5kW RF power coupling line developments

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Abstract : A first 5kW power coaxial coupling line has been developed for the 5–cells cavities of the Saclay superconducting linear accelerator prototype (MACSE). RF power tests have shown anomalous heating due to a quench in the Niobium part for a power level less than 1kW. Consequently, an improved version with a more efficient cooling of the Niobium part, in order to increase the thermal breakdown limit, will be mounted on the next 3–cells cavities of a new cryostat. In the same time, a new design with an inner conductor cooled only at 77K is under study and will be tested in a slightly modified cryostat. Preliminary theoretical results are promising in view of the LHe power consumption as well as the power handling capability.

Power Coupling Line #1

A schematic drawing of the first coupling line mounted on the 5–cells cavities of the MACSE cryostats is shown in fig. 1. The cooling of the inner conductor should be ensured by three sapphire windows : two vacuum tight windows at LHe temperature and room temperature, and the third one connected to the LN_2 shield.

In order to reduce the heat conduction, thin copper plated stainless steel conductors were used between the warm part and the 77K fixed point, in addition to a choke coupling providing a thermal insulation between the 77K point and the cold part of the line. When maintained in the s.c. state, this cold part should have given a minimal heat load at 2K.

MACSE RF power tests showed a thermal breakdown when the input power is above a critical level (about 1kW) leading to excessive dissipation into the LHe bath. RF losses in the sapphire/niobium brazings were found to be the only plausible anomalous heating source. Calculations can explain this phenomenon (Ref. 1) taken into account the RF resistance of brazings ($\rho \simeq 15\,\mu\Omega.cm$). Moreover, the sapphire lays at a point where the dielectric losses are minimal, i.e. where the current circulating in the brazings is maximal.

From this analysis, some advices can be given in order to increase the quench limit of this line :

—Put the ceramic at a current node.

—Rise the diameter of the inner conductor in the s.c. part.

—Get a better thermal conductivity by using a Niobium with greater RRR, or, which is the best, a superconductor deposited on a good thermal conductor (e.g. Nb/Cu).

Another problem encountered was the relatively high RF losses, even when the input power was below the thermal breakdown input power level. The measured dissipation into the LHe bath due to the coupling line is about 2% of incident RF power. Though the source of anomalous losses is still under investigations, the choke is suspected to be the dissipative element either by RF radiation or by dielectric losses into the centering disc.

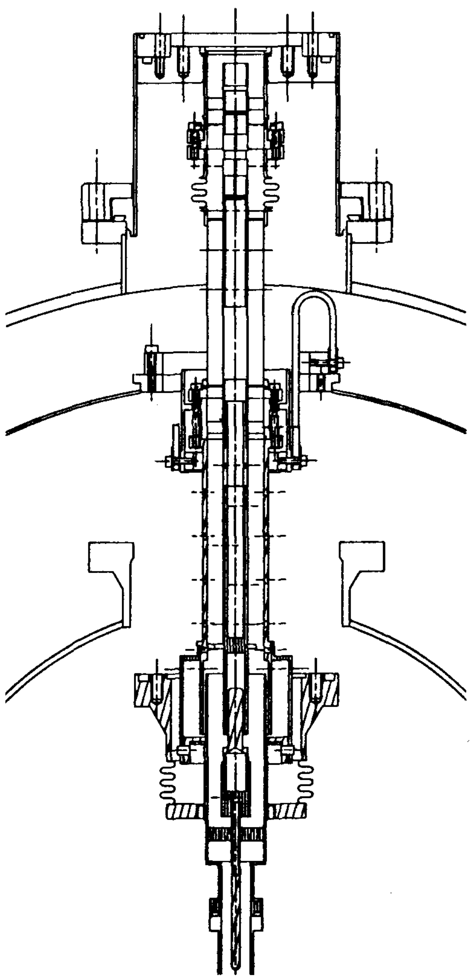

Fig.1 : Line #1 mounted in the cryostat

Power Coupling Line #2

Because of the two main problems encountered in the superconducting part of the coupling line #1 (vacuum leaks after one or several cool-downs of the lower sapphire window and bad cooling of the inner conductor due to RF losses in the sapphire/niobium brazings), the necessary elements for the tightness and the cooling of the inner conductor have been treated independently :

— More efficient cooling with a LHe circulation inside the inner conductor (fig.2), particularly close to the ceramic/niobium brazing.

— Use of an Alumina in place of the sapphire (the thermal conductivity of the sapphire is no longer necessary).

To avoid high current values, there is a local matching of the two stubs and the Alumina ; the length of the 50Ω line between the cavity and the lower stub has been optimized to obtain a current node close to the Alumina location (Ref. 2).

The upper part of this new coupling line is unchanged, excepted for the introduction of a coaxial-T at the LN_2–point.

The power handling limitation is strongly dependent on the heat transfer between Niobium and Lhe bath ; this value can vary from 1 to 10W/cm^2 depending on the surface state of the Niobium, which corresponds to a power handling limitation between 3.5 to 35kW. With theoretical calculations for a RF power of 2kW short circuited, the LHe consumption is less than 0.5W, mainly due to brazings.

This new line will be tested and mounted on the 3–cells s.c. cavities in a new cryostat.

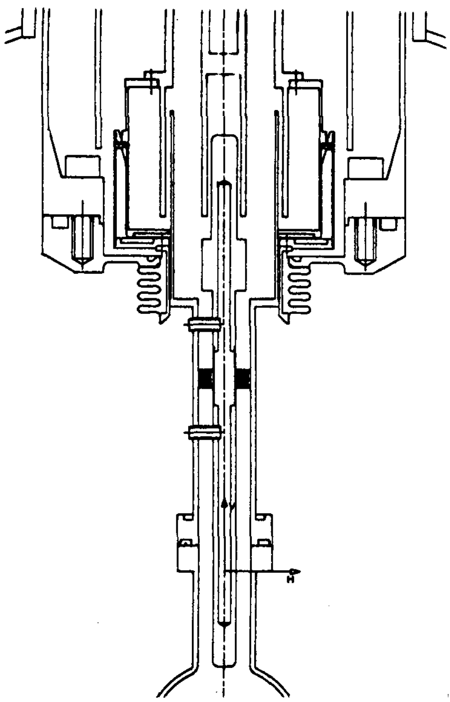

Fig. 2 : Cold part of line#2

77K-cooled Coupling Line

Obviously, the most important problems during the realization are coming from the niobium part (ceramic/Nb brazings, choke, stubs). For this reason, a version without cooling the inner conductor at LHe temperature (as in Ref.3) is under investigation.

In this version, the two fixed temperature points of 77K and 300K still remain for the inner —via vacuum tight windows— as well as the outer conductor, whereas the LHe temperature point only exists for the latter.

The main parts of this line shown in fig.3 are :

—A 300K-vacuum tight window (close to the WG/Coaxial transition) with a locally matched impedance.

—A copper plated (10 μm) stainless steel (0.2 mm) : Optimisation of length and position of this section gives a low heat flow from 300K to the cold parts (see table further on).

—A 77K-vacuum tight window : The distance to the cavity has to be small enough to avoid high temperature on the antenna tip.

—A bulk copper ending in the coupling antenna : The impedance of this part, in order to minimize the antenna temperature, is 30Ω and an impedance transformation is made (including the 77K window) to reach the 50Ω impedance.

The outer conductor is mainly composed of the two copper plated stainless steel tubes (beween 300K and 77K and between 77K and LHe), and if we except the Nb cavity coupling port, the entire line is OFHC copper made.

In the following table, we report some results of theorical calculations concerning the thermal characteristics of this line, namely the heat flux at source points and the temperature at the tip of the coupling antenna.

Pin s.c.	LHe losses	LN_2 losses	T tip antenna
0.0 kW	0.5 W	1.4 W	77.1 K
2.5 kW	1.1 W	10.4 W	80.2 K
5.0 kW	1.9 W	19.7 W	83.7 K

A good cooling at 77K is necessary ; for this reason, a slight modification of the cryostat in which this line will be mounted is needed in order to have a LN_2 intake close to 77K-window.

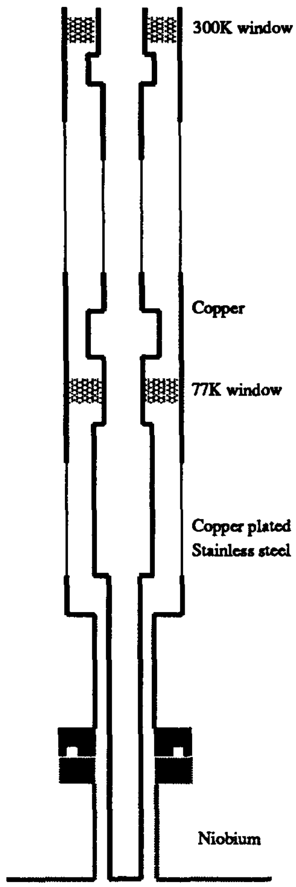

Fig.3 : 77K-line scheme

Conclusion

The running with the first coaxial lines has shown thermal breakdown for power levels between 600W and 2kW. By modifying only the cold part of this line in order to have a better LHe cooling, the power handling capability will be increased up to at least 4kW.

A 77K—cooled coupling line is under investigation. Because this line does not need a LHe-cooling of the inner conductor, the realization is simplier and the reliability should be better. Calculations shows reasonable LHe losses, and by modifying some actual constraints, the LHe consumption could be lowered significantly. This 77K-line will be tested in a modified cryostat. If tests are satisfactory, a new 77K-line will be designed to be mounted on a new cavity-cryostat assembly (coupler outside of the LHe tank). Though it is earlier to give specifications, we think this new line should be used for a c.w. power level up to 10kW, but more advanced calculations and tests are necessary to improve his running for Pin=200kW and a duty cycle of 1%.

References :

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