LHe was taken has last chance, wasting gas in the atmosphere.

CM/TL tests

During the DAFNE accelerator runs the CMs and the TLs were no longer accessible. The main problem to understand the situation came from the lack of sensors in the He line.

No temperature and pressure sensor had been foreseen before the JT, and the temperature sensor in the by-pass was set by OI just to give an idea about the TL cool down, and not to accurately measure the temperature in the line.

With P $\cong$ 3 bar if the temperature exceeds 6 K the liquid fraction after the JT expansion is null (Figure 2).

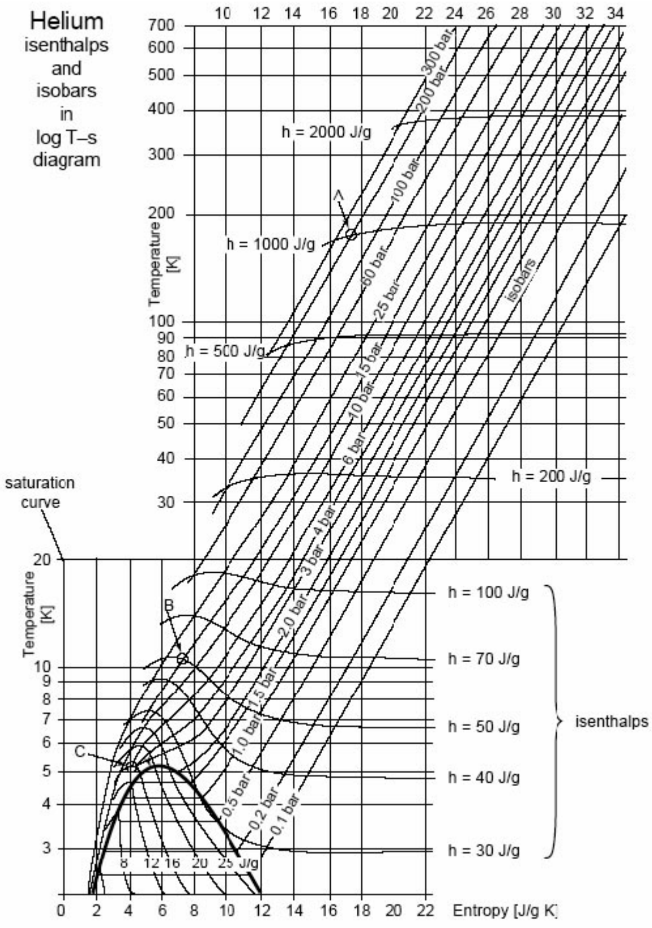

Figure 2: Helium T-S diagram

Figure 3 represents the liquid fraction obtained with a JT expansion from 3.0 to 1.2 bar vs. the initial temperature calculated with the Hepak® software.

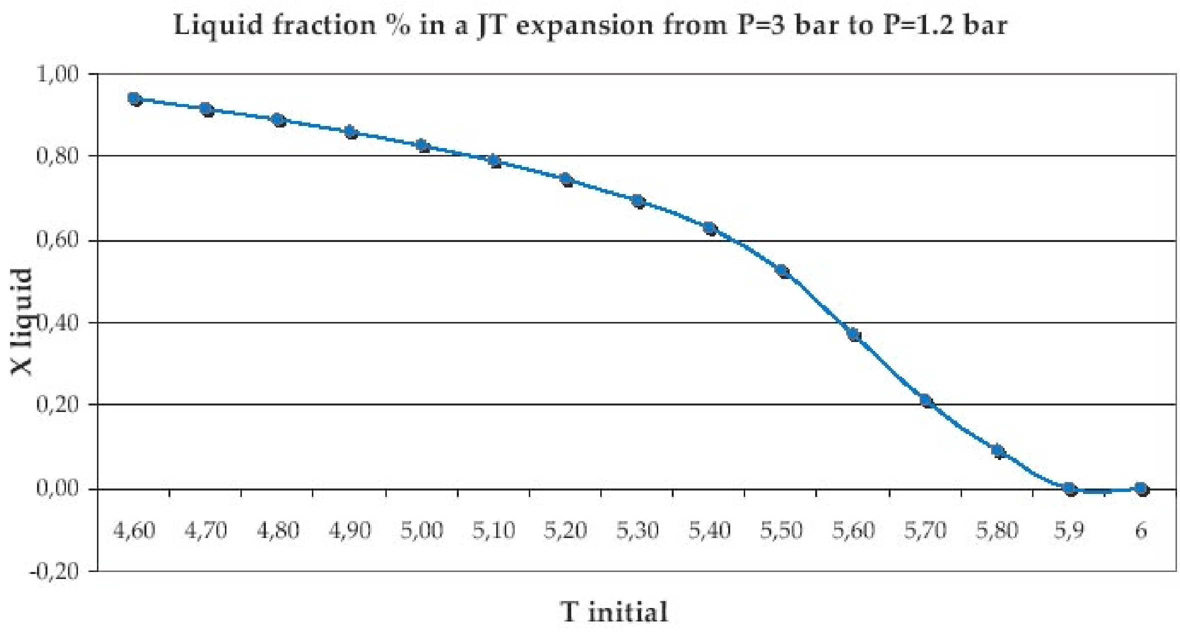

Figure 3: JT expansion efficiency vs. initial temperature

It can be seen that above 5.8 K the expansion does not produce any liquid and, in situations like this a tenth of degree can play a big differences.

In May 1999 during the first accelerator shut-down, a measurement campaign was performed with the aim of checking:

- Temperature before the JT;
- He flow in the JT.

A new calibrated temperature sensor was assembled in the by-pass element, directly immersed in the He line. As requested by Vacuum Specials (the TL builder), a procedure for a new outgassing of the TLs was performed despite the huge problems it causes due to the fact that the TLs were already installed. After many days and a new in house developed procedure the vacuum improved from $5x10^{-3}$ mbar to $2x10^{-5}$ mbar [5]. The measurement set up was as follows:

- Temperature sensor (T6): Fe-Rh 27 Ω N° 9216 OI calibration certificate 32110;
- Multimeter: HP3457 A. (1 mA);
- Evaporator: 2 Copper coils D_{in}=20 mm L=11m $R_{curvature}$=0.5m;
- Gas counter: ASTRA Q 25 (Q_{range}=4-40 m^3/h).

The new temperature sensor was previously calibrated by OI by using LHe and LN2. The tests gave the following results:

- Helium test: T=6.9 K;
- Nitrogen test: T=77.7 K.

The discrepancy with the He test (2.5 K offset with the expected value) was due to some heat leak, unavoidable [4].

The main results of the three days tests are reported in Table 1.

Table 1: CM N°2 test report.

Time	JT (%)	Sensor resistance (Ω)	T6 (K)	T6 - offset (K)	Counter (m3/h)	Flow (g/s)	T coil (K)	He level (%)	Notes
16:00	130	2.73	7.6	5.1	2935.8		8.6	0	15 May
16:35	130	2.71	7.4	5.1	2944.6	**0.81**	8.1	0	
16:45	165	2.62	6.6	4.1	2957.4		7.3	0	
17:45	165	2.64	6.8	4.3	2966.9	**1.03**	7.2	0	
17:50	100	2.72	7.5	5.0	2968.0	**0.63**	7.4	0	**By pass open**
18:20	100	2.90	9.5	7.0	2974.0	**1.07**	12.6	**42.7**	By pass close
22:00	100	3.42	17.4		3048.1		X		
6:00	100	3.46	18.2		**3052.9**	**N/A**	25.1		
10:30	100	3.59	20.9		**3052.9**	**N/A**	27.7		**Flow<0.2 g/s**

Several attempts were made, checking many JT intermediate positions without success. There was evidence that opening the JT to more than 100 % the isohentalpic behaviour, as previously tested by OI, was lost [2].

OI declared that 1 g/s was the optimum filling flow for the CM filling, but the tests demonstrated that the JT maximum flow was less than 0.2 g/s. With the JT opened 100 % k_v= 0.09 [2]; Since

$$K_v = \frac{Q}{259 * P_{up}} \sqrt{\frac{T_{up}}{\rho_g}}$$

With T_{up}=5.4 K and P_{up}=3 bar the nominal flow is: Q=0.83 g/s.

This value does not take into account the hydraulic losses due to the very small pipes (D_{in}=1 mm L= 500 mm) which bring the He from the JT to the Coil vessel.

Probably with the JT opened 100 % the flow will vanish due to the fact that the specific volume v_s increases about four times within few degrees, thus leading to high hydraulic losses (Table 2).

Even if Linde (the refrigerator builder) declared that 1.5 g/s flow was available from the refrigerator there was no way to match the TL and JT since the valve needle was not adaptable.

Table 2: He specific volume (from NIST Chemical book).

P = 3.0 bar	
T (K)	v_s (m^3/kg)
5.4	0.010
5.8	0.019
6.2	0.027
6.6	0.032
7.0	0.037

The temperature at the end of the TL vs. He flow is shown in Figure 4 (calculation made with Hepak®). The three curves relate to three different values of heat losses.

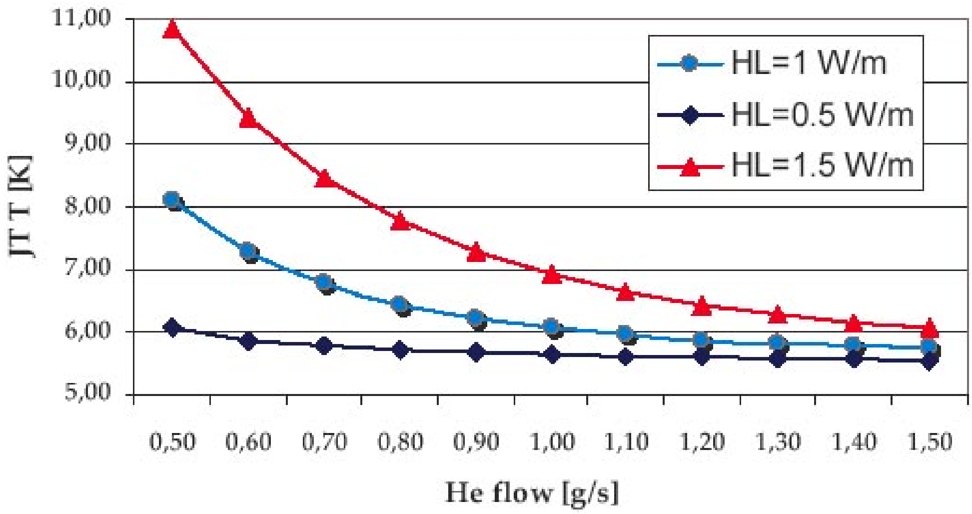

Figure 4: JT temperature vs. He flow.

Linde declared that the nominal heat losses of the TLs was 0.5 W/m, but for such TL geometry a value between 0.5 and 1.0 W/m is more likely.

Solving the problem

Just during the CM N°2 test, the CM N°4 showed a loss in the insulation vacuum coming from the He vessel (*cold leak*) not manageable with a continuous pumping. OI was immediately contacted to repair the CM.

While hardly arranging the shipment of CM N°4, in January 2000, CM N° 3 was found to have the He circuit completely blocked.

Even with the chance of solving the problem by changing the JT of the two magnets, we take into consideration the possibility to change the TLs by installing new ones having lower heat losses.

TLs with lower heat losses can be made even with the same technology (coaxial single line) just improving the design (optimization of geometry, super insulation layer and spacers), but the best performances are obtained with the shielded TLs.

In this type of TLs the inner line for the 4.4 K is shielded from the room temperature by an intermediate screen usually cooled by liquid Nitrogen (LN2). In this configuration the heat loss due to the ambient radiation drops theoretically by a factor 100 [6].

<u>The modification of the 4 DAFNE CMs TLs with the LN2 cooled shield ones would have implied important modification in the cryogenic system lay out</u>, including a new valve box for the LN2 and a tank for liquid storage; moreover the chance to modify the JT valves was acting as deterrent for such big modification.

<u>Since the modification of the two CMs was going on with many difficulties and taking a repairing time much longer that what was foreseen (18 months at the end of the story!) we decided to change the He TLs.</u>

The objective was to find a solution without using LN2 for shield cooling, since there were not the conditions to install such system due to time constrains.

An innovative flexible “auto” cooling screened TLs was then developed in collaboration with Nexans Deutschland Industries GmH & Co. KG, located in Hannover, which produces a series of flexible TLs named Cryoflex®.

The innovation was in investigating the possibility of taking advantage of the surplus of liquified He by the Linde refrigerator, and use it to cool the TL <u>without any modification on the VB or in the magnets.</u>

The TL adopted cross section is the "CERN type" shown in Figure 5; the main scheme is shown in Figure 6.

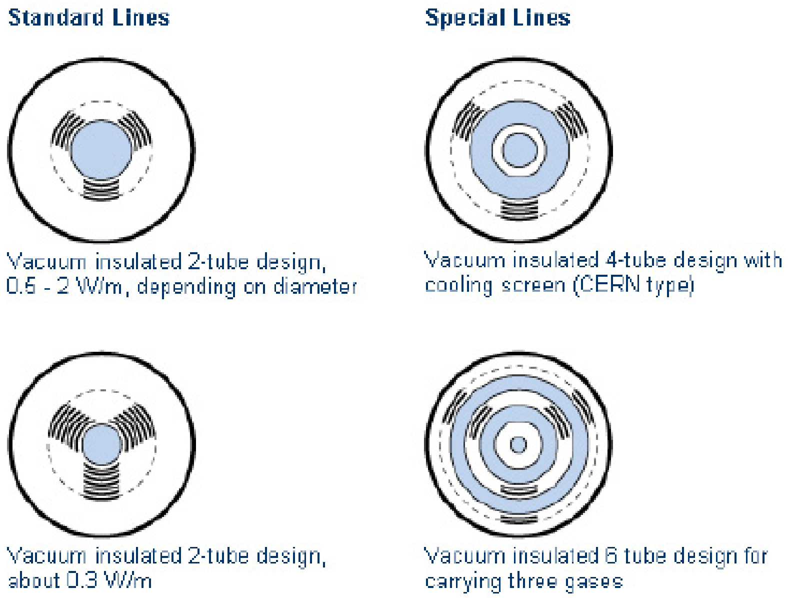

Figure 5: Nexans Cryoflex® transfer lines layout (from Nexans Cryoflex® brochure).

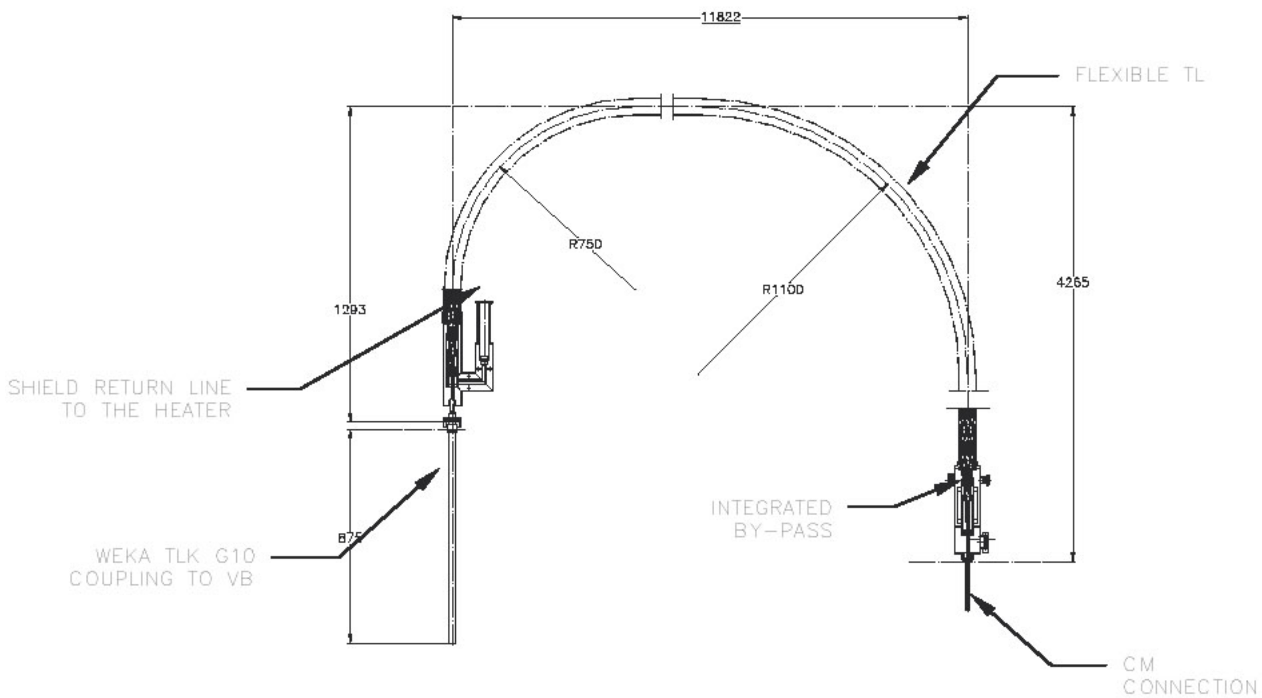

Figure 6: TL Assembly.

The TL is connected to the VB by means of a Weka TLK G10. The He is supplied through the TL to the CM that is connected by means of a OI standard coupling.

Before entering the magnet an integrated by-pass diverts a part of the flow (controlled by a valve in the warm side); this part of the flow returns to the VB via the shields, cooling them (see Figure 7).

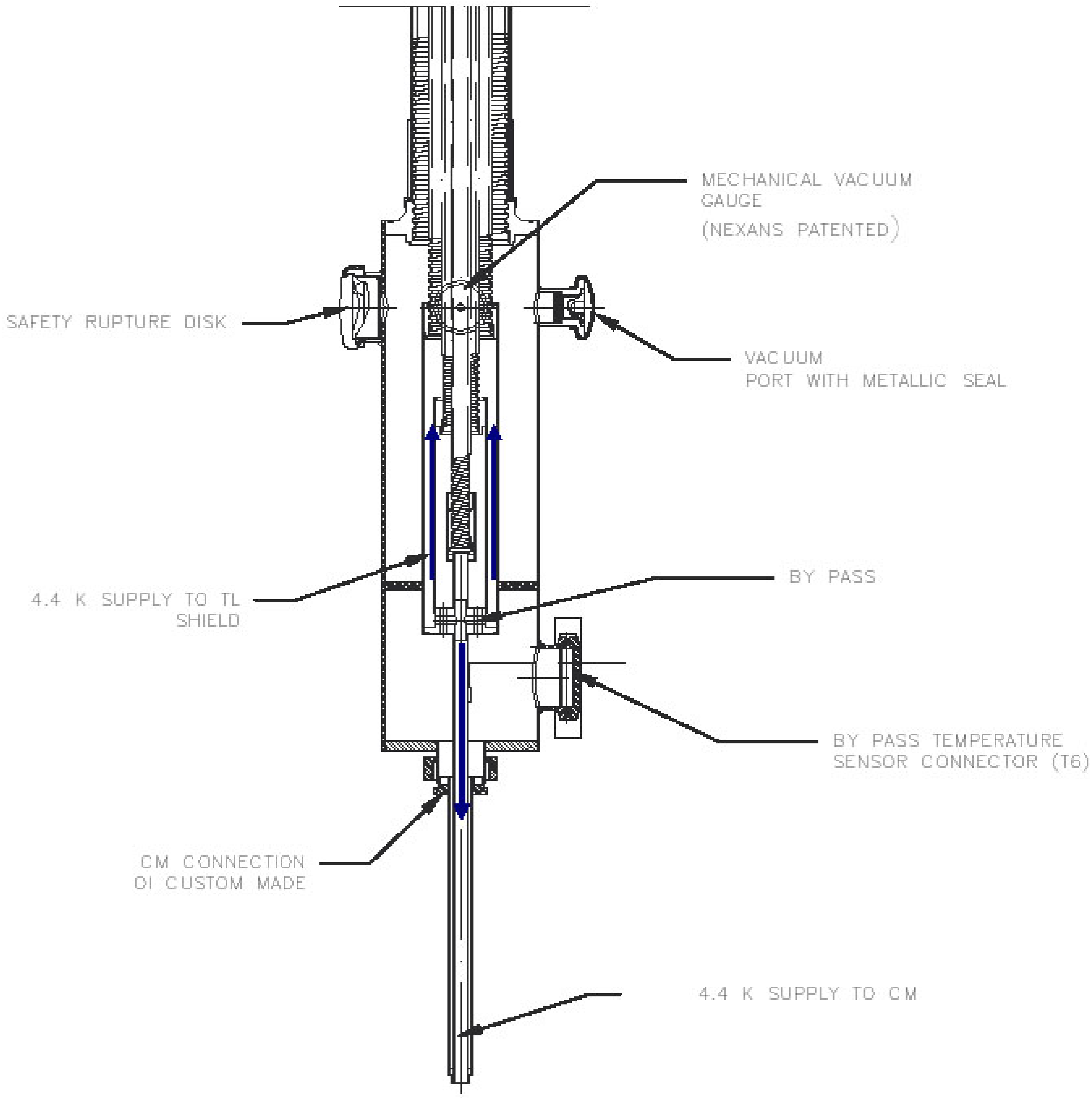

Figure 7: TL terminal to the CM.

The integrated by-pass avoid one cryogenic connection if compared with the previous solution, and then some heat losses, which can be estimated in about 1 W.

On the VB side (Figure 8) the shielding He return is taken out of the cold circuit by means of a short transfer line and it is supplied to a heater which warms it up to the ambient temperature before returning it in the plant low pressure line (LP).

With such a solution, considering a flow in the shield of 0.5 g/s, the nominal heat losses of the TL are 40 mW/m.

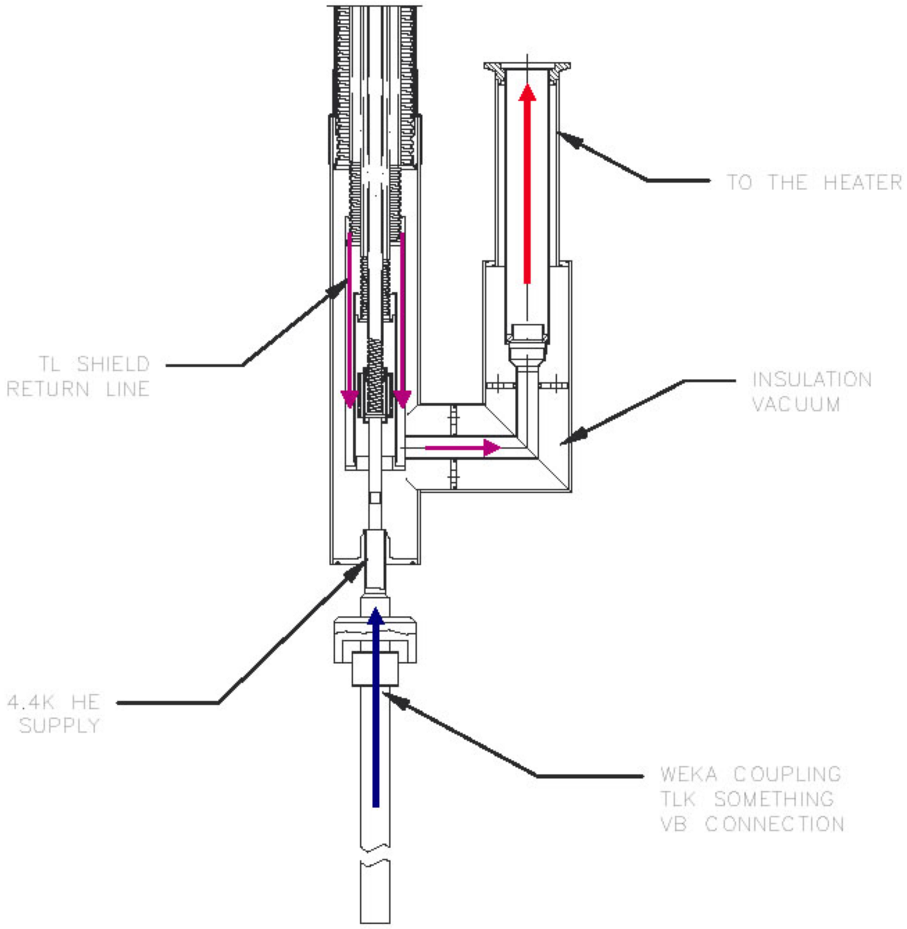

Figure 8: TL terminal to the VB.

Figure 9 shows that with this type of TLs the 4.4 K He supply flow can be of the order of few tenth of g/s to obtain a temperature at the JT upstream of around 5.4 K.

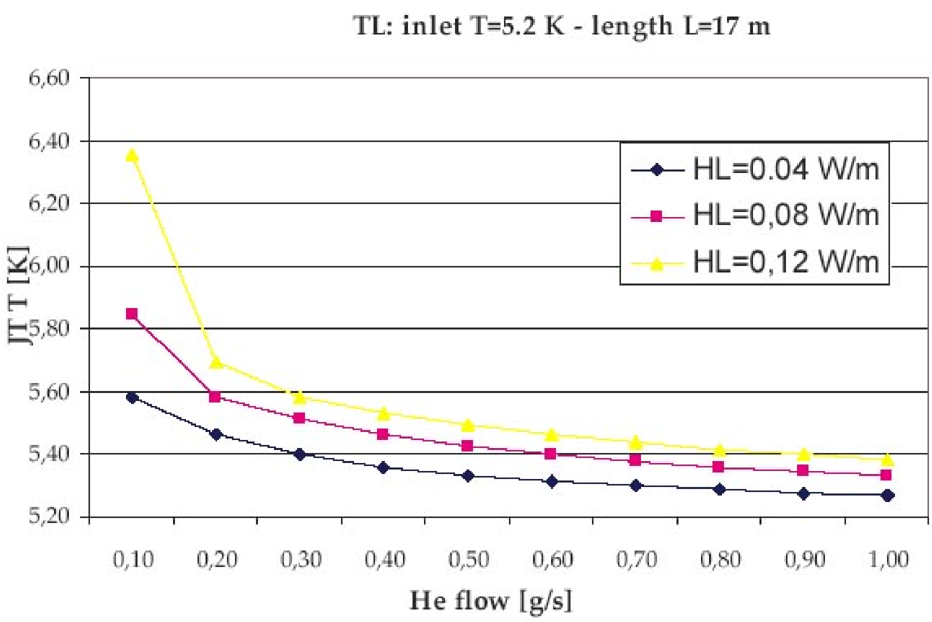

Figure 9: JT temperature vs. He flow.

Transfer line installation and operation

The 4 TL arrived completely assembled on January 2002 preformed with the two curved sectors.

Their installation was not so easy since the accelerator was running and the available time was very short.

The four CMs (two with JT modified) were installed and an attempt to cool down and fill the 2 KLOE CMs with the original JT was done.

The results were successful; all the four CMs are now filled with the refrigerator plant as it was foreseen in the beginning.

Some modifications have been made to the valves that control the flow in the shield of the TL and to the JT valves of the modified CMs to make everything fit with the refrigerator.

Conclusions

The installation of the new TLs allows saving about 500 l/week of LHe for each pair CMs when cooled and energised. This correspond to a value of about 10.000 €/week (2004 He cost).

Acknowledgments

The author wishes to thank Sergio Bertolucci and Claudio Sanelli for the continuous support in searching and finding a solution.

The author wishes to thank Riccardo Ceccarelli for the support in the TLs system final design.

The author wishes to thank Carlo Ligi for the support in developing the TL system and CMs control software.

The author wishes to thank Giuseppe Ceccarelli Maurizio De Giorgi, Michele Di Virgilio, Giuliano Ermini, Claudio Marini, Enrico Passarelli for the support in the TLs installation.

References

[1] R. Ceccarelli, M. De Giorgi, M. Modena "*Installazione e commissioning dell'impianto criogenico di DAFNE*", INFN-LNF DAFNE Technical note DI 14.

[2] E. Ambrose "*K_v value for a standard Oxford Instruments needle valve and other valve size formulas*", Oxford Instruments engineering note, 1999.

[3] Oxford Instruments "*DAFNE Compensator Magnets operation handbook*".

[4] Simon Mitchinson (Oxford Instruments), private communication.

[5] R. Ceccarelli, M. De Giorgi, G.O. Delle Monache, G. Ermini, E. Passarelli "*Misure di flusso e temperatura del Ghe nella TL del Compensatore N°2*", INFN-LNF DAFNE Technical note ME 11 (2000).

[6] F. Kreith, M.S. Bohn "*Principles of Heat Transfer*" New York: Harper & Row Publisher, 1986.