# Research and Development in the Field of SCRF at INFN- LNL

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*Abstract*

As many as 70 QWRs realized in Pb/Cu, bulk Nb and Nb/Cu are now operating in the SC linac ALPI. This offers the opportunity to compare the peculiarities, the advantages and disadvantages of the different technologies in the same working conditions. A plan to improve the ALPI performance substituting the Pb layer with sputtered Nb is in progress.

Since the last RFSC workshop a significant effort has been devoted to realize PIAVE, the ALPI positive ion injector, that includes two SC RFQs, one under construction and the other presently under cold test, and 8 bulk-Nb QWRs that are ready to be installed.

Moreover the technology of cavity construction by spinning of a circular blank is under development.

Feasibility studies for SC 100 MeV, high current, proton accelerator and related resonators, complete the activity in the RF field at Legnaro.

## 1 INTRODUCTION

The design of ALPI [1], the superconducting linac of LNL, foresaw originally 85 Pb on Cu accelerating cavities housed in 23 cryostats to increase the energy of beam, coming from the 15 MV XTU tandem, up to 20 MV/amu. Four more cryostats were foreseen for bunching.

The choice of this consolidated technology enabled us to have the first section of 44 medium β cavities installed by 1994. This gave the possibility, in the following years, to deliver to the researchers ions beams with energy up to 12.3 MeV/amu, in the case of $^{28}$Si, and up to 4.4 MeV/amu for $^{90}$Zr [2].

The installation of the low β and high β resonators was foreseen in a second stage and this postposition allowed the investigation of new, more promising, but even more challenging, options.

The sputtering of Nb on Cu has been developed for the QWR of the high β section [3], while bulk Nb technology development led to produce QWRs wholly realised, with the exception of the tuning plate, in this material [4]. Both research programs lead to very encouraging results that allow us to reach the original ALPI design goal using only 16 cryostats, housing a total of 64 accelerating resonators, without the necessity to install new units.

The main LNL task in the near future is the completion and the commissioning of PIAVE [5], the positive ion injector, whose complex RFQ superconducting structures represent a substantial achievement in the resonator development.

The spinning technology for the construction of seamless resonators, developed at Legnaro [6], is now more than a promising technology. The resonators realised by this cheap and reliable technique reach more than 30 MV/m. The new developments will take surely advantage from the new laboratory for cavity treatment that is just came into operation at LNL.

## 2 THE QUARTER WAVE RESONATORS

The Nb bulk technology has started at Legnaro, in collaboration with the Weizman Institute and CERN, to build prototypes of all Nb, double wall QWR resonators with β optimum ranging from 0.056 and 0.17 and frequency of respectively 80, 160 and 240 MHz. All the prototypes showed encouraging performance and the low frequency unit was adopted as ALPI low β resonator.

All the resonators were built by industry and the chemical treatment was performed at CERN. The Pb/Cu (or Nb/Cu) tuning plates are instead produced in our laboratory where the final treatment of the resonator surface (high-pressure water and ethanol rinsing), the assembling in the cryostat and the RF test are performed.

Up to now we have installed in ALPI 13 such resonators [2] and other 9, in which the inner conductor end was slightly modified to reduce the βopt to 0.047, as required for PIAVE QWR units, are now ready. The results of the first, very promising RF tests, are presented at this Workshop [8].

In spite of the complex shape and of the large number of EB welding, the resonator performance is extremely good. All, but one that was later repaired, exceeded 6 MV/m, the mean value being 7 MV/m at 7 W dissipated power. The first four resonators mounted on line reach an accelerating field of 11 MV/m corresponding to a maximum surface field of 50 MV/m and a maximum magnetic field of 1110 G, the average accelerating field, at 7 W dissipated power, being 7.1 MV/m

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The bulk Nb resonators are intrinsically more sensitive than copper ones to fluctuations on He pressure bath. Moreover the low frequency foreseen for the low β ALPI section, which requires in the QWR an inner conductor about 1 m long, made this resonator prone to mechanical resonant vibrations and then to frequency fluctuations. Usually a fast tuning device is used to enlarge the resonator bandwidth and to make possible the locking to an external reference, necessary in independently phased linac. These difficulties, that can prevent resonator operation at the maximum accelerating field allowed by the available cryogenic power, have been solved in an original way that does not require the reactive power used in the electronic fast tuner. A mechanical damper, inserted and coupled to the QWR inner conductor, and then operating inside the He bath, reduces the Q of the most dangerous mechanical modes. This device prevents resonator unlocking connected to resonant vibrations, even in the noisy accelerator environment. The frequency drifts, caused by pressure variations, are instead compensated by the mechanical tuner whose movement is controlled by a software program, that monitors the resonator residual phase error and moves the tuner as necessary. In this way the resonators can be locked steadily at 6 MV/m.

The technology of DC biased Nb sputtering on Cu has been applied at Legnaro to the development of QW resonators and allowed to reproducibly obtain 160 MHz β=0.13 cavities sustaining accelerating fields greater than 7 MV/m at 7W of dissipated power. The four units that were installed in the linac in 1998 are operating at an average accelerating field of 6 MV/m providing a beam energy gain up to 1 MeV per charge state per cavity. The accelerating field is slightly lower than the one measured during test and an improvement is possible by RF power conditioning [9].

The OFHC Cu substrate, which is machined out of a rod and did not present any brazed joint, makes the resonators insensitive to He bath pressure variations. As a consequence the resonant frequency is very stable and the cavity lock to the external reference is steadily reached providing a slight overcoupling (less than 20 W of quiescent RF power) without necessity of continuous tuning even when the resonators are operating at 6 MV/m.

At present, since no other cryostats are available, we cannot install new units, but we plan to replace the last four medium β units, installed in ALPI, with four of these cavities. The main effort will be instead concentrate in the substitution of the Pb electroplated coating of medium β resonators, installed in ALPI, with sputtered Nb [2]. In principle, medium β resonators can reach the same results of high β units, but these cavities were produced and installed before setting the most suitable geometry for the sputtering process. Some characteristics of copper bases limit the reachable performance. Nevertheless minor inexpensive changes in the Cu substrate allow obtaining a sputtered Nb coating that improves substantially the actual resonator performance. Eight of these modified resonators were installed last year and they are now operating at 4.8 MV/m at 7 W. Other four resonators will be mounted by the end of the year in the frame of a maintenance program that foresees the substitution of 6 cryostats in two years and that will increase the ALPI equivalent voltage practically without any adjunctive cost.

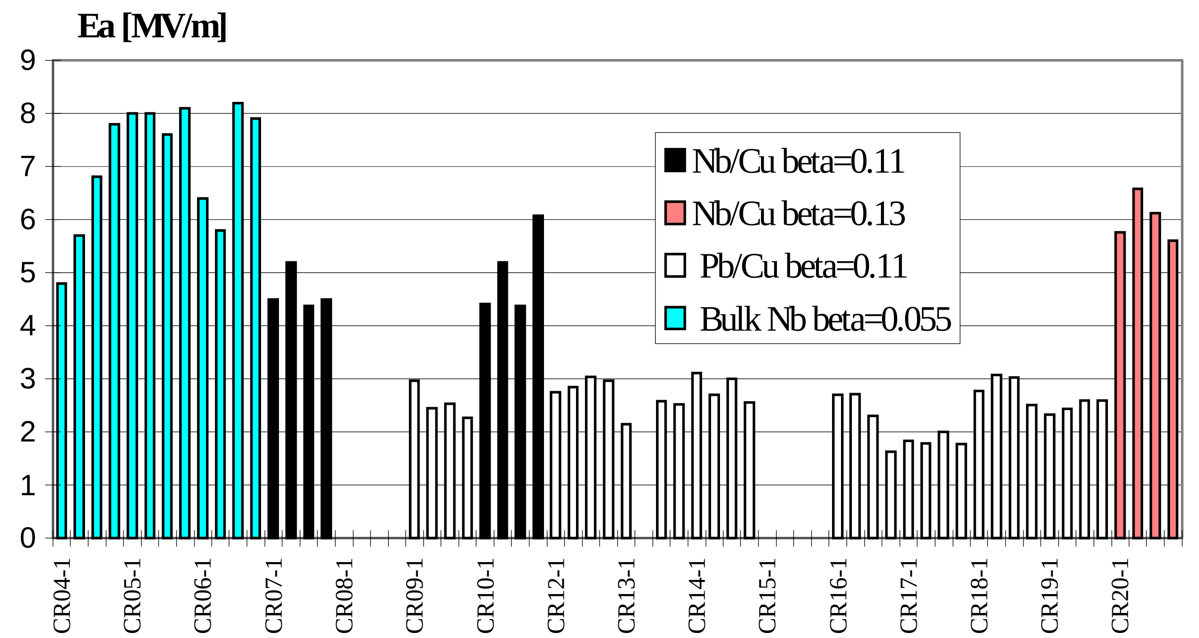


Figure 1. Performance of the installed ALPI resonators.The cryostats CR08 and CR09 are on maintenance and they will house sputtered medium β cavities.

QW Pb on Cu resonators have remained installed in ALPI for more than 5 years. Their average accelerating field is relatively low (2.7/MV/m), but they do not show any deterioration in the performance, in spite of the high number of thermal cycles, and they are very stable in frequency (unlocking extremely rare without any fast tuning device) [2]. The lead plating technology that was used to produce the first ALPI resonators is at present adopted only to coat some of the resonator tuning plates, being the main effort devoted to Nb coating of the old resonators. However it does not mean that plating will be abandoned: when high accelerating fields are not mandatory and tricky shape or defective substrates are available, it can satisfactorily be used. The substrate cleaning and the Pb passivation method developed at Legnaro [10], alone with the new plating solution available and to a better control of plating parameters, could anyway lead to good performance resonators.

## 3 THE SC RFQS

PIAVE, the ALPI positive injector, is under an advanced construction stage. The ECR source, on its high voltage platform, and the low energy transport line are under commissioning. The magnetic elements and the vacuum system are completed. The refrigeration plant and its distribution line will be ready within next year. The eight QWRs, now under test, will be housed in two cryostats of ALPI type that have already been realized. The two RFQs, SRFQ1 and SRFQ2 (figure 2) will be mounted in a single cryostat whose design will take advantage from the experience obtained in the construction and cooling of the available test cryostat. RFQ1 is now under construction, while RFQ2, equipped with tuning and coupling systems, is under cold test. Both RFQs are structures of the four-rod type and operate at 80 MHz. The cavities are realized in bulk Nb and the structure is made more stable against vibrations by a Ti stiffening cage. The end plates are Nb sputtered on OFHC copper. The project and realization of the two RFQs superconducting resonators are the more challenging parts of the PIAVE project. The construction technology, the electromagnetic characteristics and the mechanical behavior of both units have been extensively tested in purposely-built models [11,12]. The stainless steel model of the RFQ2 has been cooled down to 77 K in order to set the assembling and cooling procedures and to verify the tuning and coupling mechanisms. The cold test demonstrated that the resonator was integrally cooled and that the gas trapped in the inner electrode could be correctly evacuated using the designed draining system [13]. The RFQ2 Nb resonator has been completed in May 1999. The electrodes were machined at the LNL workshop while then EB welding were performed at Zanon spa. The structure has been tested in a liquid N bath to check the change in the resonant frequency and to evaluate the mechanical stress during cooling down. The chemical etching was performed at CERN, first on the electrodes before welding (60 µm), then on the whole inner resonator surfaces (another 60 µm). HPR followed the last CE step and since then the cavity was stored in clean N atmosphere. Bead pulling measurement allowed to determining the accelerating field profile on the beam line and the $U/(Ea)^2$ ratio, necessary for an experimental evaluation of the accelerating field. Before the final assembling in the cryostat the resonator was HPR. At present the resonator is cold and the cryogenic and RF tests are in progress. An up-to-date description of the cryogenic and RF test of RFQ2 is presented elsewhere at this workshop [13].

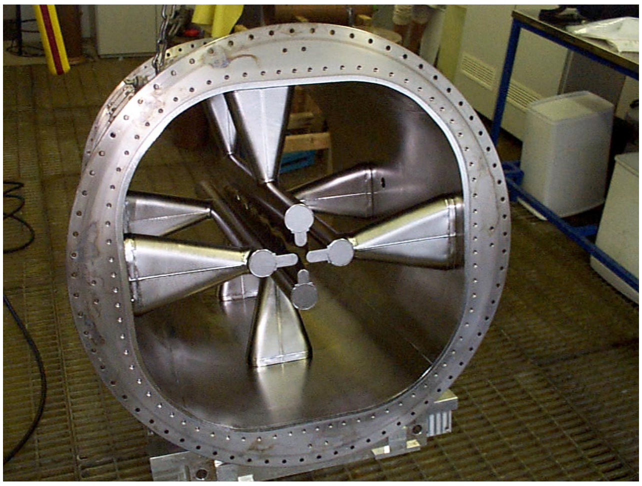

Figure 2 .SRFQ2 resonator at the final stage of rinsing, prior to installation into the test cryostat.

## 4 THE SEAMLESS RESONATORS

The spinning technology for the production resonators was proposed at Legnaro in the framework of a INFN-CERN collaboration aimed to produce superconducting resonators for future linear collider by sputtering. This innovative technology allows producing, at an extremely reduced cost and in a few hours, axially symmetric seamless resonators. In the spinning process a disk (or a tube), clamped to a rotating chunk, is plastically deformed by suitable tools. The shape is obtained by compression of the blank on a mandrel with the tool acting on the outer resonator surface. Many parameters like type, shape and thickness of the starting blank and of the resonator to be shaped, determine the tools and lathe parameter choice. Finding the most suitable process parameters, the intermediate steps and the suitable dies for a given shape and material is crucial and asked for a systematic approach. The research allowed producing, without necessity of any intermediate annealing, mono and multicell resonators in Nb, Cu, Al. Several 1.5 GHz monocells have been chemically treated and tested at JEFFERSON Lab and some of them reached 30 MV/m. Some 1.5MHz resonators, produced by spinning, have been sputtered and tested at CERN. Qo of the order of $10^{11}$ and accelerating field of 15 MV/m have been achieved in one 5-cell cavity following a removal of only 100μm of thickness by BCP [14].

In the case of multicell the resonator thickness uniformity improves when the resonators are spun from tubes. Seamless tubes are produced at Legnaro in four steps by deep drawing without the necessity of any intermediate annealing. Updated results are discussed elsewhere at this workshop [14]

## 5 A PROPOSAL FOR WASTE TRASMUTATION LINAC

Our Laboratory is involved in TRASCO, an INFN-ENEA feasibility study of a waste trasmutation, accelerator driven, system. A preliminary study of 100 MeV, 30 mA, proton linac, consisting of 253 independently phased superconducting resonators, was performed [15]. The proposed linac is a FODO structure with period $6\beta\lambda$, covering the energy range form 5 to 100 MeV. The number of resonators in each period is increasing from 1 to 4 according with the increasing of its length. The resonators are single gap reentrant structures resonating at 352 MHz. The cavity beam loading determines the choice of a single gap cavity. In this way a single 15 kW solid state amplifier can drive each resonator.

## 7 ACKNOWLEDGEMENT

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