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A BULK NIOBIUM SUPERCONDUCTING QUARTER WAVE RESONATOR

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Abstract

A bath-cooled all-niobium 160 MHz quarter wave resonator prototype was constructed and tested. The objective of this research has been the development of a high performance accelerating element with $\beta_{opt} \simeq 0.11$ for the ALPI linac at the Laboratori Nazionali di Legnaro. The design of this resonator was based upon a previous 150 MHz model [1], with minor changes due to the different frequency and to modified welding procedure. An accelerating field of 5 MV/m was achieved at a power dissipation of 10 W and the low power Q was 2.4×10^8. The resonator could dissipate 70 W of power without thermal breakdown.

Introduction

In recent years a number of laboratories have adopted the quarter wave resonator [2] in superconducting linacs for heavy ions [3,4,5,6,7,8]. The superconductor technology which has been used initially was lead plated on copper; the superior performance of niobium as a superconductor prompted some laboratories to try it in quarter wave resonator configuration [1,9,10]. It has been demonstrated that the thermal treatment at high temperature and ultra high vacuum improves considerably the performance of niobium resonators [11,12,13]. The niobium quarter wave resonators so far (except for our 150 MHz prototype [1]) included parts made of explosively bonded niobium-to-copper and thus were limited to lower temperature treatments. We have designed a niobium quarter wave resonator which contains no other material than niobium so it may be treated at very high temperature. In order to solve the problem of the outer conductor cooling we have used a double wall design (see fig. 1); the thermal path length between the liquid helium and the rf surface of the resonator was minimized by keeping the thickness of the inner and outer conductor within 2 mm. The use of thin wall niobium has also kept the cost and the weight within reasonable limits.

Design, construction and surface treatment

The goal of the design was to get a quarter wave resonator made of high thermal conductivity niobium using a minimal quantity of material, with a structure which would allow for good cooling and for baking at high temperatures. A high accelerating field to peak surface electric field ratio E_p/E_a was required.

The design of the shape of the resonator inner conductor was tested initially with computer codes. We were concerned with two problems, the optimization of the inner conductor shape for lowest peak surface electric field and the reduction of multipactoring. An electrostatic approximation of the fields at the tip of the inner conductor was studied using the computer code FEARS (Floating Electrode Axisymmetrical or Rectangular Simulation)[14]. In a later stage we have tested the electromagnetic solution of the complete resonator using the computer code SUPERFISH [15]. The calculated and experimental values of the resonator parameters are shown in table 1. It is interesting to note that the theoretical values obtained by using the transmission line theory [2] are close to the ones received using the SUPERFISH program.

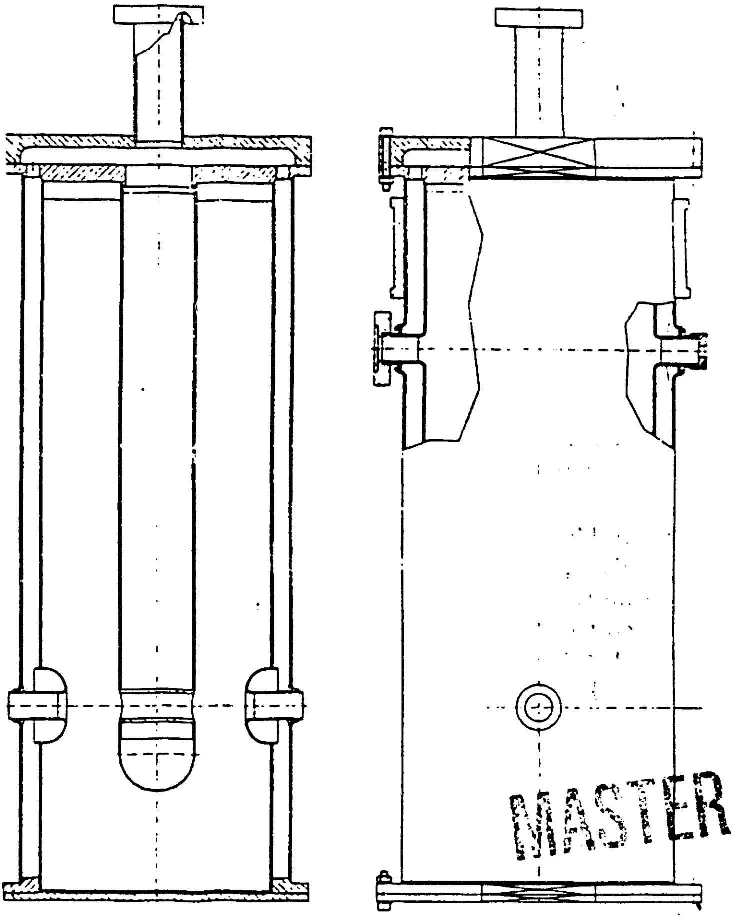

Figure 1. View of the all-niobium quarter wave resonator.

The multipactoring characteristics of the resonator were studied using the computer code ELT [16]. The conclusions drawn from the simulation of the multipactor levels were to increase the diameter of the outer conductor from 16.3 cm (optimal value for a high E_a/E_p) to 18 cm.

The resonator was constructed to operate at 160 MHz and $\beta = 0.11$ to meet the requirements of the ALPI linac presently under construction at the Laboratori Nazionali di Legnaro. The dimensions of this cavity were set so that four such resonators would fit the standard ALPI cryostat with minor modifications.

The result of the design is shown in fig. 1. The resonator is made of niobium parts joined together using electron beam welding. Two grades of niobium were used in order to reduce the cost of the resonator. The parts of the resonator exposed to rf fields were made of RRR-150 or better material. For all the other parts much less expensive niobium (ASTM B393-8 Type 2) was utilized. The ellipsoidal tip of the inner conductor and the beam ports were produced by spinning.

The construction of the resonator followed the design very closely, and the machining and welding were successful; the modifications introduced in the new mechanical design allowed us to overcome the difficulties encountered while welding the previous 150 MHz prototype [1].

The machined niobium parts were supplied by the Laboratori Nazionali di Legnaro, Italy, the welding and the chemical treatment were performed at CERN, Switzerland, and the thermal treatment was done at the Weizmann Institute, Israel.

The chemical treatment, the standard "slow" etching process used at CERN for niobium cavities, was followed by a long ultrapure deionized water rinse. The resonator was then dried and packed in a clean (class 100) room, and transported to the Weizmann Institute.

The thermal treatment was based upon the experience of other laboratories [12,13] which have used titanium sublimation in order to improve the thermal conductivity of niobium. In spite of the complex geometry of our resonator we have succeeded to deposit a thin layer (about 50 μm) of titanium over all the surfaces except for the ones to be exposed to rf. We did not etch the titanium off the niobium surfaces after the furnace treatment.

The furnace vacuum that we could reach at 1200 C was approximately 1×10^{-6} Torr; we have decided to stay at this temperature in order to avoid degradation of the niobium characteristics [11]. The duration of the treatment at 1200 C was 4.5 hours preceeded by 17 hours of degassing and warmup and followed by 14 hours cooldown. No further treatment followed at the Weizmann Institute; the resonator was packed without special care (except for the constant flow of dry nitrogen during its removal from the furnace and during packing) and then shipped to Legnaro.

Measurements

The rough preliminary rf measurement taken at the Weizmann Institute before the heat treatment gave a maximum of 4.5 MV/m at 60 W forward power; thermal breakdown was the limit. All the rf measurements after the furnace treatment were performed at Legnaro. The resonator shipped from Rehovot was received at Legnaro one week later. A 30 minutes rinse with deionized water was followed by an ethanol rinse and dry nitrogen flush until it was deposited in a vacuum storage cylinder where it was kept for the next 3 weeks. There was no clean room at our disposal and the rinse was done with standard deionized water. The resonator was stored at a vacuum of 2×10^{-3} Torr for the first 10 days and at 10^{-6} Torr for the rest of the time.

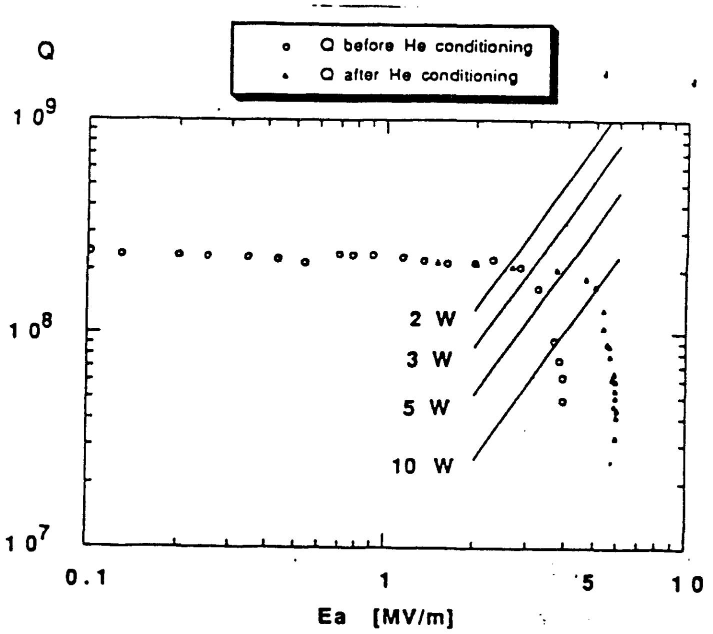

Figure 2. Plots of Q versus E_a, before and after helium conditioning.

The multipactoring conditioning was performed at room temperature, keeping the vacuum around 10^{-7} Torr. The conditioning, which did not present any particular problem, took 10 hours. The conditioning was done with cw, up to 70 W forward power. The operation was at slight undercoupling; the multipactoring conditioning above 70 W was done with 10 ms pulses at a duty factor of 0.15, so that a 300 W pulse could be used without endangering the coupler connections or the cables feeding power to the resonator. During the measurements the resonator was magnetically shielded. The results of the measurements at 4.2 K after helium conditioning were as follows (see diagram in fig.2):

a) Low power $Q = 2.4 \times 10^8$, almost flat up to a field of 5 MV/m.

b) Field of 5 MV/m at an input power of 10 W.

c) Maximum field of 5.9 MV/m obtained with a power dissipation of 54 W . The resonator field was stable even at high power input.

d) Maximum rf power dissipated in the resonator, with no significant increase of the field level, was 70 W limited by thermal breakdown. The X-rays measured at the top side of the cryostat were at very high level (much above 3000 $\mu S/h$).

Conclusions

The high RRR all-niobium, bath-cooled quarter wave resonator described here is an extremely promising accelerating element for superconducting heavy ion linacs. It can be operated routinely at 5 MV/m and 10 W; the thermal breakdown occurs only at 70 W, which is a very high power for such resonators.

Table 1: Niobium quarter wave resonator data

	Ben-Zvi Brennan[2]	Superfish* [15]	Experiment (bead test)
β_{opt}	0.11		0.11
T(*transit time factor*)	0.942		0.9
$U/E_a^2[mJ/(MV/m)^2]$	58.8	67.3	63.6
$H_p/E_a[G/(MV/m)]$	100	~103	
E_p/E_a	3.0	~5.2	
$R'_{sh}[M\Omega/m]$	29.0	25.1	
$\Gamma[\Omega]$	32.7	29.5	
$Q(Cu)$	9573	8621	
$Q(Nb)^{**}$	4.4×10^9	3.9×10^9	

* Using experimental T value
** Using theoretical BCS resistivity of niobium

Those excellent results were obtained in spite of the resonator handling (no dustfree area and no filtration of the deionized water) after it left the CERN laboratories. The value of 2.4×10^8 for the low power Q, which is lower than one could obtain with a niobium cavity, shows that there is room for a significant improvement of the surface quality. In the future we shall try to organize proper dustfree handling of the resonator; with this operation we expect to increase the low power Q value and thus to push the resonator performances to even higher fields at lower power dissipation.

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