STATUS OF RF SUPERCONDUCTIVITY AT LABORATORI NAZIONALI DI LEGNARO

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Abstract

ALPI, a superconducting linac for heavy ions, is presently under construction at Laboratori Nazionali di Legnaro. The activities on rf superconductivity which are part of the ALPI project are divided into four main branches: lead plated copper cavities, bulk niobium cavities, niobium sputtering and superconducting RFQ. Part of the R&D work (copper-lead and niobium medium β cavities) was successfully concluded and the installation of the linac medium β section has started; other projects (low β niobium and medium β niobium-copper cavities) are in advanced stages of development.

1. The ALPI project

The ALPI project [1] consists of a superconducting linac for heavy ions (fig.1) capable to accelerate all kinds of ions above the Coulomb barrier of any beam-target system; since this machine will be used mainly for nuclear physics experiments, good beam quality and energy tunability will be required. ALPI will have two injectors: the first one is the recently upgraded and equipped with a new pulsing system 16 MV XTU Tandem; the second one will be a positive ion injector based upon the ECR source Alice, presently being tested at Legnaro [2], followed by a set of six superconducting RFQs. The beam from the injector will enter a series of superconducting cavities: 24 low β (optimum velocity β_o=0.055) 80 MHz quarter wave resonators, 48 medium β (β_o=0.11) and 21 high β (β_o=0.15) 160 MHz ones; four more cavities (low and medium β) will be used as bunchers. In the first phase of operation the 160 MHz medium β lead plated copper cavities will serve as accelerating elements and a bulk niobium resonator will be used as a buncher. In the second stage of construction the low β and the high β resonators will be added; the third step will be the installation of the positive ions injector. Eventually, the linac will be upgraded by replacing the lead plated on copper with niobium sputtered on copper or bulk niobium resonators.

A small part of the linac, consisting of the 160 MHz superbuncher and one cryostat containing four medium β cavities, was tested with the beam; the results confirmed the field calibration of the cavities previously obtained by means of RF techniques, as well as the adequacy of the pulsing system.

The first beam through the medium β section is expected within 1992.

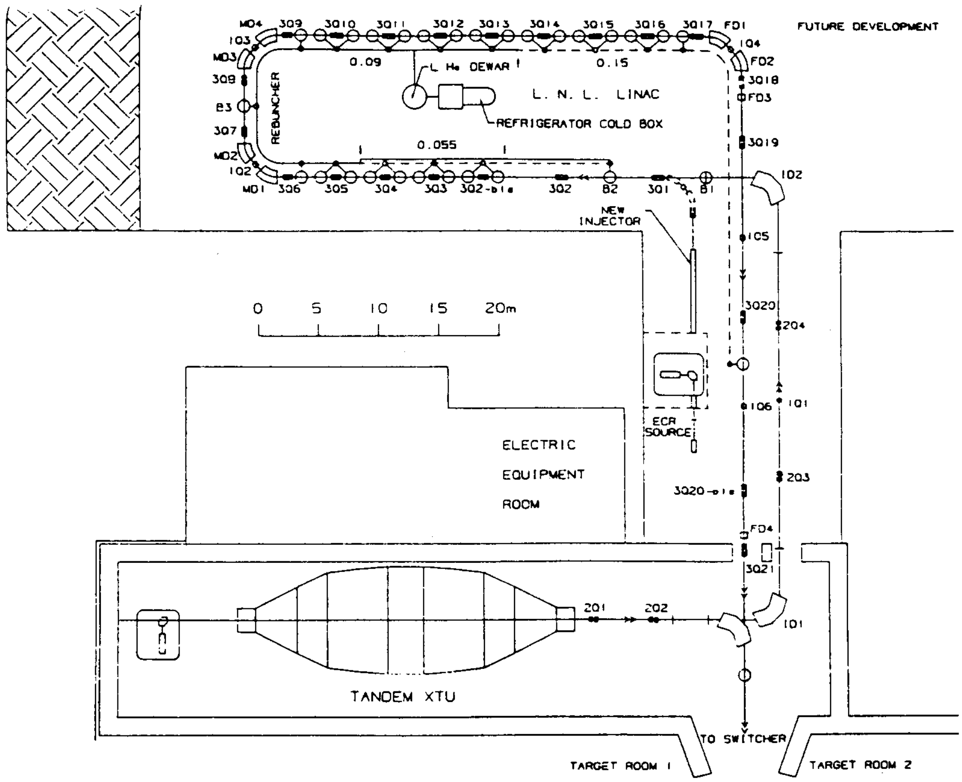


Fig. 1. ALPI layout.

2. Lead plated copper resonators

The Cu-Pb cavities that will be installed in the medium β section are quarter wave resonators with resonance frequency of 160 MHz and β_o=0.11 [3]. The final shape was defined after a long period of measurements and took advantage of the experience obtained with the niobium prototype (see next paragraph). Its main characteristics were the absence of the traditional donut-shaped drift tube, replaced by a simple hole through the inner conductor and a hemispherical termination (fig.2); accurate calculations and measurements of the electric field distribution in the region of the rf gap with the dielectric probe (bead) technique have shown [4,5] that the presence of the donut was not justified in our case and gave some problems in machining, sputtering and welding, as well as in the peak field optimization.

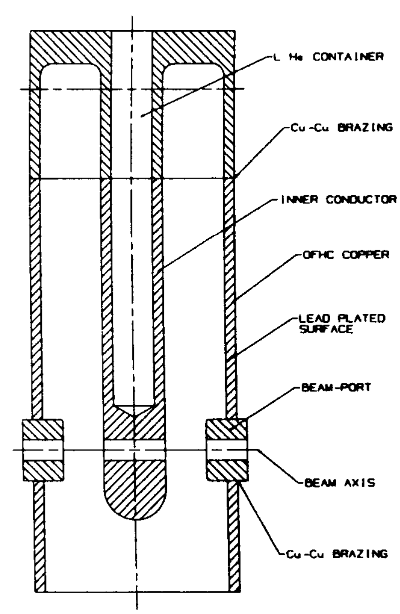


Fig. 2. 160 MHz, $\beta_o = 0.11$ *copper resonator.*

Another significant change is the absence of inner conductor tapering which was responsible for the strong multipactoring levels in the previous configuration. The parameters of the resonator are shown in table 1. Important improvements were also achieved in the fabrication technology: one of the main problems was related to the electron beam welding of copper, which often leaves bubbles and cracks in the copper substrate; in order to avoid the need of electron beam welding a big effort was made in order to improve the high vacuum brazing technique, which is now perfectly reliable [6]. The resonator body, now, can be produced in two different ways: 1) by machining separately the inner and the outer conductor and then brazing them together; 2) by machining it from a rod of bulk material; in both cases the frequency of the resonator has to be adjusted by proper positioning of the beam ports which then have to be brazed to the resonator. The steps of the production cycle are listed in table 2. In the future the second technique would be probably preferred for Nb sputtered resonators, since the cleaning procedure seems to affect the surface of niobium sputtered over the brazing material.

Fig. 3 illustrates the typical performance of a brazed resonator at liquid He temperature. The measurements were preceeded by 15 hours of baking at 350 K; the multipactoring conditioning was done at room temperature and needed a few hours; in addition, the resonators were rf- and He-conditioned with 470 W maximum peak power for 2 hours. The results were very good for a Pb resonator and

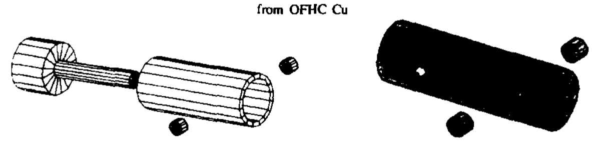
Table 1. Pb-Cu cavity parameters.

	Theoretical	Measured
f [MHz]	160.000	160.000
β_{op}	0.10	0.11
TTF (β_{op})	0.92	0.91
Q_{copper}	8759	8400
Γ [Ω]	29	32
R_{sh}' [MΩ/m]	24	24
U/E_a^2 [mJ/(MV/m)^2]	63	64
E_p/E_a	4.6	4.7
H_p/E_a [Gauss/(MeV/m)]	104	

Table 2. Pb-Cu resonator production cycle.

BRAZED TYPE — BULK MACHINED TYPE

ROUGH MACHINING from OFHC Cu



Cu-S.S. TRANSITION BRAZING AND STRESS RELIEVING BY THERMAL CYCLE IN FURNACE (840 °C; 10^{-3}Pa)

BRAZED TYPE	BULK MACHINED TYPE
MECHANICAL FINISHING + BRAZING JOINT PREPARATION + CAVITY ASSEMBLING BY BRAZING (800 °C; 10^{-3}Pa)	MECHANICAL FINISHING

MILLING OF HOLES FOR BEAM PORTS

MILLING OF BEAM HOLE IN THE CENTRAL CONDUCTOR

1st STAGE TUMBLING (large size, around 25 μ, abrasive imbedded in plastic material)

BEAM PORTS POSITIONING ACCORDING TO FREQUENCY REQUIREMENT

BRAZING OF BEAM PORTS (800 °C; 10^{-3}Pa)

2nd STAGE TUMBLING (medium size, around 8 μ, abrasive imbedded in plastic material)

3rd STAGE TUMBLING (small size, around 5 μ, abrasive imbedded in plastic material) more than fulfilled the design requirements of 3 MV/m at 5 W forward power. The maximum field obtained in cw operation was 4.4 MV/m at 17 W power, limited by field emission. The field calibration was tested also online with a ^{32}S beam at 154 MeV scattered by a gold foil and using a solid state detector (SSB) [3].

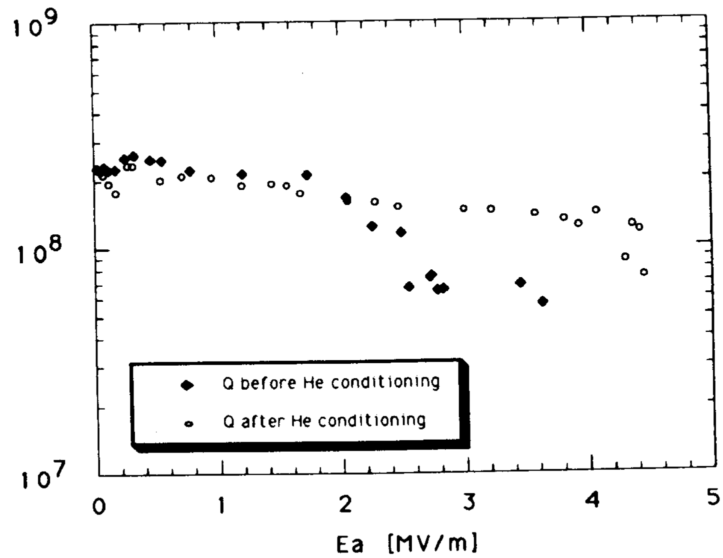


Fig. 3. Cu-Pb performance at 4.2 K.

3. Bulk niobium resonators

A bath-cooled all-niobium 160 MHz quarter wave resonator prototype was constructed and tested [7]. The objective of this research has been the development of a high performance accelerating element with $\beta_{opt} \simeq 0.11$ for ALPI. The goal of the design was to get a quarter wave resonator made of high thermal conductivity niobium with a structure which would allow for good cooling and for baking at high temperatures. The resonator shape was optimized for lowest peak surface electric field and reduction of multipactoring. The calculated and experimental values of the resonator parameters are shown in table 3. The result of the design is shown in fig. 4a. 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 was utilized.

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

The thermal treatment was based upon the experience of other laboratories [9] which have used titanium sublimation in order to improve the

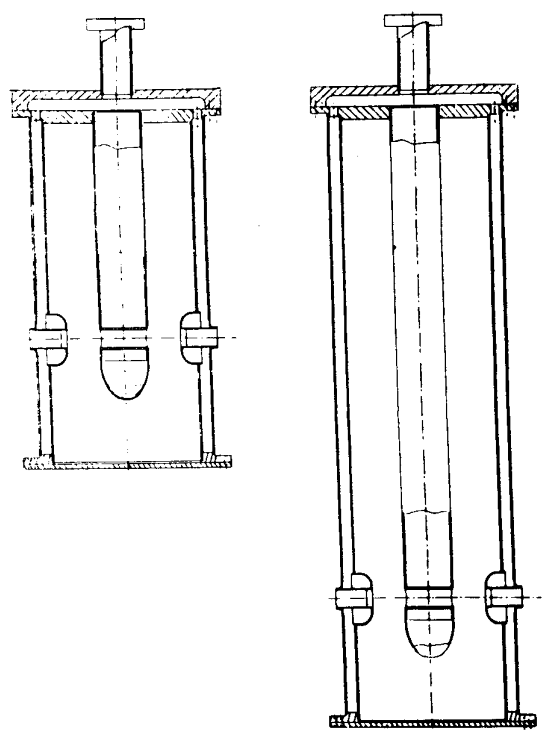


Fig. 4 Bulk niobium cavities:
a) 160 MHz, $\beta_o = 0.11$;
b) 80 MHz, $\beta_o = 0.055$.

thermal conductivity of niobium. The duration of the treatment at 1200°C and 1×10^{-6} Torr was 4.5 hours preceeded by 17 hours of degassing and warmup and followed by 14 hours cooldown. The surfaces exposed to rf were protected from titanium during the treatment. We did not etch the titanium off the niobium surface after the furnace treatment.

All the rf measurements were performed at Legnaro, after rinses with deionized water followed by ethanol. There was no clean room at our disposal and the rinsing was done with standard deionized water.

The multipactoring conditioning did not present any particular problem. The results of the measurements at 4.2 K are shown in fig. 5. The low power $Q = 2.4\times10^8$ is almost flat up to a field of 5 MV/m, reached at an input power of 10 W; at 5 W,which is the standard ALPI operation power per resonator, the field was 4 MV/m . The maximum rf power dissipated in the resonator was 70 W limited by thermal breakdown.

Table 3: Bulk niobium quarter wave resonator data

	Ben-Zvi Brennan[8]	Superfish*	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

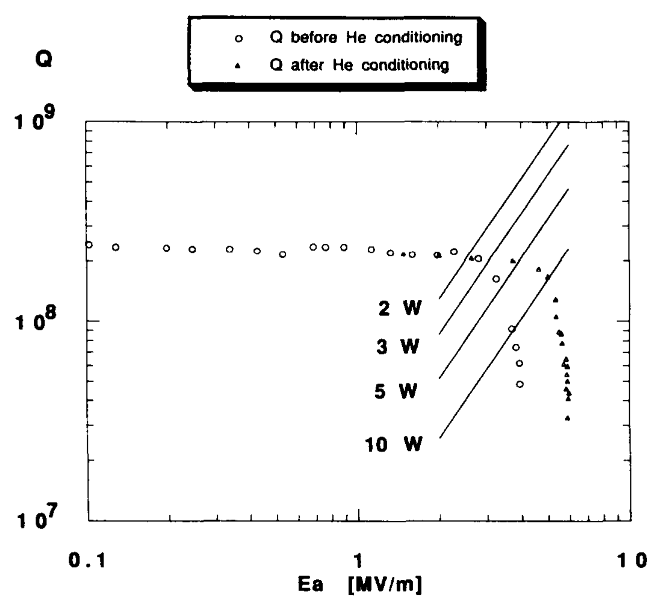


Fig. 5. Medium β niobium resonator performance at 4.2 K.

This resonator will be used as a superbuncher; similar cavities could also be used for upgrading the ALPI linac. 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 still room for a significant improvement of the surface quality by proper dustfree handling of the resonator.

Another bulk niobium cavity was constructed and is going to be tested (fig.4b): it is an 80 MHz low β resonator, to be used as a buncher and which represents the prototype for the ALPI low β resonators; again, the same shape could be produced also using the Cu-Pb or the Cu-Nb technology.

The design philosophy is the same as for the 160 MHz resonator, and the only significant change is in the length; this choice may not be optimal for maximum shunt impedance, but it allows us to use the cavities with our standard components and to reduce the total cost of the accelerator at the expense of rather small increase of power consumption.

4. Niobium sputtering

Niobium Sputter-coated Copper cavities can represent an elegant solution for high performance resonators. In comparison with lead cavities, higher accelerating fields are expected, also improved thermal conductivity and reduced costs would be achieved when compared to bulk Nb or explosively bonded Nb/Cu QWRs.

The sputtering of Niobium in a DC Biased Diode configuration has been investigated for Legnaro OFHC Copper QWRs. Using this method, high purity superconducting Niobium thin films have been deposited with a uniform thickness of $1 \pm 0.2\ \mu m$ and a critical temperature $T_c \geq 9.2K$ onto the whole inner surface of the resonator. The sputtering feasibility of high quality superconducting Niobium thin films onto Copper QWR has been demonstrated and the results were presented at this conference [10].

5. Superconducting RFQ

As a part of the positive ion injection project for ALPI linac a Superconducting Radio Frequency Quadrupole (SRFQ) is under development in collaboration with the State University of New York at Stony Brook. In this collaboration framework a prototype has been constructed and tested in Stony Brook and the results here presented refer to the SUNY resonator.

The RFQ structure is a focusing channel that provides also an acceleration using the properly shaped electric field inside an rf cavity. This property is very useful in the low energy range of the acceleration, i.e. from few keV/u up to few MeV/u.

In order to have a suitable structure for both, heavy ion acceleration and superconducting operation, a new design philosophy has been developed. The result of this study is a very short RFQ resonator, which we call RFQ-let, based on the four rods structure [11] and containing only a few acceleration gaps, typically four (fig. 6). Consequently the RFQ-let has a large acceptance with respect to the velocity range of the input particles and the resonator volume is small enough to make possible the cooling at L-He temperature.

A complete design for an RFQ-let chain covering the velocity range of $\beta = 0.01 \div 0.05$ has been done considering the lead ion with a charge over mass ratio of 1/6 (Pb^{+35}_{208}). A maximum surface electric field of $E_s = 16$ MV/m has been chosen . The input parameters of

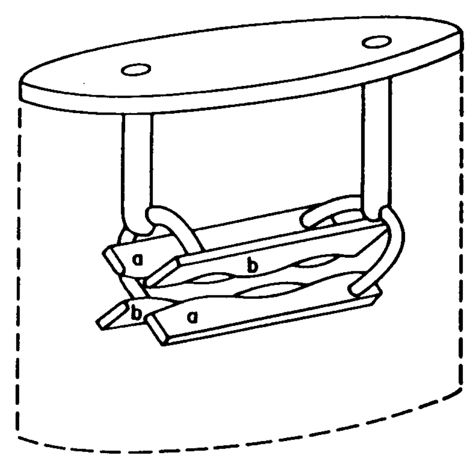


Fig. 6. Schematic drawing of a $2\beta\lambda$ RFQ resonator.

the beam that we used were 0.1π mm-mrad for the normalized transverse emittance in both planes, and for the longitudinal phase space an energy spread of 0.07 MeV total ($\delta W/W=10^{-4}$) and a phase spread of 20 degrees total (1.1 ns at 50 MHz). Using the possibility of controlling the phase of the single resonator we applied the "modulated phase focusing" technique [12] to achieve the required transverse stability.

The E_a/E_s is of the order of 1/6 which is comparable with the other superconducting structures. The number of required resonators is 6, each of them being about half a meter long.

For the prototype we have chosen a resonator with the β variation from 0.03 to 0.0358. The prototype was built and the measurements of the electrical characteristics have been performed [13,14] on the copper resonator at room temperature. At the resonant frequency of 57.374 MHz the main parameters of the resonator were: U/E_a^2=24.9 mJ/[MV/m]^2, B_s/E_a=177.6 Gauss/[MV/m], Γ=14.1 Ω, Q=7200 (copper substrate)

A full chain of resonators operating at 80 MHz will be designed and constructed in Legnaro.

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