COMPLETION OF ALPI MEDIUM BETA SECTION UPGRADING

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Abstract

The upgrading of ALPI has just been completed. All the 44 accelerating medium β cavities and two bunching resonators had their Pb coating replaced by sputtered Nb; further eight installed resonators, of high β type, are produced by the same technology. The refurbishing of the resonators allowed to increase their average accelerating field from 2.6 to more than 4.4 MV/m, at 7W dissipated power, in spite of geometry and copper quality problems in the existing substrates. Some resonators can reach and operate at more than 6 MV/m.

The renewed cavities are driven by the same amplifiers and control systems of the previous Pb/Cu resonators and maintain the same reliability even when set at much higher accelerating fields. The low sensitivity of their resonant frequency to He bath pressure fluctuations allows their operation without necessity of any continuous tuning system. The upgrading of resonators, that was realized at a negligible cost and was combined to a necessary programme of cryostat maintenance, did not interfere with ALPI beam time schedule.

INTRODUCTION

The DC biased Nb sputtering on Cu QW substrates, which was developed at Legnaro [1,2], allowed the production of high β resonators operating steadily in ALPI [3] at accelerating field E_a exceeding 7 MV/m at 7W dissipated power. The same technology was applied in 1998 to refurbish eight Pb/Cu, β=0.11, resonators dismounted from the beam line for cryostat maintenance [4]. The resonators performance increased from an average value around 2.4 MV/m to more than 4 MV/m at 7W, showing that a substantial improvement of ALPI average accelerating field could be obtained without building new cavities, but only replacing the superconducting layer in the existing resonators. In between 2000 and 2003 all ALPI medium β cavities had their Pb film replaced by Nb in the frame of a general cryostat maintenance programme [5], that did non ask for any devoted funding, did not interfere with ALPI experiment schedule and went in parallel with the assembling of the two QWR cryostats of ALPI new positive injector PIAVE [6].

At present all the 11 medium β accelerating cryostats (44 resonators), but one that is in the final assembling stage, are mounted on line. Only two resonators are not operational, the first because has its coupler line damaged, the latter because its frequency cannot be adjusted to the linac design value of 160 MHz. Medium β Pb/Cu resonators remain now installed only in the rebunching and debunching cryostats, the bunching ones having had its cavities upgraded in 2002. In ALPI other 12, β=0.056, 80 MHz, bulk Nb cavities are installed [7].

RESONATOR PRODUCTION

Fig. 1 sums up the performance of cavities, produced by Nb sputtering in the last years, which are installed or are waiting to be installed in ALPI. The first four resonators produced in 1997 (β=0.13) were shaped taking into account the production technology [2]. In particular they have their shorting plate completely rounded, do not have beam ports protruding inside the resonators and do not present any hole in high magnetic field locations. Moreover their substrates do not have any brazed joint being milled from a rod of certified OFHC Cu. These resonators are in ALPI since 1998 and operate at an average accelerating field of 6 MV/m, which is twice the design value for ALPI. We had not the possibility to produce other cavities of this type, not having further available high β cryostats. Moreover we could not have taken full advantage of their performance because so high accelerating fields are not compatible with the existing ALPI beam optics when applied to the whole cavity array. Consequently we devoted our attention in the possibility of upgrading, at low cost, the existing Pb/Cu resonators even though some characteristics of their shape and construction technology would have limited the reachable performance. Four medium β resonators were produced taking advantage of ready still unused medium β cavities. They were installed in ALPI at the end of 1998 and could operate at an average operational field higher than 4 MV/m. Other resonators could be upgraded in 1999 when a cryogenic leak forced to dismount a cryostat for maintenance, in this way making four other substrates available.

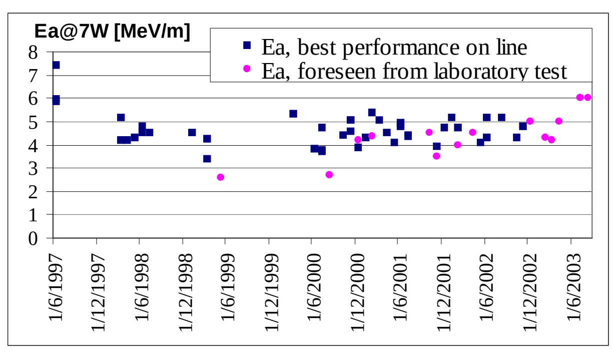

Figure 1: Performance of QWR Nb sputtered resonators as measured on line (blue squares) or in laboratory (pink circles) when not yet measured on line.

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When in the following years leaks developed in other three cryostats, it appeared clear that a general cryostat maintenance program was necessary. We took advantage of that and tried to combine the cryostat maintenance with the upgrading of resonators.

In the beginning, we were forced to reinstall the cryostats as soon as possible to provide the required beam energy to experiments. Consequently we had to accept without any possibility of choice, all the produced resonators, even when the substrate was not enough suitable or there was a problem during chemical treatments or sputtering process. As a result we had sometimes a performance lower than the usual one in the resonators installed in that period.

As soon as a few upgraded cryostats were installed, and ALPI previous beam energy was restored, we could plan a suitable programme of maintenance involving all the cryostats. Up to now this has avoided the appearing of new leaks and the necessity of unscheduled cryostat removal.

The increase in performance allowed substituting, in the last medium β cryostat, the medium β cavities with four high β type substrates built in 1994. In this way four spare medium β resonators became available, thus allowing producing in advance some resonators and making the cryostat replacement faster.

As it is possible to notice in fig.1, forty resonators were produced and tested in the last three years. The accelerating fields measured on line (blue squares) or in laboratory, in case the line cryostats are not cooled yet (pink circles), are generally higher than 4 MV/m, the average value on line being 4.4 MV/m.

Lower values are connected to the use of not suitable substrates or to vacuum deterioration during the sputtering process. We plan to use such less performing, not yet installed, cavities in ALPI buncher cryostats.

We are having higher performance, at least in laboratory, in the last produced resonators. This seems connected to replacement of the sputtering Nb cathode that, after about hundred cavity cycles, became too thin and with holes, and started to deliver fragments, which induced discharge during the sputtering process. The new one has been made thicker (3 instead of 2 mm), thing that appears more suitable for producing a more uniform film on the flat shorting plate of medium β resonators.

RESONATOR PERFORMANCE ANALYSIS

Fig. 2 presents the dependence of performance, both in Q_0 and accelerating field (E_a) sustained at 7 W, by different types of cavities Nb/Cu cavities installed in ALPI. High β resonators (HB), whose substrates are built without brazing and using certified OFHC Cu, reach the best results. The resonators called hb, which have the same inner shape of HB cavities, but are realized with the same technology and material of medium β resonators, have performance lower than the HB, but higher than medium β resonators (FC type), which are built mainly in SE CU 99,95% and have brazed joints.

As it is possible to notice in fig. 2, only seven built cavities have not yet their performance included in the picture. Four of them are still mounted in ALPI, in the rebuncher and debuncher cryostats, the others are going to be processed soon and will be used as spare units.

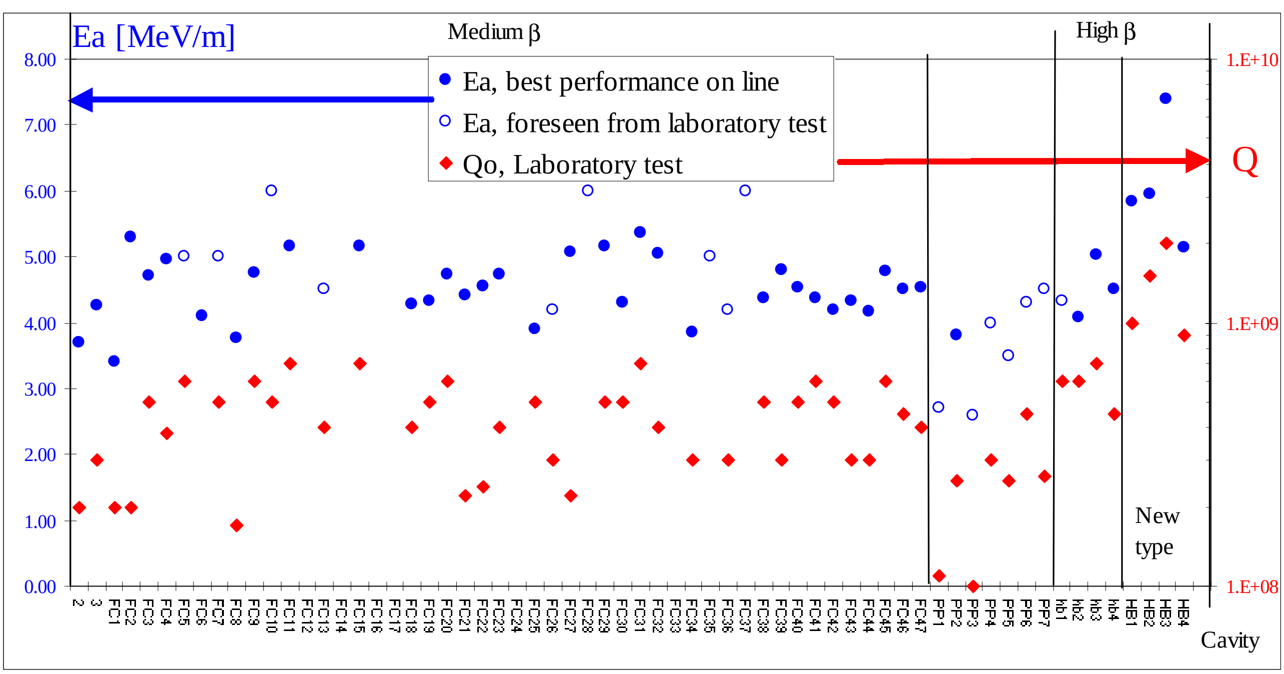

Figure 2: Performance of produced and measured sputtered resonators; the highest Q_0 and accelerating field values have been obtained in properly built substrates. Average operational accelerating field is now 6 MV/m for high β new type resonators; 4.4 MV/m for medium β cavities.

Resonators having an extra coupler hole drilled by mistake in the high magnetic field region (PP type) present the worst performance. Resonators called 2 and 3 are ALPI prototype cavities.

We used, for producing ALPI medium β resonators, the sputtering apparatus (fig. 4) set up in Legnaro for the development of this technology. The only major improvement in the last two years was the possibility to use a second sputtering chamber that was built to produce the ending plates of the PIAVE RFQs [8], in which 9 plates for QW resonators could be sputtered together reducing the production time.

We do not describe here the production procedures, reported in detail in reference [9], but we prefer instead to analyse the results obtained and indicate where we see possibility of improvements. The flat shorting plate, where it is difficult to deposit an enough thick and uniform film, and the presence of holes in high current regions clearly limit the performance reached by recovered ALPI medium β resonators, but a further crucial handicap is connected to the presence of hidden enclaves left under the screws used to keep connected the resonators components during the brazing process. The opening of such trapped volumes, when the cavity temperature rises during the sputtering process, delivers impurities that contaminate the growing film worsening its superconductive characteristic. Only after having systematically opened all such volumes, operation that if tedious and time consuming resulted to be however essential, the performance of the upgraded cavities reproducibly increased.

Since 2000 we have been working on resonator production cycle and no time or manpower has been devoted to trying to optimise the resonator performance. Having only one chamber where to sputter the QWRs, any change in configuration or sputtering parameters would have slowed the production cycle and was potentially risky.

Moreover we had not enough personnel to devote to this activity so there was space only for changes strictly necessary. Minor adjustments in the support systems of cavities, cathode, grounding and bias electrodes would help to make the assembling and alignment easier and more reliable and would reduce the possibility, during the sputtering process, of discharges, sometimes responsible of performance reduction.

The same advantage would come from the availability of spare supports and holders whose more frequent chemical treatment and/or cleaning would allow reducing the presence of contaminations in the sputtering chamber without stopping the production process. Powder coming from fragmentation of film deposited on supports or electrodes can contaminate the resonator, spoiling its performance.

Even if it delays the production time, it was found useful to rinse always, with high-pressure deionised water, the resonator after the sputtering process. This rinsing is not only effective in reducing the field emission, but also, in some case, leaded to resonator Q_0 increase.

We did not have the possibility to connect the vacuum system of our sputtering apparatus to a back-up electrical power generator.

Figure 3: A medium β ALPI cavity mounted in the sputtering chamber.

So in case of power failure during the sputtering process, which fortunately has not been so frequent up to now, the vacuum in the sputtering chamber deteriorates and the Nb film oxides. If the break lasts more than about 10 minutes the cavity is surely spoiled and needs reprocessing; in case of short interruption the deterioration can be not so bad and the cavity is measured. In a few cases these cavities have been installed, not having time to reprocess them, and this justifies reduced performance in some cases.

The substrate chemical treatments are crucial in reaching good performance. The processes are realized in our new chemical laboratory, operating since 1998, by automatic procedures that make the operations safer and reproducible even though, in a few cases, some inconveniences made surfaces less uniform and shining than usual; in most cases we did not have the possibility of repeating the treatment.

Even if we could often reach full resonator conditioning and we arrive to obtain a flat Q (Ea) curve at least up to 7 W dissipated power, we have some resonators whose performance is limited by field emission. Both high and medium β QWR are aligned in ALPI line cryostat keeping the beam ports open. The process is not performed in a clean room environment so powder can penetrate inside the resonators and can cause field emission.

The problem is even more critical in case we have to vent the cryostat after having installed the resonators. In such cases it is inevitable to move contamination inside the resonators having cavities and cryostat common vacuum. Even though a very slow venting process helps to reduce the possibility of damage we could not exclude it in all the cases. Consequently a cryostat design, which allows cavity alignment keeping the resonator closed, and high-pressure water rinsing, in case of necessity of venting them, are mandatory if high reliability in performance is required. The best solution is however to design the cryostat with separate cavity vacuum.

OPERATIONAL EXPERIENCE

Fifty Nb sputtered resonators are installed in ALPI up to now; four others are waiting to be put on line. The resonator conditioning and setting procedures are unchanged with respect to the ones described in reference 10. The cavity accelerating fields sustained in line, at 7 dissipated power, have been generally increasing with time, due to longer conditioning. For this reason we wait for a performance improvement in the last installed resonators whose conditioning time has been rather short (a few hours). Instead most of the previous installed cavities have reached now a flat Q-Ea field curve, at least up 7 W dissipated power; so further improvement is not foreseen for them. If a few hours of He conditioning are necessary to recover the performance after a thermal cycle, the cavities do not show any sign of degradation with time. At present only 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, E_a – frequency 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.

The average accelerating field reached up to now, at 7W dissipated power, as measure in last cooling cycles being higher than 4.6 MV/m (high β resonators included). We remind that traditionally we compute the accelerating field value considering an active resonator length of 0.18 m. This average accelerating field value means the cavity provides an energy gain per state of charge exceeding 770 keV/u in case of optimum beam velocity and synchronous phase.

Even though the use of recovered Cu substrates did not allowed to obtain the maximum accelerating field reachable by this technology, the cavities realized by Nb sputtering show very good performances, which are competitive with the other, much more expensive, resonators in operation.

The main advantage of this resonator type is however connected to their low sensitivity to fluctuation of He bath pressure (<0.01 Hz/mbar). Due to this intrinsic mechanical stability, they do not need continuous frequency adjustment or the use fast tuners; a slight overcoupling is sufficient to increase the bandwidth enough to accommodate their frequency shifts even in the accelerator environment. Once locked in amplitude and phase, the cavities remain locked for weeks without necessity of any adjustment, making their operation easy and reliable. In ALPI we have sometimes fluctuations in He bath pressure exceeding 200 mbar, but the unlock of Nb/Cu resonator is really rare. This is not only due to the resonator stiffness, but also to the high reliability of the rf resonator controller installed in ALPI [11].

CONCLUSIONS

The upgrading of medium β resonators by Nb sputtering has substantially increased the performance of ALPI at negligible cost. The technology showed to be really effective in producing reliable cavities having high operational accelerating fields. Better results can surely be obtained using suitable designed substrates. The high number of produced and operational resonators and the very low rejection rate (<10%) in the production process demonstrate the technology is ready and can be industrially applied.

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