SC CAVITY DESIGN FOR THE 700 MHZ TRASCO LINAC

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Abstract

We present here the design of the 700 MHz cavities for the TRASCO linac. The influence of the cavity geometry on the electromagnetic and structural behavior has been extensively investigated in order to determine the final shape. The main requirements to the design come from the choice to limit to 50 mT the peak surface magnetic fields at the operating accelerating gradient and to enable pulsed operation if required. A stiffening ring similar to that of the TTF cavities has been integrated in the design. Results of the electromagnetic and mechanical properties of the chosen geometries will be discussed, together with a similar work performed for the SNS cavities, where a 27.5 MV/m maximum electric field limit has been chosen.

1 INTRODUCTION

By using the cavity shape parametrization and the analysis tools presented at the 1999 Superconducting RF Workshop in Santa Fe [1] we studied in detail the RF cavities proposed in the context of the Collaboration between the Italian program TRASCO[2] and the French program ASH[3], both aiming at studies of a superconducting linac driver option for a nuclear waste transmutation system, possibly integrated in a multipurpose facility.

In defining the reference cavity geometries that are needed in order to start the construction and test of single cell and multi cell prototypes, both electromagnetic and mechanical aspects have been taken into account.

The number of possible parameters involved in the design of a SC cavity is relatively big and, without a proper choice, it can be very hard to correlate a single geometrical parameter to the electromagnetic and mechanical performances of the cavity. In addition to that, the number of possible different strategies for the cell tuning can complicate this correlation process, and a suitable tuning strategy helps to control more easily the cavity performances, including the mechanical aspects.

The guidelines described in the following paragraphs help in meeting the design choices of a specific linac project. Note that the TRASCO and ASH programs aim mainly at continuous (CW) operation, and the operating peak surface magnetic fields have been limited to 50 mT. While a stiffening structure for the lowest beta cavities is needed for vacuum load problems, no stringent requirements on the Lorentz force detuning have been set.

As a second example, in the last paragraph we describe the cavity design for a pulsed linac in which we have been recently involved: the SNS β=0.61 and 0.81 cavities[4,5].

2 INFLUENCE OF CELL GEOMETRY

The parametrization described in reference 1 allowed us to finely control each aspect of the cavity performances in terms of one, or at most two, geometrical parameters. The correlation between performances and the seven geometrical parameters needed to define a bi-elliptical cell shape are summarized in the following list:

- The **cell length** determines the cavity beta value.
- The cell **iris radius** is mainly determined by the cell-to-cell coupling requirements.
- The **side wall inclination and position** with respect to the iris plane can be set to achieve a tradeoff between electric and magnetic peak fields with a minor effect on cell-to-cell coupling.
- The **iris ellipse ratio** is uniquely determined by the local optimization of the peak electric field.
- The **equator ellipse ratio** is ruled by purely mechanical considerations and has no influence on the electromagnetic performances.
- The **cell radius** is used for the frequency tuning without modifying any electromagnetic or mechanical cavity parameter.

Each of the points listed above will be discussed in the following paragraphs, taking mainly the TRASCO/ASH β=0.5 cavity as a working example.

2.1 The iris radius

The bore radius of the cavity at the iris has been chosen taking into account the cell-to-cell coupling and the beam line aperture. The TRASCO β=0.5 cavity has a coupling nominal value of 1.35% for an iris radius of 40 mm.

2.2 The wall inclination and position

The cavity wall can be described in terms of the angle and the distance with respect to the iris plane. By moving the wall position towards the iris, both through the angle or the distance, the volume of the "magnetic" region of the cell is increased, while that of the "electric" region is reduced. The opposite is obtained moving the wall towards the equator plane. This effect can be used to balance the electric and magnetic volumes of the cavity, and hence to balance the peak fields. For a meaningful cavity comparison, we chose to keep a fixed coupling by slightly varying the iris radius.

The results of these analyses are shown in Figures 1 and 2. Here we kept the same coupling value of 1.35% (the TRASCO design value) by varying the iris radius and for all cases the iris aspect ratio has been optimized in order to achieve a local minimum for the peak electric field. Figure 1 shows, for an accelerating field of 1 MV/m, the peak electric field (diamonds, MV/m), the peak magnetic field (boxes, mT), the iris radius (crosses, %) and the ratio between the peak fields (triangles, (MV/m)/mT) as a function of the wall distance, d. The relative tradeoff between electric and magnetic fields can be seen clearly from the plot. A small variation (10%) of the iris radius is necessary to keep a constant coupling.

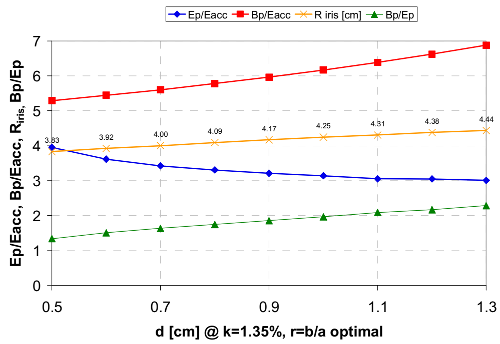

Figure 1. Peak fields, iris radius and peak fields ratio as a function of the wall distance d, fixed coupling of 1.35%.

In Figure 1 an elliptical equator with R=B/A=1.6 has been used (nominal TRASCO value), but the differences for the case of a round equator are well below 1% and cannot be appreciated in the scale of the Figure.

In Figure 2 we show the behavior of the Lorentz forces coefficient KL (in $Hz/(MV/m)^2$) at the stiffening ring position of 70 mm, for the case of a round (upper curve) and elliptical (lower curve) equator. It is clear that smaller d values (i.e. a wall closer to the iris plane) allow to reduce the Lorentz force effect. The round equator case leads to a smaller Lorentz force coefficient, even if, for the stress distribution and the end cell tuning for field flatness, the elliptical equator would be preferred.

For the TRASCO cavity, aiming at CW operation, the requirement on the Lorentz forces detuning is not stringent (as for SNS cavities) and so we preferred to design a 3-die cavity (one internal half-cell and two end cells) with an elliptical equator. In fact, in order to compensate for the presence of the large coupler beam tube, magnetic volume has to be added to the coupler end cell. This can be done either increasing the full end cell radius (as done for SNS and which requires an extra die) or starting from a central cell with an elliptical equator.

The wall angle effect can be summarized with the following considerations:

1. Small angles are preferred from the electro-magnetic viewpoint (more volume, higher R/Q and minimum product for the two peak fields).
2. A large angle is preferred for stress distribution, but Lorentz force prefers small angles.
3. Larger angles are preferred for the cavity treatment (chemistry and high pressure rising mostly).

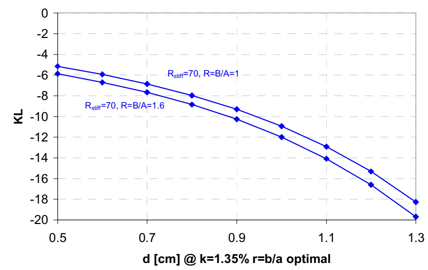

Figure 2. Lorentz coefficient for a round (upper) and an elliptical equator (lower) as a function of d.

For the TRASCO β=0.5 cavity item 2 is of secondary importance and we set the angle of 5.5 degrees as the minimal acceptable for the technological treatments.

2.3 *The stiffening ring position*

The position of the stiffening ring is extremely important for the mechanical stability of the cavity both under vacuum load and for the Lorentz force detuning. In Figure 3 we show the KL coefficient as a function of the stiffening ring position. Since the cavity has a bore of 40 mm, we placed the stiffening ring at 70 mm in order to stay in the region where KL has a minimum and to leave the necessary space for the welding. We used a niobium thickness of 4 mm (reduced by 200 µm of chemistry).

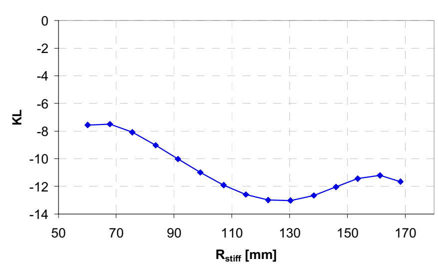

Figure 3. Variation of the Lorentz force detuning coefficient as a function of the stiffening radius position.

2.4 *The iris aspect ratio*

For any cavity geometry and parameters, there is an optimal value for the iris aspect ratio that minimizes the peak electric field with marginal influence on the other electromagnetic parameters. In Figure 1 and 2 the iris aspect ratio was always set for minimal peak electric field.

2.5 *The equator ellipse ratio*

The equator ellipse ratio (defined as the ratio between the vertical axis with respect to the horizontal axis) is a free parameter for what concerns the electromagnetic characteristics of the π-mode.

The peak electric and magnetic fields, the cell-to-cell coupling and the R/Q value are not altered varying only this parameter, but the cell mechanical parameters are sensibly affected by the equator shape. The round equator provides a KL value of –6.8 $Hz/(MV/m)^2$, and going to an ellipse with an aspect ratio of 2 the KL reaches the value of –9.0 Hz/(MV/m)^2, i.e. an increase of about 30%.

4 TRASCO AND SNS CAVITIES

Following these design criteria the cell shapes for the TRASCO and SNS cavities have been analyzed and characterized. After the internal cell shapes the full multicell cavities have been designed. The beam tube at the cavities coupler side was increased, to improve the power coupling. Table 1 lists the cavity characteristics.

As stated above, the major criteria at the basis of the TRASCO/ASH cavity design have been the maximum peak magnetic field at the operating accelerating gradient (set at 50 mT) and a simpler mechanical construction, based on only three dies for the fabrication of each cavity beta family. The cell-to-cell coupling and the value for the Lorentz force detuning coefficient have been taken into account, but not considered as driving parameters.

Conversely, the cavity requirements for the SC SNS linac are dominated by the pulsed operation. Moreover the SNS design asks for a stringent limit of 27.5 MV/m of peak electric field (instead of magnetic) and a Lorentz forces coefficient of about -3 Hz/(MV/m)^2 (dominating the cost of the RF system). In this case a round equator was chosen, in order to minimize the KL factor and 4 die cavities have been designed, with a stiffening ring at a radius of 70-80 mm (the final position to be fixed after the first CEBAF multicell prototypes) in order to finely control the longitudinal mechanical eigenfrequencies of the cavities. A different compromise between magnetic and electric volume has also been chosen, because of the limiting field criterion based on peak electric field.

REFERENCES

[1] P. Pierini et al., “Cavity Design Tools and Applications to the TRASCO Project”, 9th Workshop on RF Superconductivity, Santa Fe , Nov. 1-5, 1999.

[2] C. Pagani et al., “Status of the INFN High Current SC Proton Linac for Nuclear Waste Transmutation”, Proceedings of the XIX Linac Conf. Chicago Aug. 23-28, 1998, p. 1013

[3] H. Safa, “Superconducting Proton Linac for Waste Transmutation”, 9th Workshop on RF Superconductivity, Santa Fe , Nov. 1-5, 1999.

[4] J. Alessi et al. “SNS Preliminary Design Report”, SNS/ORNL Tech Note, November 1999.

[5] C. Pagani, “Cavity Design Criteria for SNS”, SNS Cavity Shape Workshop, TJNAF, April 12-13, 2000.

Table 1: TRASCO and SNS cavities parameters

TRASCO CAVITIES									
Cavity β	**0.5**			**0.68**			**0.86**		
Number of dies	3			3			3		
Cell type	Int.	Ext left	Ext right	Int.	Ext. left	Ext. right	Int.	Ext. left	Ext. right
Half-cell length [mm]	50	50	50	70	70	70	90	90	90
Iris radius [mm]	40	40	65	45	45	65	50	50	65
Equator ellipse ratio, R	1.6	1.7	1	1	1.1	1	1	1.1	1
Iris ellipse ratio, r	1.3	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4
Wall angle [deg]	5.5	5.98	4.84	8.5	8.85	5.6	8.5	9.1	5.74
Wall distance [mm]	7	7	6	10	10	10	10	10	8
Cell-to-cell coupling [%]	1.34			1.1			1.28		
Phys. cavity length [mm]	830			1050			1460		
Number of cells	5			5			6		
E_{peak}/E_{acc}	3.57			2.60			2.37		
B_{peak}/E_{acc} [mT/(MV/m)]	5.88			4.87			4.07		
r/Q [Ohm]	90			169			309		
Stiffening radius [mm]	70			Under discussion			N/A		
KL [Hz/(MV/m)^2] (inner)	-7			w/o –7.8/-2.7 @ 70 mm			-3.4		

SNS CAVITIES								
Cavity β	**0.61**				**0.81**			
Number of dies	4				4			
Cell type	Int.	Ext. left	Ext right 1	Ext right 2	Int.	Ext left	Ext. right 1	Ext. right 2
Half-cell length [mm]	56.8	56.8	56.8	56.8	75.5	75.5	75.5	75.5
Iris radius [mm]	43	43	43	65	48.8	48.8	48.8	70
Equator ellipse ratio, R	1	1	1	1	1	1	1	1
Iris ellipse ratio, r	1.7	1.5	1.7	1.5	1.8	1.6	1.8	1.6
Wall angle [deg]	7	8.36	7	10	7	10.07	7	10
Wall distance [mm]	11	10	11	10	15	13	15	13
Cell-to-cell coupling [%]	1.53				1.52			
Phys. cavity length [mm]	1001.6				1246			
Number of cells	6				6			
E_{peak}/E_{acc}	2.72				2.19			
B_{peak}/E_{acc} [mT/(MV/m)]	5.73				4.72			
r/Q [Ohm]	140				243			
Stiffening radius [mm]	70-80				70-80			
KL [Hz/(MV/m)^2] (inner)	-2.9/-3.4				-0.7/-0.8			