# A NOVEL SPUTTERED MEDIUM BETA CAVITY FOR ALPI

S. Stark, A.M. Porcellato, A. Palmieri, V. Palmieri, P. Favaron, E. Bissiato, F. Stivanello, F. Chiurlotto, G. Donà, D. Giora, M. De Lazzari, Istituto di Fisica Nucleare - Laboratori Nazionali di Legnaro, Legnaro, Padova, Italy

*Abstract*

The installed medium β ALPI cavities were produced by Nb sputtering on old Cu substrates, which were originally Pb plated. The cavity renew could practically double the previous average operational accelerating field but the performance obtained in high β resonators, whose Cu bases were designed to be sputtered, could not be reached [1, 2]. To overcome this performance gap, we designed, built and tested a novel medium β cavity, which has the shorting plate rounded as in high β cavities, while the beam ports are obtained by plastic deformation of the outer conductor instead of being brazed to the cavity body as in the previous medium β QWRs. The paper describes cavity design, substrate construction technology, surface treatments and results of the first resonator cold test.

## INTRODUCTION

We have presently installed in ALPI 44 medium β QW cavities. The cavity substrates were produced in between 1991 and 1993. Their Pb superconducting layer was replaced by a sputtered Nb film in between 1999 and 2003. The new superconductor allowed rising ALPI cavity average operational accelerating field from 2.5 to 4.5 MV/m @7W, but the performance obtained in QWRs produced by sputtering on properly designed substrates could not be reached when using the old substrates. Their main drawbacks are the small curvature radius blending the shorting plate to inner and outer conductors, holes located in high current area and the presence of brazed joints delivering impurities during the sputtering process. A further handicap comes from the shape of beam ports, which made it difficult to obtain a good quality film on the surfaces around them due to the sharp junctions.

## CAVITY DESIGN

In the construction of new substrates we adopted all the innovations that allowed accelerating fields ($E_a$) exceeding 7 MV/m @7W in ALPI sputtered high β resonators. The new cavity main feature is a rounded shorting plate connecting inner and outer conductors thus eliminating the two sharp edges around the flat shorting plate where a good sputtered film was difficult to produce. The cavity coupler is capacitive and is located on the outer conductor at about 6 cm from the bottom plate; the pick up port is symmetrically positioned in front of it. In this way the cavity does not present holes in high current regions. The cavity shape is sketched in fig 1.

The resonator electromagnetic properties were computed by HFSS and resulted in the parameters listed in tab. 1. The Transit Time Factor (TTF) curve is presented in fig. 2. Its maximum value is 0.899, corresponding to a cavity optimum β (βopt) of 0.11. The cavity provides an energy gain of 0.18 MeV/MV/q to the synchronous $\beta_{opt}$ particle with state of charge q. The wide TTF curve allows efficient acceleration for beams having 0.07<β <0.2.

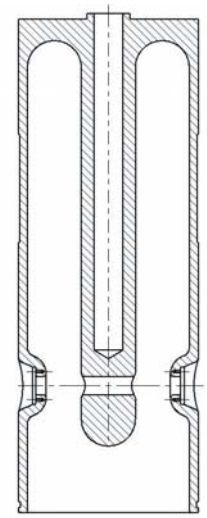

Figure 1: New medium β QWR design. The beam ports are obtained by plastic deformation of the outer conductor

Table 1: Computed cavity parameters

| | | |
|---|---|---|
| Frequency | 160 | MHz |
| Stored Energy/$(E_a)^2$ | 65 | mJ/$(MV/m)^2$ |
| Peak magnetic field/$E_a$ | ≈110 | Gauss/MV/m |
| Peak electrical field/$E_a$ | ≈5 | |
| $\beta_{opt}$ | 0.11 | |
| TTF ( $\beta_{opt}$) | 0.899 | |
| Active length | 180 | mm |

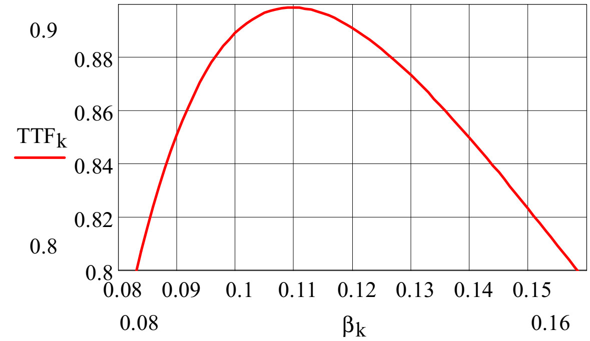


Figure 2: T.T.F-curve

## SUBSTRATE PRODUCTION

### *Mechanical construction*

We had available 4 mushroom shaped preformed units and 4 outer cylinders in OFHC Cu, which were left unused since the first production cycle of ALPI medium β QWRs. As a consequence the new medium β cavities maintain the circumferential brazed joint of the old medium β cavities. The presence of this joint and the Cu quality are the main construction differences between these cavities and the ALPI high β QWRs, which were instead worked out from a Cu billet.

Initially the cavity production followed the established sequence which foresaw a preliminary machining of parts followed by a thermal cycle in high vacuum furnace for stress release. Once the parts were machined to state dimensions and tolerances (very critical for the coupling surfaces) they could be assembled for the circumferential brazing. A second brazing cycle, always using NiCuSil as brazing material, allowed to add the two supports that make the cavity perfectly compatible with the standard ALPI cryostat. All the thermal cycles were performed in the LNL high vacuum furnace. The following step was to drill the axis of the beam hole in the middle plane between the cavity supports at the fixed distance from them. After the beam port shaping, described in the following paragraph, the mechanical construction foresaw the drilling of the holes used for screwing the stainless-steel collar to the cavity body. The collar was fixed directly onto the sputtered cavity by a vacuum tight junction. The outer plane of the deformed surfaces was also machined to add external beam ports which allow the electro-magnetic fields to decay before meeting normal conducting surfaces. These beams ports are screwed to the cavity before the sputtering process in order to be covered with the Nb film together with the cavity body.

We decided to eliminate the In wire, which previously used to assure the rf contact between the cavity and its bottom plate, in order to have the possibility to rinse the resonator with high pressure water before its assembling on line. This was made possible by minor changes both in the bottom plate and in its fixing ring in order to force the contact between the plate and the cavity border towards the inner cavity side, where the sputtered film has still a sufficient quality. We also doubled the number of fixing screws to increase the contact strength. Small adjustments on the tuning itself allowed maintaining a smooth movement in all its range without having to replace it.

### *Shaping of the beam ports*

The novel method of the beam port shaping was developed in house; all the necessary dies and tools were designed and produced in the LNL workshop where our technicians also performed the beam port shaping of the 4 cavities using the existing press having an axial load of 20 tons. The localized pressure necessary to produce the plastic deformation of the beam port area produces a side thrust which could break the cylindrical symmetry of the outer conductor outside the interested area. For this reason we contained the outer conductor, both in the inner and outer surfaces by means of a suitable cage we designed and built. We also produced the tools necessary to apply the suitable strength to obtain the required deformation and to minimize at the same time the stress on the deformed material. The shape of the necessary punches and dies, which are shown in fig. 3, was adjusted in a few steps according to the results obtained.

Figure 3: Cage, dies and punches used for deforming the beam port area of the new medium β cavity

We studied the plastic deformation in a dummy OFHC Cu tube before proceeding to the real cavity shaping. Once we obtained the wanted shape in the prototype, the same technology has been applied for the construction of the 4 cavities shown in fig. 4

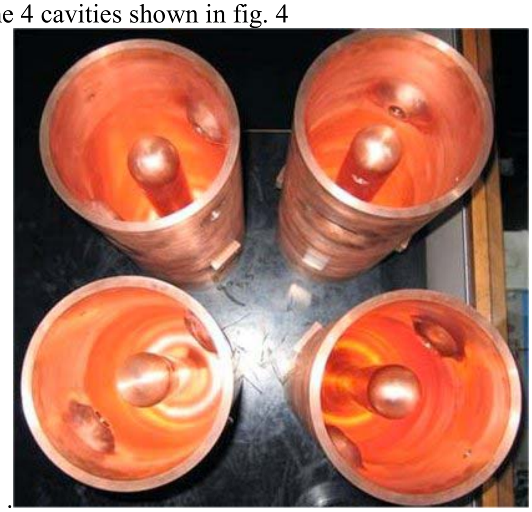

Figure 4: The four cavities after the beam port shaping

### *Substrate final adjustment*

The inner cavity surfaces needed grinding to eliminate the signs left by the dies and to smooth the surface interested by the mechanical deformation. We had also to round the inner edges of the cavity holes.

The cavity target frequency was reached by decreasing the inner conductor length, purposely left slightly longer than necessary. This process was performed by removing material from the inner conductor tip by electro-polishing. If the electro-polishing solution was suitably mixed during the process, a few hundreds of microns were easily subtracted leading to a smooth surface. In our experience electro-polishing resulted easier to control than the chemical etching in which the material removal was faster, heavily dependent on the freshness of solution and leaded to a rougher surface. A further advantage of this method for frequency tuning is the reduced work load on the mechanical workshop.

## CAVITY PERFORMANCE

We completed the construction of 4 substrates but we had the possibility to perform chemical treatment and sputtering process only in one of them up to now.

### *Surface treatment and sputtering process*

The surface treatment followed successfully the established sequence, which includes a few days of tumbling, then electro-polishing and chemical polishing cycle. After high pressure water rinsing the cavity was baked in the sputtering chamber for a few days at about 700°C. The vacuum level in the sputtering chamber improved up to $10^{-8}$ mbar level, but some vacuum deterioration appeared also at the end of the process. Usually it comes from brazed joints or from defects in the Cu. Unfortunately we could not get rid of them completely. The configuration and the parameters of the sputtering process were the same used for the production of the standard medium β cavities. We deposited about 2 microns of Nb in 14 sputtering steps of about 15 minutes with about 3 hours of pause in between, to maintain the cavity under the baking temperature. Before being mounted in the test cryostat the cavity was rinsed by high pressure de-ionized water then closed by a bottom plate previously used.

Figure 5: The new cavity after being Nb sputtered

### *Cold test procedure and cavity performance*

We assembled the cavity in the test cryostat equipped with the standard equipment. We baked the cavity for 12 hours at 350 K reaching $10^{-7}$ mbar vacuum level. Unfortunately we had to vent the cryostat for adjusting the coupler which was not working properly. After that we repeated the baking process again. The multipacting conditioning was performed during resonator cooling to room temperature. We did not see the low field multipacting typical of medium β standard resonators and in less than two hours we could condition two multipacting levels which usually appear at higher fields. Qo, measured in critical coupling condition, was $9 \times 10^{8}$ (fig. 6). This value is higher than the best value obtained in medium β cavities ($7 \times 10^{8}$ at best), but it is still lower than the value obtained in high β resonator ($1\text{-}2 \times 10^{9}$). The possible reasons are both the vacuum deterioration we detected during the baking process and possible contamination during the cryostat venting. Due to radioprotection authorization limits we could not exceed 3 MV/m during the resonator test so we could explore only the fist part of the resonator Q-curve. As usual in both high and medium β cavity we had a barrier at about 2 MV/m which was conditioned at low power in about half an hour. The accelerating field was then gradually increased up to 3 MV/m. Based on the experience of previous cavities with similar Q-curve behavior, we expect an operational accelerating field of about 6 MV/m at 7W. We will prove it only after having installed the cavity in ALPI. The cavity matched the ALPI frequency of 160 MHz and had tuning range of -10/+20 kHz.

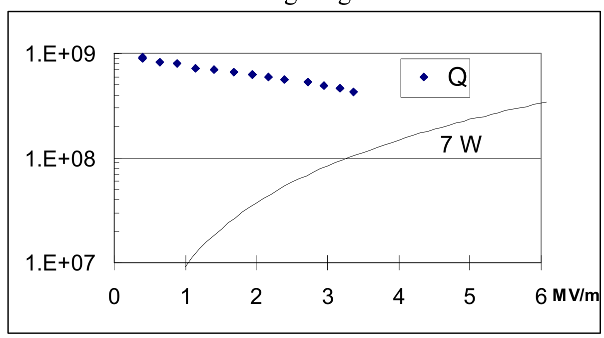


Figure 6: Resonator Q-curve measured in laboratory where we were not allowed to exceed 3 MV/m for authorization reasons. Anyway, based on our previous experience we expect the cavity to reach on line 5.5-6MV/m.

## FUTURE PLANING

We plan now to complete the production of the remaining three resonators and, after a preliminary test at low field in laboratory, to install all of them in a standard ALPI cryostat, where we will have the possibility to exploit their performance and use them for beam acceleration. This new set of cavities allows to have some spare cavities which will make the cryostat maintenance faster. It will be possible moreover to eliminate the less performing resonators installed in ALPI, thus increasing the operational average accelerating field.

## REFERENCES

[1] A. M. Porcellato, S. Stark, V. Palmieri, F. Stivanello, Proceeding of the 12th International Workshop on RF Superconductivity, Cornell University, Ithaca, NY 10-15 July 2005

[2] A.M. Porcellato S. Stark, V. Palmieri, F. Stivanello, Proceeding of The International Workshop on Thin Films and new ideas for pushing the limits of RF superconductivity, Legnaro, 0ctober 30-31 2006