UPGRADING OF MEDIUM BETA ALPI RESONATORS BY NB SPUTTERING

A.M. Porcellato, L. Badan, L. Bertazzo, A. Capuzzo, D. Carlucci, D. Giora, F. Stivanello, V. Palmieri, INFN Laboratori Nazionali di Legnaro (Pd), Italy

S.Y. Stark, Strumenti Scientifici, CINEL, Vigonza (Pd), Italy

Abstract

ALPI is the superconducting linac for heavy ions in operation at Legnaro. Its medium β section used to be composed by Pb/Cu QWRs. The replacement of Pb by a Nb sputtered film allowed improving the resonator performance substantially at very low cost. The average operational accelerating field of the cavity rose from about 2.5 MV/m to more than 4 MV/m. The upgraded resonators maintain the same thermal and mechanical stability typical of copper-based resonators, making their lock in field and phase easy and reliable. At present 2/3 of the resonators have been upgraded and installed without interfering with ALPI beam time schedule.

1 INTRODUCTION

ALPI [1] is a super-conducting linac for heavy ions, booster of a 16 MV XTU Tandem, in operation since 1994 at Legnaro. Its accelerating structures are Quarter Wave Resonators (QWR) of three different β.

The lower β section (β=0.056) includes 12 cavities housed in three cryostats [2]. The resonators are 80 MHz QWR realized in full Nb. They can reach an average E_a (accelerating field) of 7 MV/m at 7 W dissipated power. Their installation was completed in 1999 but problems in He distribution lines prevented the possibility to operate them routinely up to now.

ALPI medium β section consists of 44, β = 0.110 and f = 160 MHz, QWRs in 12 cryostats. The resonators, whose original superconducting layer was Pb electroplated on Cu, were installed n 1992-1993, and were operated, at their best, at an average E_a of 2.7 MV/m. The first beam was accelerated in ALPI in May 1994 and since then the cavities have been routinely used to provide beams to nuclear physics experiments in scheduled beam runs [3]. In the frame of a cryostat maintenance programme started in 1998, 9 medium β cryostats were removed from the beam line and had their cavity upgraded, as later described, substituting the Pb layer by a Nb film (fig.1). The refurbishing of the remaining 12 cavities is foreseen soon, compatibly with ALPI operation.

The high β section (β=0.13) includes only 8, Nb/Cu QWRs. Their shape was optimised for the sputtering process and this allows reaching accelerating field exceeding 7 MV/m at 7 W [4].

Three buncher units, containing two, Pb/Cu 160 MHz resonators each, complete the ALPI superconducting structures.

Further 8, β=0.045, QWRs and two RFQs are going to enter into operation in PIAVE, the second positive injector for ALPI [5].

2 QWR NB SPUTTERING AT LNL

Pb/Cu resonators, operating at 3 MV/m, had been chosen for ALPI design, because they were thought to be more affordable and cheaper, but the hope to upgrade them in future inspired a research project aimed at studying the sputtering process in QWRs. The method developed in Legnaro was DC biased Nb sputtering and it was first applied for producing the high β resonator [6].

In 1998 four resonators, whose shape and construction technology were chosen keeping into account the needs of the sputtering process, were produced and installed in ALPI where they are still operating at an average E_a of 6 MV/m [7]. No other cryostats were available for installation so we had to stop the productions. Ea = 6 MV/m is twice the design value for ALPI, and if it can be used for the last resonators, it is not compatible with the beam optics when applied to the whole cavity array, being the magnetic lattice and the cryogenic distribution line fixed. So, instead of searching for the limit performance in new designed substrates, we decided to try if it was possible to increase the performance of the existing resonators, even though some of their characteristics were not so good for such process. The expected E_as were lower than the ones reachable by the Nb sputtering technology but however higher than the ones obtained by the Pb/Cu resonators. In this way, with negligible cost, it would have been possible to substantially upgrade ALPI.

Fig. 1 Upgraded medium β resonators; by replacing its Pb layer with a sputtered Nb film it could reach an accelerating field exceeding 4 MV/m @ 7W dissipated power.

Four medium β resonators were produced and installed in a medium β cryostat in 1998, taking advantage of ready, still unused, Cu bases. In the same year a cryogenic leak forced to remove a cryostat from the beam line making 4 other substrates available, which were sputtered and reinstalled in 1999 [4]. No other resonators were available to continue the cavity refurbishing process.

New leaks developed the following year in three other cryostats suggesting a general maintenance program aimed at avoiding such events and to increase the cryostat reliability in the future [8]. We tried to combine the cryostat maintenance with the upgrading of resonators making a considerable effort to establish an efficient cavity production cycle, which allowed a fast replacement and improvement of the cavities dismounted from the cryostats. With the contribution of an external factory (Strumenti Scientifici Cinel, Vigonza (Pd), Italy), in a couple of years, other 24 cavities were produced and reinstalled. The necessity to recovery as soon as possible the ALPI performance did not allow any selection of resonators and practically all the resonators produced were installed. At present a further cryostat is going to be reinstalled after upgrading, and only 3 cryostats, having Pb/Cu accelerating resonators, are still operating in ALPI.

The bunching cavities do not need high accelerating fields, but because Nb has a more stable surface than Pb with respect to oxidation, the replacement of the superconductor will make the cryostat maintenance easier avoiding having to keep the resonators in N_2 atmosphere.

3 PERFORMANCE OF UPGRADED RESONATORS

The resonators dismounted from ALPI need some minor mechanical adjustments to make the substrates compatible with the sputtering process. Then they have to be chemical and electrochemical polished. After being sputtered they are tested at 4 K to measure Q_0. For lack of time and for limiting the LHe consumption, the resonator conditioning is performed for only half an hour, just to see if Q switches are present and to determine the Q curve drop. Generally the conditioning straights the Q curve, at least up to 7 W of dissipated power so, knowing its drop, it is possible to foresee the field the cavity will reach in operation. The full cavity conditioning is performed on line, after mounting the resonators in the ALPI cryostats.

A description of the production cycle of the sputtered resonators is described in detail in reference 9, so we prefer to concentrate here on the results obtained from the upgrading programme up to now. The operational accelerating field and the Qo values, obtained in laboratory, by both medium and high β resonators produced in between May 97 and now, are presented in fig.1. The first two resonators, named 2 and 3, are medium β cavity prototypes, similar in the construction characteristics to the following (FC) resonators, which were obtained by brazing a cylinder to a mushroom preformed. Beam ports, cavity supports and the stainless steel (SS) collar are brazed to the cavity body. The PP type cavities are instead milled out of an OFHC Cu rod; however beam ports, SS collar and holders are always brazed to the resonator body. Instead the high β resonators, labelled HB, do not have any brazed joint and are milled out of an OFHC 99.99%, certified grade, Cu rod; the cavities named hb are similar in shape to the high β type (completely rounded shorting plate, beam ports external to the outer cylinder, connected by In joints to it), but follow the construction technology and make use of the same material of FC type resonators (SE Cu 99.95% or not certified OFHC Cu; SS collar and cavity holders are brazed to the resonator body). High β resonators have capacitive couplers; medium β resonators have inductive couplers that means that the cavity have a hole in a high current region.

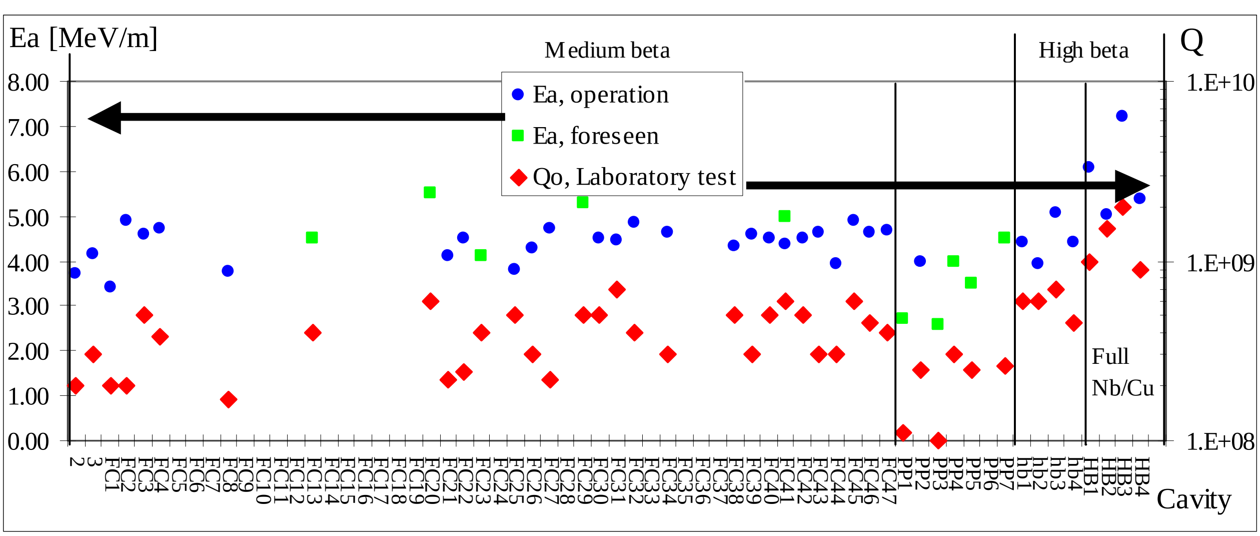

Fig.2 Performance of sputtered Nb resonators; the highest Q_o and accelerating field values, @ 7 W dissipated power have been obtained in properly built substrates. Average Ea in operation is 6 MV/m for high β cavities; 4.2 for medium β resonators.

The picture 2 shows that the HB type resonators have Q_0 value exceeding $1x10^9$ and they work at an average accelerating field exceeding 6 MV/m. The cavities with the same geometrical shape, but with different construction technology have Q_0 between 3 a $7x10^8$. The reached average E_a is 4.6 MV/m, only slightly higher than the medium β resonators (4.2 MV/m), and, if some improvement is expected by conditioning, their performances are anyway worse than the ones obtained by resonators whose substrate construction procedures were under control since the beginning. The main handicap the recovered medium β substrates seem to have is the presence of trapped hidden volumes in the brazing joints located on the outer resonator body.

4 OPERATIONAL EXPERIENCE

Thirty-two Nb sputtered resonators are installed in ALPI; 30 are routinely used, two are not operational, one because of a short in the RF input line, the other because it can not be tuned to the linac frequency (the tuning plate available is very deformed, but there was not time to build a new one). At present 2 resonators are working at a lower value than the ones obtained just after reinstallation. The cryostats in which one of them was installed had a cryogenic valve substituted because of a leak without the possibility to dismount the resonators. Once conditioned, all the cavities of the cryostat recovered the previous fields, but later, without any apparent reason, a resonator showed again strong field emission. High power He processing could get rid of it, but it could not restore the previous performance, because of Q degradation. One further cavity has a reproducible, frequency – E_a dependence, probably due to a bad contact between tuning plate and resonator; consequently we have to keep it at a reduced field level, when we operate it at the linac frequency. All the remaining 30, high and medium β resonators are working at the maximum E_a reached up to now, i.e. 4.3 MV/m at 7 W dissipated power, which means an energy gain per cavity and per state of charge exceeding 700 kV/u.

We use to run ALPI three times per year for a couple of months; in between the cryostats are warmed to room temperature. After a thermal cycle the resonators are multipactoring conditioned at room temperature for a few hours, keeping the thermal shield cooled. Then the cavities are cooled at 4 K and He conditioned for a few hours using the 100 W installed amplifier. The cavities are set for operation at the field sustained at 7 W dissipated power and at a loaded Q of about $5x10^7$. Before a beam run, they are adjusted in frequency, locked in phase and amplitude, monitored for a few hours; at the end, if necessary, the frequency is readjusted (1-2 Hz) [10]. At this point the feeding amplifier can be turned off and powered when necessary. The cavities do not need further adjustment, but the setting of the right phase for beam acceleration.

The sputtered QWRs are very stable both thermally and mechanically; their frequency is insensitive to change in He bath pressure, so they can remain locked in amplitude and phases for weeks without any fast tuners or necessity of continuous frequency adjustments, thus making their operation very easy and reliable.

5 CONCLUSIONS

The refurbishing process of medium resonators had substantially increased ALPI performance. At present the operational accelerating field is 4 MV/m, the remaining 12 installed Pb/Cu cavities included; E_a certainly will overcome such value when the remaining medium β resonators will be upgraded. By the end of the year, after repairing the cryogenic line valves, the low β resonators could be reliably cooled at 4K and in this way a further improvement in ALPI performance is foreseen.

Even though the use of recovered Cu substrates did not allowed to obtain the maximum reachable accelerating field, the cavities realized by Nb sputtering show very good performances, which are competitive with the other, much more expensive, resonators in operation. Their intrinsic mechanical stability makes the Nb sputtered resonators very attractive. The large number of built resonators and the very low rejection rate in the production process demonstrate the technology is ready and can be industrially applied.

6 REFERENCES

[1] A. Dainelli et al., Nucl. Instr. and Meth. A382 (1996) pg.100

[2] A. Facco and V. Zviagintsev, Proc. of 9th rf Superconductivity Workshop, Santa Fe, New Mexico, http://laacg1.lanl.gov/rfsc99/tup016.pdf

[3] A. M. Porcellato, et al., Nucl. Instr. and Meth. A382 (1996) pg. 121

[4] A.M. Porcellato et al, Proc. of the 8th HIAT Conference, Argonne (USA) 4-11 October 1998, pg. 228

[5] A. Pisent et al., Proc. of EPAC'98, http://accelconf.web.cern.ch/AccelConf/e98/PAPERS/MOP08H.PDF

[6] Palmieri et al., Nucl. Instr. and Meth. A382 (1996) 112

[7] S. Stark et al, Proc. of 8th Workshop on rf Superconductivity, Abano (Pd) Italy, October 97, pg.1156

[8] A.M. Porcellato et al., Proc. of 9th rf Superconductivity Workshop, Santa Fe, New Mexico, http://laacg1.lanl.gov/rfsc99/tup010.pdf

[9] A. M. Porcellato et al. Proc. of the 9th HIAT Conference, New Delhi 19-18 January 2002, in press

[10] A.M. Porcellato et al., Proc. of the 10th Workshop on rf Superconductivity, 6-11 Sep 2001, Tsukuba City, Japan, http://conference.kek.jp/SRF2001/indx.html

[11] Bassato et al., Nucl. Instr. and Meth. A328 (1993) pg.195