OPERATION EXPERIENCE WITH ALPI NB/CU RESONATORS

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Abstract

The refurbishing, by replacing the Pb superconducting film by Nb, of the medium β ALPI cavities was completed in 2003. All the 52 cavities are now in operation showing an average accelerating field (Ea), exceeding 4.4 MV/m. This value means a maximum energy gain of 790 kV per state of charge per cavity. The performance of produced resonators has been increasing with time reaching 6 MV/m in the last produced units. The cavities, whose frequency is not affected by He bath pressure fluctuation, and which do not need any fast or slow tuner in order to remain locked, are very reliable and easy to be conditioned.

INTRODUCTION

The Nb sputtering process on QW resonators was first applied in Legnaro for the production of β=0.13, 160 MHz resonators. In 1998 it was demonstrated that the same technology could be applied to the previously installed, β =0.11, 160 MHz Pb/Cu resonators allowing a substantial increase of their performance in spite of the difficulties due both to their shape and to the substrate construction technology. The results suggested to plan for the upgrading of resonators in parallel to the necessary cryostat maintenance programme, which started at the end of 1999 and was completed by the end of 2003.

8 high β and 46 medium β Nb sputtered resonators are now operating in ALPI where 12 β= 0.056 bulk Nb 80 MHz resonators and further 4 medium β Pb/Cu cavities are also installed. An increase in performance is not required for the latter cavities, however 4 sputtered resonators are ready to substitute them when the cryostats will be removed for maintenance.

PRODUCTION EXPERIENCE

At the end of 1999, when we started the upgrading program, we had 4 not operational cryostats because of cryogenic leaks and consequently we needed to recover as soon as possible the ALPI equivalent voltage to provide for the required beam energy for the experiments.

We did not have spare resonator bases to prepare in advance and we had to perform the cavity upgrading in parallel to the cryostat maintenance. The schedule was very tight and consequently we had to accept, without any possibility of choice, all the produced resonators, even when the substrate was not enough suitable or there were problems during chemical treatments or sputtering process.

Later on, when the production cycle was slightly more relaxed, we could repeat the treatments in case of failure during the processes, avoiding installing resonators performing at a significant lower level than the standard results. The production process is described in detail in reference 1. Both cavity treatments and sputtering processes were performed in house. The OFHC Cu substrate, after having the Pb layer stripped, has a few minor mechanical adjustments and it is electro and chemically polished before being sputtered and tested in laboratory. A medium β cavity after being Nb sputtered is presented in fig.1.

Figure 1: A medium β QWR after being Nb sputtered

The average performance of produced cavities has been increasing with time as we achieved more experience in counterbalance the drawbacks present in the existing substrate. The major improvements came from the systematic opening of all the enclaves present in the outer substrate surface under the brazing joints. Previously the opening of them, when the cavity temperature increased during the sputtering process, endangered the film quality.

A further increase in performance was associated to the substitution of the Nb cathode, consumed by the repeated sputtering process and delivering dangerous fragments, with a new thicker one. After that, the cavity Q_0 was always exceeding $5x10^8$ reaching a value of $2x10^9$ when a test cavity of high β was sputtered.

We use an indium wire to joint the bottom plate to the resonator body in the cavities installed in ALPI, because the existing flanges did not permit a good rf and thermal contact without it.

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The indium presence does not affect the cavity performance until the Q is in the 10^8 range, but Q degradation is noticed in case of higher Q. The performance reached in the last produced resonators advised to explore the possibility to eliminate it. Devoted tests were possible once completed the resonator installation in ALPI. We found that a suitable modification of the bottom plate shape permitted to reach a good contact without necessity to substitute the connection flanges. This solution will be applied in future making easier the maintenance procedure. In particular it will make possible the systematic rinsing of resonators after cryostat assembling that we plan to perform in the future. We have to align the cryostat keeping the cavity beam ports open, so the possibility of rinsing the resonators after this procedure will reduce the contamination e consequently should increase the performance and reduce the conditioning time.

OPERATING EXPERIENCE

The on line performance, measured in February 2004, of the sputtered resonators installed in ALPI is presented in fig. 2. The average accelerating field of the installed resonators is 4.4 MV/m, but the value could reach 4.7 if the cavities were properly conditioned. We cannot perform high power rf conditioning in laboratory due to the radioprotection limit. Usually it is performed after the cavities are installed on the beam line but, due to the tight schedule and lack of manpower, not all the cavities could have such a treatment. This is the case of cryostats CR12, CR13, CR16, which are not yet performing as foreseen.

A few cavities are working at values lower than the previously reached ones, CR10-2 had a Q degradation after a cryostat venting; CR19-1 had a rf input line failure and CR15-2 has a Q_0 depending on frequency, probably due to a bad contact between the cavity and the tuning plate (the indium joint is missing in that cavity).

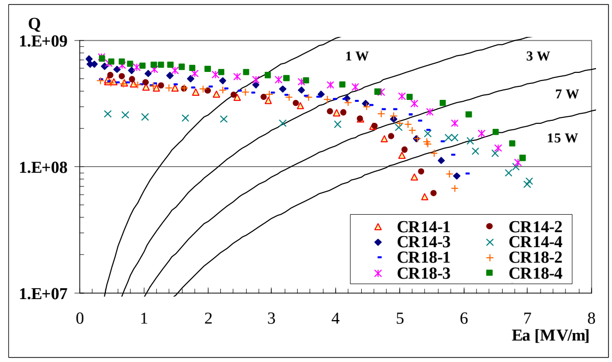

Figure 2: Q-curves of the CR14 and CR18 cryostat resonators, which were installed in 2003.

Other two cavities of the cryostat CR15 have low performance and this is connected to the use of not suitable substrates.

The last cryostats installed (CR14 and CR18) have the best, still improving, performance. The Q-curves of their resonators, measured on line after about 3 hours of high power (1 kW, pulsed) He conditioning, are presented in fig. 3.The conditioning time was not sufficient to straight the curve up to design power of 7 W, which would lead to the expected accelerating field (at 7W dissipated power) reported in table 1, so a further improvement is expected. The cavities were later on used for beam acceleration at the accelerating field reported in table 1. All the cavities, but CR14-4, which had discharges from the high voltage feed through during the sputtering process, have Q_0 equal or exceeding 5×10^8.

We cool down the cavities three times per year. After each thermal cycle the cavities are fed at 7-10 W, by the 100 W installed amplifiers, for a few hours in presence of He gas. Generally this treatment recovers the accelerating field to values approaching the previously reached performance, if the resonators were previously conveniently conditioned.

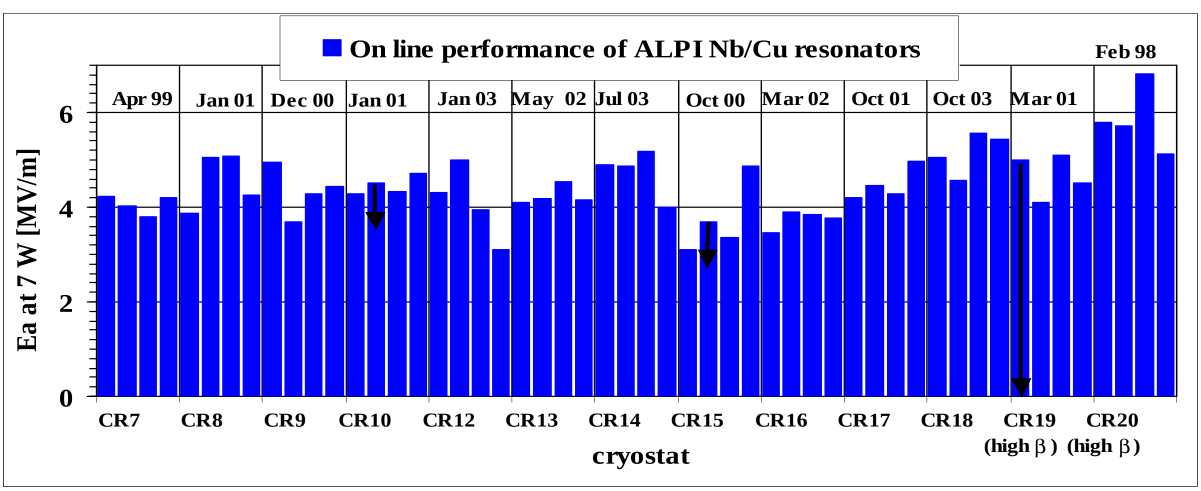

Figure 2: Operational Ea @ 7W of medium and high β ALPI resonators. The installation date is reported on the top of the picture. Three resonators are working at a lower level than in the past (black arrows)

Table 1. Operational and expected performance of CR14 and CR18 resonators.

Cavity	**Production data**	**Q_0**	**Foreseen Ea [MV/m]**	**Operational Ea [MV/m]**
CR14-1	Dec 02	6E8	5.5	4.9
CR14-2	Dec 02	6E8	5.4	4.9
CR14-3	Apr 03	6E8	5.8	5.2
CR14-4	Mar 03	3E8	4.8	4.0
CR18-1	Aug 03	5E8	5.8	5.0
CR18-2	Jul 03	6E8	5.7	4.6
CR18-3	Sep 03	6E8	6.2	5.6
CR18-4	Jul 03	6E8	6.3	5.4

The operational accelerating fields of the cavities after the last three conditioning cycles are reported in fig. 4.

In June 2003 we had the better average performance. In December 03 we had to operate at a lower average field because a beam run was scheduled less than 30 hours after the resonator cooling. It can be noticed that the fields reached the expected value (within 10%) only in the resonators installed since a longer time.

The dramatic improvement in performance of the cryostats CR14 e CR18 in February 2004 is due to the devoted high power conditioning. We expect reaching comparable results in the cryostats CR12, CR13 and CR16 once there will be time to treat them too.

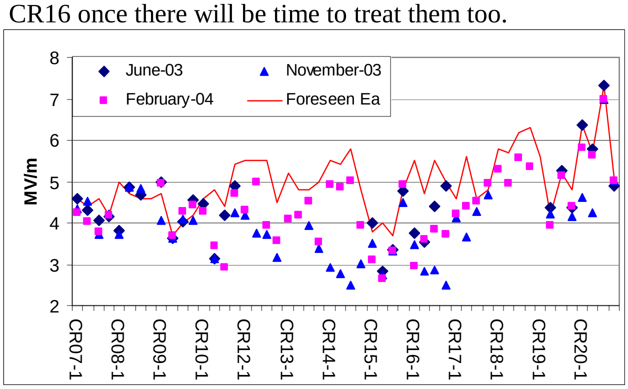

Figure 4. Operational accelerating field sustained by medium and high β ALPI resonators in the last three beam time scheduled periods. The values should reach the foreseen values after convenient conditioning.

Medium β and high β cavities were used for providing beam acceleration in the 2004 beam runs. The accelerated ions, the number of used cavities, the beam β at ALPI input and output, are reported in table 2 together with the average beam energy gain per state of charge and per cavities obtained. The energy gain is at present about twice the value that could be obtained when the same cavities were Pb plated.

If the increase in ALPI performance is the most important benefit of replacing the Pb by Nb, other advantages arose by the process, both for cryostat maintenance and operation [2]. In particular the high accelerating fields can be reliably sustained in lock condition even in the ALPI environment, where the pressure fluctuations are very important [3], without the necessity of any, fast or continuously moving tuner, due to the resonant frequency intrinsic insensitivity of such Cu made resonators to He pressure changes. For the same reason the Nb/Cu cavities do not require a big enlargement of the resonant bandwidth by strong over-coupling, thus limiting the power dissipation in the rf lines. The upgraded resonators can be controlled and fed by the same controllers and amplifiers used by the previously installed Pb/Cu resonators; they maintain the same reliability and easy way of operation of Pb/Cu cavities. The upgrading of medium β resonators by Nb sputtering has substantially increased the performance of ALPI at a negligible cost without interfering with ALPI beam time schedule.

The technology of Nb sputtering on QWR, developed at Legnaro, showed to be really effective in producing reliable cavities having high operational accelerating fields. Even 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 that the technology is ready, competitive with other more expensive resonators, and can be industrially applied.

Table 2: Beams accelerated by the medium and high β resonators in the 2004

Ion	**Cavity**	**βin**	**βout**	**Energy gain /cavity/u [MeV/u/C]**
$^{54}Cr^{+10}$	22	0.080	0.108	0.615
$^{40}Ca^{+10,14}$	47	0.104	0.184	0.651
$^{54}Cr^{+11}$	20	0.080	0.108	0.615
$^{58}Ni^{+11}$	31	0.077	0.114	0.563
$^{36}S^{+9}$	12	0.094	0.116	0.704
$^{64}Ni^{+11}$	35	0.075	0.116	0.602
$^{82}Se^{+12}$	46	0.068	0.115	0.597
$^{90}Zr^{+13}$	46	0.067	0.115	0.612

REFERENCES

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[3] A.M. Porcellato et al., Pressure recording system in ALPI low energy branch cryostats, LNL-INFN (REP)202/20