A BULK NIOBIUM LOW β SUPERCONDUCTING QUARTER WAVE RESONATOR FOR ALPI

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Abstract

An 80 MHz superconducting resonator with optimum velocity $\beta_o = 0.055$ has been designed, constructed and tested. The cavity is an all niobium quarter wave structure where both inner and outer conductor are cooled by direct contact with liquid helium [1]; a thermal treatment at 1150 K using the titanium sublimation technique [2] was applied in order to improve the thermal conduction of the niobium and consequently to improve the high field performance of the resonator. In spite of the serious vacuum accident which occured just prior to the resonator testing, causing its serious mechanical deformation, the best low power Q was 1.1×10^8 and the maximum field achieved was 3.8 MV/m with 55 W input power. The accelerating field was 3.0 MV/m at 13 W. We would be expecting much higher values in normal conditions, but we must consider these as positive or even promising results in these circumstances. This resonator was built as a prototype of the low β cavities of ALPI, the superconducting linac under construction at Laboratori Nazionali di Legnaro; this prototype was planned to be used as a superbuncher in the ALPI pulsing system, together with the 160 MHz one of similar conceptual design [1].

1 DESIGN AND CONSTRUCTION

Our aim was to design a low beta, 80 MHz niobium resonator, preserving the advantages of mechanical characteristics of our 160 MHz resonator. The basic requirements for this resonator were:

1. 1. High accelerating field to peak surface electric field ratio E_p/E_a.
2. High magnetic field to peak surface electric field ratio H_p/E_a.
3. $\beta_o \simeq 0.055$.
4. Limited dimension along the beam line.
5. Wide transit time factor (2 gaps).
6. Minimum deviations from the mechanical design of the 160 MHz resonator.

A proper approach to meet all these requirements seemed to be to design a 80 MHz resonator with the the same shape as the 160 MHz cavity ($\beta_o = 0.11$) except for its length. The length had to be approximately doubled for reaching the lower frequency. We examined this version very carefully; the main questions were related to the shunt impedance and to the mechanical stability of the resonator. The rf behaviour of this design was studied by means of the SUPERFISH computer code [3] and we have also constructed a copper model for testing its mechanical properties.

Calculated resonator parameter values are shown in table 1. The theoretical values obtained using the transmission line theory [4] are in good agreement with the values received applying the SUPERFISH code.

Parameter	Ben-Zvi Brennan[4]	Superfish* [3]
β_{opt}	0.056	
$T(transittimefactor)$	0.939	
$U/E_a^2[mJ/(MV/m)^2]$	121	114
$H_p/E_a[G/(MV/m)]$	96.8	~100
E_p/E_a		~4.9
$R'_{sh}[M\Omega/m]$	22.2	20.44
$\Gamma[\Omega]$	16.4	15.4
$Q(Cu)$	6793	6392
$Q(Nb)^{**}$	5.7×10^9	5.4×10^9

Table 1: Niobium quarter wave resonator data

1. * Using theoretical T value
2. ** Using theoretical BCS resistivity of niobium

Dimensions of this cavity are such, that four of them would fit the standard ALPI cryostat with minor modifications.

The result of the design is shown in fig. 1.

All parts were machined at the Laboratori Nazionali di Legnaro, Italy, the welding and the chemical treatment were performed by the Israel Aircraft Industries, MASHAM Engine Maintenance Plant and the resonator was thermally treated at the Weizmann Institute, Israel.

The thermal treatment was based upon the experience of other laboratories [2,5] which have used titanium sublimation in order to improve the thermal conductivity of niobium.

The resonator, enclosed in a titanium box, was treated at 1150 C for 10 hours at 2.5×10^{-6} mbar.

We did not etch the titanium off the niobium surfaces after the furnace treatment.

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

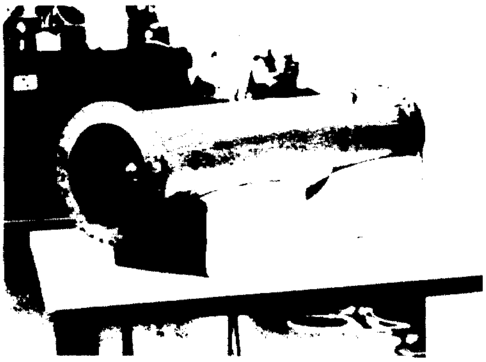

Figure 1: The 80 MHz niobium resonator

from the furnace and during packing) and then shipped to Legnaro.

2 MEASUREMENTS

We were compelled to delay by six months the cold test due to the fact that a test cryostat which would fit the length of the resonator was under construction. The resonator was stored in a vacuum container during this period. Once we were ready for the measurement we rinsed it with deionized water followed by an ethanol rinse in standard dusty laboratory conditions, since we still do not have a clean room at our disposal.

A serious accident has occured during filling the thermal radiation shield of the cryostat with LN_2: the shield has imploded, hitting the resonator coupler and thus causing extensive deformation of the resonator.

We managed to extract the resonator from the damaged cryostat, the vacuum tightness of the resonator was not affected, however its resonant frequency was shifted up by 340 kHz and it was also expected that the large deformation of the outer conductor would most probably change the resonator response to the multipactoring conditioning as well as degrade its quality factor.

The multipactoring conditioning, which for technical reasons had to be limited to a maximum of 20 W average rf power arriving at the coupler, was performed partly at room temperature and partly at liquid nitrogen temperature at a vacuum around 10^{-8} Torr. The conditioning went surprisingly smoothly and did not present any problem.

The results of the measurements at 4.2 K were however definitely affected by the above described accident as well as by the extremely long storage time before the measurement. The results of the rf measurements were as follows (see fig. 2):

1. The best low power Q $= 1.1 \times 10^8$ before helium conditioning,
2. Low power Q $= 7 \times 10^7$, remains quite flat up to a field of 2 MV/m.

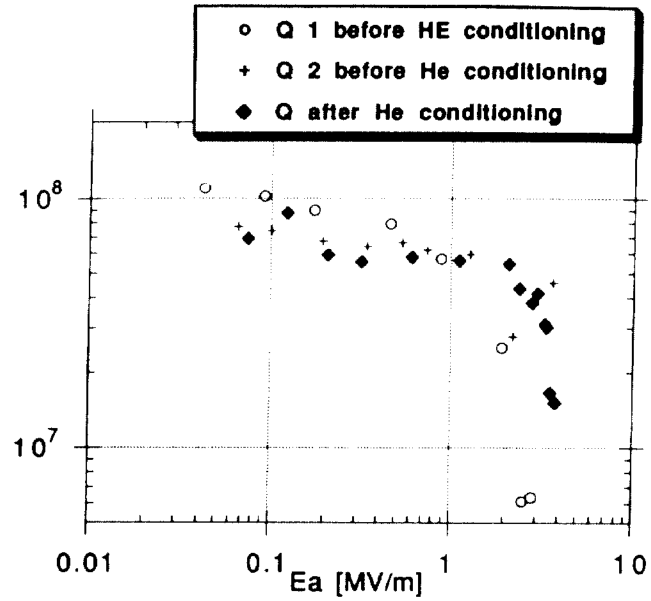

Figure 2: Plots of Q versus E_a before and after helium conditioning.

3. Field of 3 MV/m at an input power of 13 W.
4. Maximum field of 3.8 MV/m obtained with a power dissipation of 55 W . The resonator field was stable even at high power input.
5. Maximum rf power dissipated in the resonator, with

no significant increase of the field level, was above 55 W limited by thermal breakdown. The level of X-rays measured at the side of the cryostat was high (180 $\mu S/h$).

3 CONCLUSIONS

The 80 MHz high RRR all-niobium, bath-cooled quarter wave resonator seems to be a very good design solution for an accelerating element of the low beta section of the ALPI linac. It has the advantages of relatively low weight and if treated properly (clean room treatment, no long term hardly controlled storage and no vacuum accidents) it would most probably reach a much higher low power quality factor and could be routinely operated at about 5 MV/m for 10 W of rf power; its thermal breakdown which occurs only at 70 W, proves that the cooling is excellent. We hope to be able to restore the shape of the resonator, using most probably "surgery" treatment, to its previous shape and thus bring it back to its original frequency and get the expected higher (both, low and high power) Q values.

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