

## DESIGN OF A MAGNETIC SHIELD INTERNAL TO THE HELIUM TANK OF SRF CAVITIES\*

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### Abstract

The TRASCO elliptical cavities for intermediate velocity protons ( $\beta=0.47$ ) employ a coaxial cold tuner of the blade type. To meet the performance goals of the 700 MHz cavities in the foreseen horizontal cryostat tests, the cavities are being equipped with a magnetic shield which lies internally to the cavity helium vessel and has a simple mechanical design and assembly procedure.

### THE TRASCO CAVITY AND COAXIAL TUNING SYSTEM

As part of the TRASCO program in the past years two multicell superconducting cavities of the elliptical type have been designed, build and extensively tested for the design of an ADS system based on a superconducting linac [1]. Both cavities (shown in Figure 1) outreached the nominal specifications (8.5 MV/m of accelerating field at a Q value  $> 5 \cdot 10^9$ ) with a considerable operational margin. Table 1 resumes the cavity design parameters.



Figure 1: The bare TRASCO cavity.

The cavities have been vertically tested at TJNAF and Saclay [2] and reached peak electric and magnetic fields of 61 MV/m and 100 mT with performances similar to the standard TTF cavities production. In both tests the cavity performance was limited by field emission at high fields, and considering the peak electric field on the surface, the performance limits were compatible with a BCP treated TESLA cavity shape in the 25-30 MV/m range.

A “blade” tuner, derived from the one successfully tested in the TTF and proposed for the ILC linac, has been developed and fabricated for the two cavities [3] (Figure 2). This coaxial device will allow both a slow and a fast piezo-assisted tuning action for dynamic compensation of the Lorentz force detuning in pulsed operation.

The two completely equipped cavities will be tested under operating conditions in the EUROTRANS and CARE/HIPPI programs of the 6<sup>th</sup> FP of the EC in the near future. One cavity will be tested for high power pulsed

operation for Lorentz Force Detuning compensation experiments in CRYHOLAB and the second will be tested in high power CW operation and microphonics control in a prototypical cryomodule for ADS activities.

In both the experimental conditions foreseen for the cavities, the earth magnetic field needs to be shielded efficiently from the niobium cavity surfaces in order not to increase the surface resistivity due to magnetic field trapping and limit the cavity performances.



Figure 2: The He-tank and tuner assembly.

### THE INNER MAGNETIC SHIELD

The coaxial tuner is located outside the cavity He tank, thus a solution based on an external shield enclosing the cavity-tuner assembly would result in a large size for the shell enclosure needed for shielding, imposing relevant clearance constraints and limiting access to the tuner mechanical components. For these reasons, we choose to use a magnetic shield located internally to the cavity He tank, in order to limit the amount of expensive CRYOPERM material and provide simple and effective design and assembly procedures.

#### Required shielding factor

The wall losses on the cavity surfaces are determined by the surface resistance, which has contributions arising from several physical phenomena:

$$R_{surf} = R_{BCS}(v, T) + R_{res} + R_{mag}(H_{ext}) \quad (1)$$

The first fundamental term comes ( $R_{BCS}$ ) from the BCS theory and depends on the temperature and to the square on the RF frequency [4]. At 704.4 MHz and 2 K operation the BCS term accounts for a contribution of 3.2 n $\Omega$ .

The second term, the residual resistance, is related to the technology of the cavity fabrication and treatment processes and can arise from various sources (foreign material inclusions during fabrication, residues of chemical etching, condensed gases, ...).

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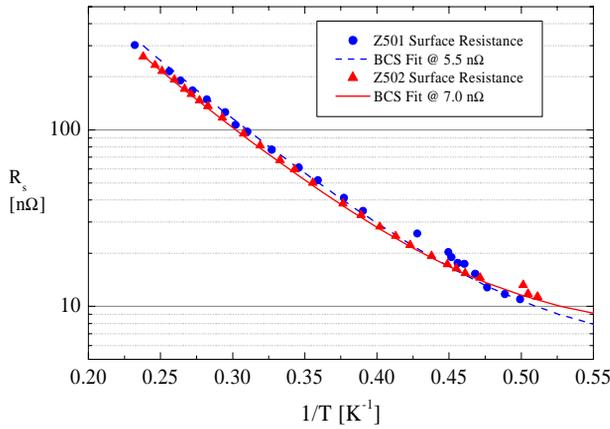


Figure 3:  $R_s$  values from RF measurements.

Figure 3 shows the comparison of the surface resistance estimations derived from the vertical RF tests with the fit to the BCS model, which gives an estimation of the residual resistance term in the range of a few (5-7) nΩ [3].

The last term in equation 1 is due to the pinning and trapping of DC magnetic flux (typically the earth magnetic field) in the superconductor. For high RRR niobium this contribution can be estimated as

$$R_{mag} = 3 [n\Omega] \langle H_{ext} [\mu T] \rangle \sqrt{\nu [GHz]} \quad (1)$$

where  $\langle H_{ext} \rangle$  is the average magnetic field flux seen by the cavity surface.

Finally, the surface resistance and the quality factor of the resonator are related through the cavity geometrical factor  $G=R_{surf} Q$ , which for the TRASCO cavity has the value of 160 Ω. Figure 4 shows the expected Q as a function of the average surface field on the cavity walls (for the two values of the residual resistance determined from the RF tests). Values of 2-3 μT are sufficient to achieve a goal Q at the  $10^{10}$  level.

### Shield design

The shield is composed by 1 mm thickness “CRYOPERM 10” sheets and it is located across the cavity, internal to the He tank. The shield is supported at the cavity tubes by means of small G10 blocks that separate the high permeability metal from the niobium surfaces at the tube and avoid possible contact to the end irises which may occur at cold conditions due to the differential thermal shrinkage of materials.

The shield (shown in Figure 5) is composed of three parts: two split end dishes at the cavity ends, and a tubular section. The tube allows the longitudinal adjustment to the final cavity length and can be laterally inserted from one side, where the smaller diameter He tank support dish is located.

We note here that the cavity length (i.e. the distance between the end dishes) is the nominal fabrication distance and a 10-15 mm regulation is needed in the design to account for the cavity length adjustment that was required to bring each cavity to the correct nominal frequency and with a good field flatness.

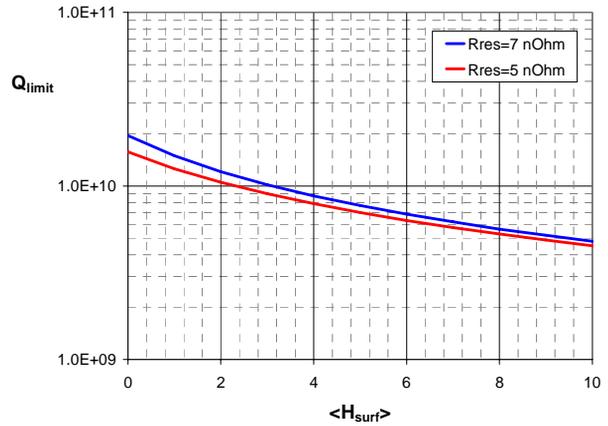


Figure 4: Cavity expected Q as a function of the average magnetic field on the surface (units of μT).

The end parts of the shield are shaped in order to keep them at a distance from the region where the weld to the He tank need to be performed, in order to limit the possibilities of heating them during the weld operations and deteriorate the high permittivity of the material.

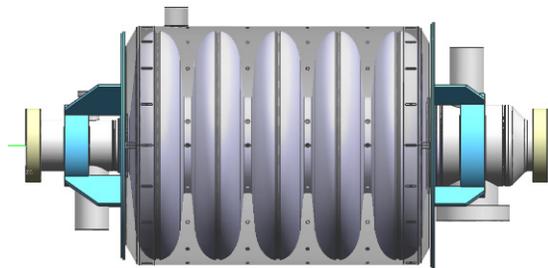


Figure 5: The shield around the cavity.

The slotted ends at the connections from the end shields to the tube allow the longitudinal adjustment to the final cavity length and provide a good contact between the different shield parts in order to avoid field leaking. Moreover, small (3 mm diameter) holes are foreseen on the shield tube to allow He gas flow during cooldown.

The following figure shows the sequence of the assembly procedure of the main shield components.

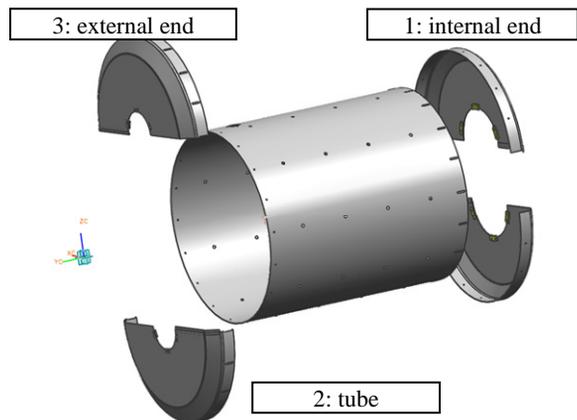


Figure 6: Assembly procedure for the shield portions.

First, the smaller diameter end shield pieces (“internal” end) are assembled at the coupler side of the cavity. Then the shield tube is slid from the other side of the cavity. Finally, the two halves of the external end at the left cavity side are connected externally to the internal tube and fastened to it.

At this point the He tank can be inserted and welded to the support dishes. After the He tank integration a small Cryoperm pipe can then be inserted and fastened (for the He gas exhaust flow), to minimize the field penetration.

### Shield performances

To evaluate the shielding performances of the internal shield solution, we performed further studies with respect to the preliminary results presented in reference [5], which assessed the feasibility of the design. We considered a 1 mm thick Cryoperm shield ( $\mu_r = 150000$ ), a 30  $\mu\text{T}$  external magnetic field oriented along the cavity axis and studied the effect of non perfect contact between the parts in order to estimate the field lines penetrations on the cavity surface due to non idealities.

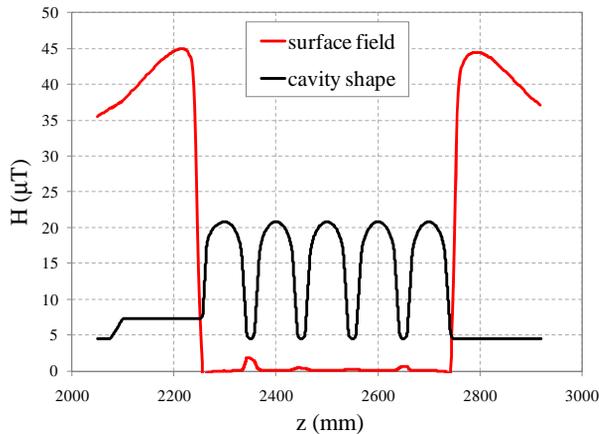


Figure 7: Field levels along the cavity surface (the cavity profile is shown for clarity), for a 30  $\mu\text{T}$  axial background field.

In the case of the ideal shield installation, corresponding to a perfect joint of the end pieces with the cylinder tube which leaves no air gaps, the residual magnetic field on the cavity surface is shown in Figure 7. As it can be seen, the internal shield exposes the beam tubes to nearly the background field levels. However, due to the good shielding of the inner region, the average field flux on the cavity surfaces exposed to the RF field is still relatively low, as it can be seen from the first line of Table 1, and within the limits set by Figure 4.

Further analyses have been performed to take into account the magnetic field leaking between shield components due to air gaps when the assembly does not guarantee a perfect contact between the different shield parts. To evaluate the surface field increase in this configuration, we left a gap of 0.1 mm between the shield cylindrical section and each end section. Figure 8 shows the calculated magnetic field line contours obtained for this not ideal case, and the penetration of field lines.

Table 1 resumes the average magnetic field evaluated on the RF cavity surfaces and the derived surface resistance due to magnetic field trapping according to equation 1 for the two cases: ideal condition (no gaps) and not ideal condition (0.1 mm gap at each shield end). Even in this condition the shield efficiency is kept within the design limits.

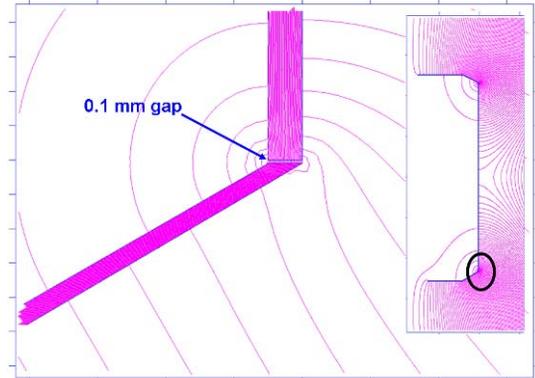


Figure 8: Magnetic field line contours (not ideal case).

Table 1: calculated magnetic field and surface resistance.

Case	$\langle H \rangle$ ( $\mu\text{T}$ )	$R_s$ ( $n\Omega$ )
Ideal: no gap	0.44	1.10
Not ideal: 0.1 mm gap at each end	2.08	5.23

## CONCLUSIONS

We presented the design and performance analysis of an inner magnetic shield for the TRASCO cavities. The moderate RF frequency and the performances required for the cavity operation allows this solution, less efficient compared to an external design covering the beam tubes with continuity but more attractive for its simplicity and cost. Two shields have been procured and their shielding performances will be measured before the final integration of the tanks for the horizontal tests of the cavities under the HIPPI and EUROTRANS programs.

## REFERENCES

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