Bulk Niobium Low-, Medium- and High-β Superconducting Quarter Wave Resonators for the ALPI Postaccelerator

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Abstract

A family of three solid niobium quarter wave superconducting resonators, cooled by direct contact with liquid helium, having resonant frequencies of 80 MHz, 160 MHz and 240 MHz and optimum velocities $\beta_o = 0.056$, $\beta_o = 0.11$ and $\beta_o = 0.17$ respectively, has been designed, constructed and tested. In addition to the standard chemical surface treatment also thermal treatment at 1200°C using the titanium sublimation technique was applied. The low-beta 80 MHz resonator $Q_o = 2.3 \times 10^8$, and the quality factor was almost constant from low level up to the maximum field achieved of 4.2 MV/m at 5 W. The intermediate beta 160 MHz cavity had $Q_o = 2.2 \times 10^8$, almost constant up to the field of 5 MV/m at 10 W. The high beta 240 MHz resonator, after deionized water high pressure rinsing, reached $Q_o = 3.5 \times 10^8$ and a maximum field of 4.7 MV/m at 6 W. The 80 MHz cavity serves as a prototype for the recently started production of the low-beta section of the ALPI linac.

1 INTRODUCTION

The first all-niobium quarter wave resonator was designed at the Weizmann Institute of Science in 1987. The intention was to build a resonator with much better performance than the lead plated copper resonators in use at that time at the Weizmann Institute. The prototype of this resonator was constructed in cooperation with INFN Laboratori Nazionali di Legnaro and with CERN [1]. The construction flaws prompted us to build another prototype and the tests of this new 160 MHz resonator have proven that our goal was achieved [2]. The successful performance of the 160 MHz resonator has triggered the idea, that also the other resonators, needed to complete the Alpi linac [3], could be constructed of bulk niobium and have a similar conceptual design [4].

The beam dynamics calculations for ALPI have shown that, in order to accelerate ions of all masses coming from the LNL 16 MV tandem, three different sections (with optimum velocities $\beta_o = 0.056$, 0.112 and 0.169 respectively) of two gap resonators would be required; due to the need of a wide phase acceptance for heavy ions the frequency of 80 MHz was chosen for the low beta section.

We matched the velocity of ions along the low, intermediate and high beta sections by using three frequencies, 80, 160 and 240 MHz respectively; that way we could maintain the same resonator shape along the beam line and the mechanical design of all the resonators stayed almost identical except for their lengths (fig. 1).

2 DESIGN CONSIDERATIONS

A number of basic considerations had to be taken into account when designing the new type of resonators. They had to meet the requirement of short time and relatively low power required for multipactoring conditioning. This condition has been thoroughly investigated [5] and the shape design of the inner conductor of the resonator (see fig. 1) was based upon it.

The resonator is all-niobium in order to allow for high temperature treatment; the outer conductor is cooled directly by liquid helium contained in the double wall structure.

The medium and high beta resonators fit the dimensions of the ALPI cryostat; the low beta cavities require minor modifications in the cryostat design due to their length. The 80 MHz resonator is relatively light and easy to handle in spite of the fact that it is about 1 m long.

The mechanical design of the cavities fits the requirements of relatively easy machining and minimum number of welds. The mechanical parts are identical for all three cavities, except for the lengths of the outer envelope and the inner and outer conductors. The advantages of modularity were obtained without loosing in terms of rf characteristics (see table 1).

Resonator type Frequency $[MHz]$	low-β 80	medium-β 160	high-β 240
β_{opt}	0.056	0.112	0.169
Transit time factor	0.9	0.9	0.9
$U/E_a^2[mJ/(MV/m)^2]$	114	67.3	45
$H_p/E_a[G/(MV/m)]$	100	103	110
E_p/E_a	4.9	5.2	5.4
$R'_{sh}[M\Omega/m]$	20.4	25.1	26.6
$\Gamma[\Omega]$	15.4	29.5	41.9

Table 1: Niobium resonators calculated parameters.

3 PROTOTYPE SURFACE TREATMENT AND TESTS

All three resonators have undergone at least one standard CERN chemical treatment and one thermal treatment at

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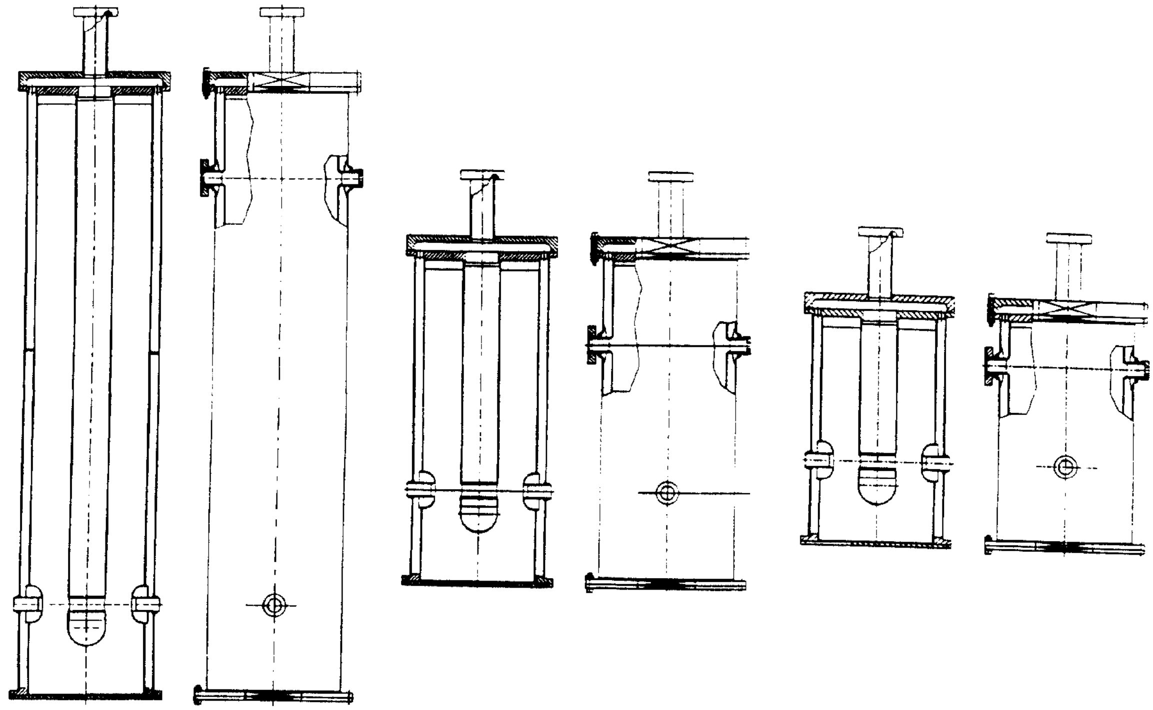

Figure 1: The 80, 160 and 240 MHz niobium resonators.

1200°C and $1 \times 10^{-6} mbar$ using the titanium sublimation technique.

3.1 The 160 MHz resonator

The chemical treatment was followed by the thermal treatment. No rf test was done after chemical treatment, the measurements after thermal treatment gave the results shown in fig. 2. The maximum field was limited by field emission at 60 W [2]. We have used this resonator on the linac test beam line as a buncher.

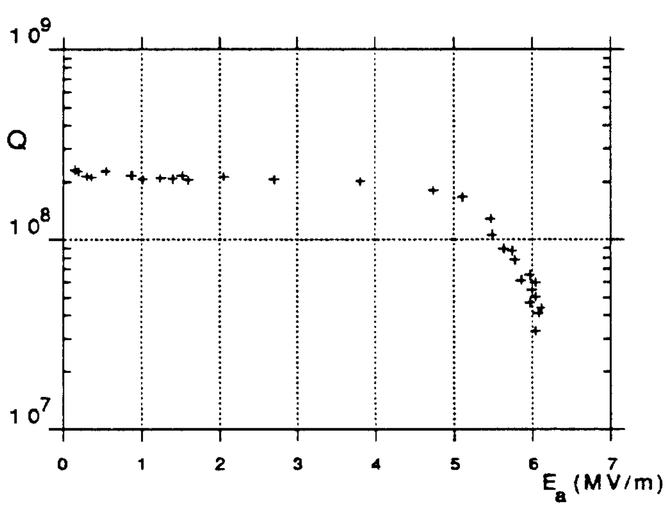

Figure 2: The 160 MHz resonator Q vs. E_a curve

3.2 The 80 MHz resonator

The thermal treatment was followed by chemical treatment. The results of the rf measurements are shown in fig. 3; the maximum field of 4.2 MV/m was reached at 5 W forward power, limited most probably by local thermal breakdown. Power and helium conditioning did not change this limit. The mechanical stability of the resonator at 4.2 K was tested by scanning frequencies from 5 to 1000 Hz applied to the cryostat using a mechanical vibrator. The only resonance frequency detected was 44 Hz with a bandwidth of 2 Hz.

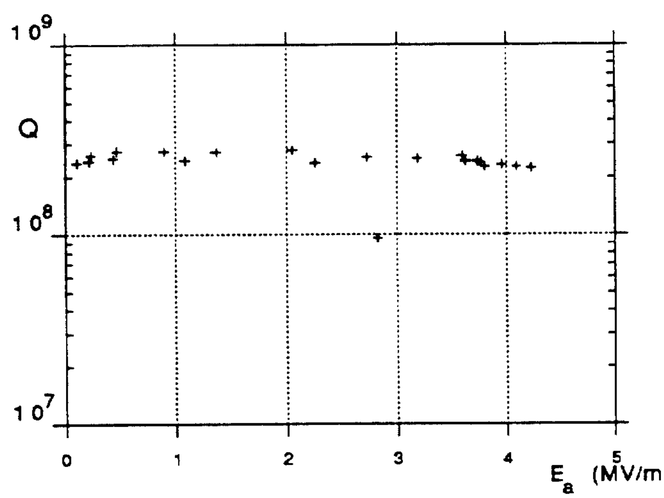

Figure 3: The 80 MHz resonator Q vs. E_a curve

3.3 *The 240 MHz resonator*

In this resonator we did the thermal treatment first and then the chemical treatment. We tested the resonator and we found a maximum field of 3.2 MV/m at 4 W, again limited by local thermal breakdown as in the 80 MHz cavity. High pressure rinsing with deionized water at 100 bars [6] [7], followed by ethanol rinsing, without nitrogen gas drying of the resonator, was applied. The new rf test showed that the upper limit of field level was shifted up to 4.7 MV/m at 6 W (see fig. 4). This could indicate that the quench was caused by some surface impurity, which has been removed by the high pressure rinse.

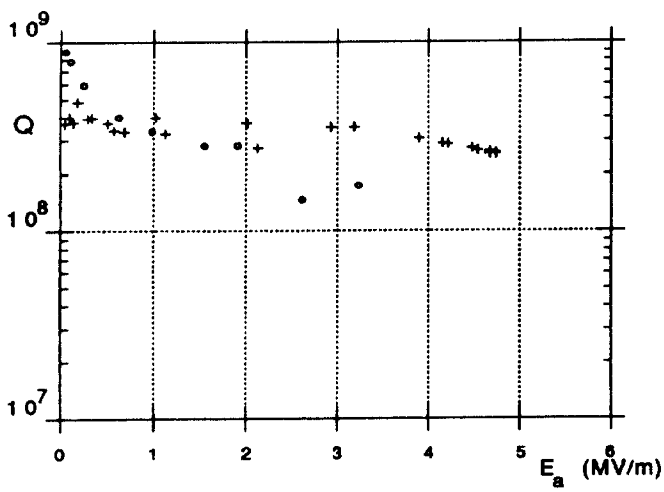

Figure 4: The 240 MHz resonator Q vs. E_a curves: "o" before high pressure rinse; "+" after high pressure rinse.

4 CONCLUSIONS

A set of three resonators, corresponding to the ALPI linac requirements for the low, intermediate and high β sections, was designed, constructed and tested. The resonators are all-niobium made, allowing for high temperature treatment. They have identical shape except for their lengths; the differences in their optimum velocities are due only to their different resonant frequencies. The design similarities simplify considerably the construction procedure and reduce production costs.

A series of experiments aiming at optimizing the surface treatment is still continuing; we have had clear evidence that high pressure deionized water rinsing could increase the maximum field attainable after chemical treatment.

The 80 MHz resonator became the prototype for the low β section of the ALPI linac, consisting of 7 cryostats which would be housing 24 accelerating cavities and one buncher; the production of the first 6 resonators of this section has begun recently.

There are still some open questions to be solved in order to have a complete picture of the resonator characteristics and of the operations necessary for optimum performance: the best sequence of surface treatment operations, the effect of working in clean room conditions, that could not be tested yet on our cavities, and whether a fast tuner would be necessary to cope with the mechanical oscillations.

5 ACKNOWLEDGMENTS

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