IMPROVED ON LINE PERFORMANCE OF THE INSTALLED ALPI NB SPUTTERED QWRS

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Abstract

The average accelerating field of the ALPI 160 MHz sputtered QWRs has been improving with time up to reach, after the last conditioning cycle, the average accelerating field of 4.8 MV/m @ 7 W. Such value can be effectively sustained in operation due to the intrinsic mechanical stability of the sputtered cavity whose frequency is practically not influenced by fluctuations in the bath He pressure.

The present average cavity performance approaches the maximum average accelerating field obtainable in the presently installed cavities, most of which were produced by replacement of Pb with Nb in the previously installed substrates. A higher average value can be obtained in ALPI replacing the less performing units; it is instead necessary to sputter on appropriately built substrates to produce QWRs which can reliably exceed 6 MV/m @7W.

The cavity Q-curves, which were recently measured in ALPI, show a wide range of Q_0 and Q-drop, mainly associated with the substrate characteristics, but in some cases also influenced, as discussed in the paper, by cryostat assembling procedures and by cavity production and conditioning.

INSTALLATION OF SPUTTERED CAVITIES IN ALPI

ALPI initial project planned a large number of Pb plated Cu Quarter Wave Resonators (QWRs) of 3 different β. Only the 44 resonators of the medium β section (β= 0.11, f=160 MHz) were built in this way. They were installed in 11 medium β cryostats (CR7-CR10; CR12-CR19) by 1994. Such resonators reached their maximum performance in 1996 when sustained 2.7 MV/m @ 7W in average [1].

In parallel 80 MHz, bulk Nb, QWRs were developed for the low β (β=0.056) section. Twelve of these resonators were installed (in CR4-CR6) by 2000; the installation of further 4 cavities is planned this year in CR3. In spite of their high intrinsic performance, the operational accelerating field of these resonators in ALPI is still limited to a maximum average value of 3 MV/m, but a substantial increase in performance is foreseen by increasing the power management capability of both the coupler and cryostat RF input lines [2].

There are only two cryostats in ALPI high β section. As a matter of fact they are spare medium β cryostats in which we installed high β (β=0.13) QWRs produced by Nb sputtering. The first cryostat (CR20) was installed a first time in 1995, but it had its cavities replaced with new ones in 1998. The second cryostat (CR19) had its medium β resonators substituted by high β resonators in 2001.

A couple of medium β cavities are also installed in each of the 3 ALPI bunching cryostats (B2, B3, and B4).

The sputtering technology on QWRs was developed at Legnaro in parallel with the installation of ALPI medium β section. A usable high β resonator, suitable to be installed in a standard medium β cryostat, was produced by 1993. Two years later, 4 cavities of this type reached on line an average accelerating field of 4.2 MV/m @7W, in spite of contamination occurred during the cryostat assembling [3]. In 1998 we substituted these cavities with new and more performing resonators obtained from new substrates [4]. These resonators are still in operation at an average field approaching 6 MV/m.

In the following years we applied the sputtering technology to the upgrading of the previously installed medium β QWRs. Both the cavity shape and other substrate characteristics limited the reachable accelerating field in these resonators; nevertheless a substantial increase in the ALPI performance was clearly possible, at negligible cost, substituting the Pb with Nb. Between 1999 and 2003, the need to uninstall the cryostats, to repair (or later to prevent) cryogenic leaks, gave us the opportunity to renew all the ALPI Pb on Cu accelerating cavities [5]. Initially, the lack of spare substrates prevented both to optimize the cavity production process and to reject the less performing resonators. Only in 2001, by replacing in CR19 the medium β cavities with high β ones previously installed in CR20, we had at hand a few more substrates which could be prepared in advance.

The first installed medium β cryostats (CR7, CR8, CR9, and CR10) had to be open to air again because of cryogenic leaks. For lack of time we fixed them without removing the resonators. Only in 2007/2008, when we repaired the cryostats CR8, CR9, CR10, and CR13 because of a new leak in the thermal shield, we could perform High Pressure Water Rinsing (HPWR) in the resonators. In that occasion we replaced also 6 resonators [6].

THE SUBSTRATES

The high β Resonators

All the high β resonators have a similar inner shape, a straight inner conductor ending in a hemisphere (Fig. 1). A shorting plate, having 30 mm curvature, joints the inner and the outer conductors. The beam ports are external and are connected to the cavity body by an In gasket. The cavities have a capacitive coupler, which is located on the outer conductor, in the plane perpendicular to the beam line, 10 mm lower than the inner conductor tip. The pick-up antenna is on the opposite side, in front of it. The cavity is closed by a thin plate, about 7 cm apart from the inner conductor edge.

The cavities housed in the two high β cryostats are very different in the construction technology. The CR19 cavities (named hb) are made of Se-Cu and have a circumferential brazed joint in the outer conductor, about 14 cm apart from the shorting plate. Moreover they have both the cavity collar (in stainless steel) and the cavity supports, which are brazed to the cavity body. The CR20 resonators (named HB) are instead drilled out of OFHC 99.95%, certificated graded Cu billets and do not have any brazing joint, being the cavity collar screwed to the cavity body after the sputtering process and the cavity supports milled out of the outer conductor.

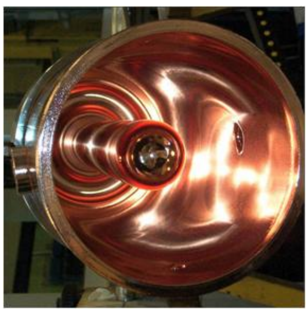

Figure 1: A high β cavity before being sputtered.

Medium β Resonators

Only 7 medium β substrates, labeled PP, are drilled out of OFHC copper billet. Most of the others are instead obtained by brazing a cylinder to a mushroom shaped preformed (FC). Two cavities, still in use, are prototypes built before starting the cavity series production. They do not have any label before the series number. Se/Cu and OFHC Cu were both used for FC series production, but, due to the low relevance of Cu composition for Pb plating, the composition of each prototype is not recorded. All the resonator types present many drawbacks which make the sputtering on them difficult. They have a flat shorting plate, where a hole, used during the plating process, is drilled. Moreover they have the coupler input in a high current region, nearby the cavity top. The PP series, but PP7, has moreover an extra similar aperture which further increases the rf losses.

Figure 2: An upgraded medium β cavity with its tuning plate.

All the presently installed medium β resonators have both beam ports and the stainless still collar brazed to the resonator body; connection supports are similarly connected to it. The brazed joints, especially between different materials, can hide enclaves which can release contamination during the sputtering process. We found useful both to open the hidden volumes inside the joints and to make round the inner edges of the cavity apertures for improving the Nb film quality. A cylindrical spacer mounted outside the coupler hole and sputtered together with the resonator, helps reducing the rf losses. All these drawbacks are eliminated in the 4 new medium β cavities (Fig. 3), which have construction technology similar to the high β resonators while the beam ports are obtained by plastic deformation of the outer conductor [7].

Figure 3: A newly designed medium β cavity.

S.C. RESONATOR PRODUCTION

Surface Finishing and Chemical Treatments

Most of mechanical and chemical surface processes of the QWR substrates are described in detail in reference 8. They have been practically unchanged during all the period of ALPI cavity production. The unique real innovation to be mentioned here is the cavity frequency adjustment, now performed by electro-polishing. Due to the mechanical and chemical treatments, the cavity frequency is modified by the upgrading processes. Now we set the cavity resonant frequency to the linac reference point ourselves, without waiting for access to the mechanical workshop. In the past, for saving time, we had to tolerate a higher discrepancy, which was later adjusted by deforming the tuning plate. The strength necessary to buckle the plate ended to stack the tuner mechanism in CR19-2, thus making that cavity unusable.

Nb Sputtering

We adopted the DC biased sputtering technology for producing the resonators. The process was performed in steps to limit the cavity temperature during discharge. We used cylindrical cathodes for both the high and the medium β cavities, lower in diameter in the second case. In 2003, after producing more than 50 medium β resonators, we had to replace with a new one the cathode, which had become too thin and started to lose fragments.

Stainless steel nets located in between the cathode and the inner and outer conductors provide grounding during the sputtering process, while the resonator body is negatively polarized. An accurate alignment of the sputtering configuration is fundamental to avoid short circuits or sparks. Experience allowed reducing their occurrence although the cathode high voltage was increased from 700 V to 1kV during the sputtering optimization process.

Vacuum spikes in the sputtering chamber during baking are often associated to lower resonator performance. In 1998 we used to produce cavities with Q-values very different. Later on, we systematically opened all the hidden volumes under the brazing joints reducing the differences in Q_0 values.

Initially the cavity bottom plates were coated one by one. Since 2001 we used a new system where it was possible to sputter up to 9 plates in the same cycle, thus making the resonator producing cycle more efficient.

Evolution in Assembling Procedures

Due to both tight schedule of cryostat maintenance programme and lack of spare resonators, we could not risk any change in the cavity production processes until the installation of the upgraded resonators restored the previous ALPI gradient. Only in July 2001, on cavity FC41, we tried the effect of HPWR on a sputtered cavity, previously rinsed only with alcohol. We found Q_0 increasing from 2.5×10^8 to more than 5×10^8. Since then we rinsed all the cavities after sputtering in this way.

In 2004 we succeeded in eliminating the In gasket, which assured the rf contact between the cavity body and the plate, by modifying the fixing flanges and the plate itself. The previous attempt to eliminate the gasket maintaining the old ones, resulted in the performance of cavity 2, still installed in CR15, which decreases its accelerating field when its plate is pulled out to reach the target frequency (from 3.7 to 2.8 MV/m @ 7W). The absence of In gives the possibility to rinse the cavities just before their installation in the line cryostat, as we perform regularly nowadays. In future, hopefully, it will be also possible to rinse the resonators after each cryostat venting.

A further improvement would derive by performing the final rinsing after the cryostat alignment process which, for the medium and high β cryostats, has to be performed with the cavities installed and opened to air.

CONDITIONING

Not being assembled in a clean room, the cavities installed in ALPI usually present field emission. We process them in pulsed mode by 1 kW amplifier before using them for the first time. In many cases this treatment resulted sufficient to obtain a flat Q curve up the design operational power of 7W, however we still have some cavities which would benefit from a few hours more high power conditioning. Up to now we devoted a limited time to this process, because we have to operate locally, one cavity at a time, limited by radioprotection and cryogenic limits.

The high power conditioning process is a little risky and, in two cases, CR19-1 and CR14-2, the rf input line was not able to sustain the high power and failed. We should open the cryostats to put the cavities again in use.

Routinely, after either a thermal cycle to room temperature or a long inactivity period, we perform a couple of hours of He conditioning by the installed 100 W amplifiers. This is generally sufficient to restore in the cavity the previous reached accelerating field at the quoted power. If there is no enough time for that, it is possible to have an increase in the power consumption necessary to sustain the previously reached accelerating field. This is a rather rare event but it is the reason why the cavities, in which field emission is still active, are set at a slightly lower field than the value sustained ad 7W.

CAVITY PERFORMANCE IN ALPI

We gathered the last measured Q-curves of the sputtered medium β accelerating field installed in ALPI in Fig. 4. Each plot collects the Q-curves of the cavities installed in two cryostats. A parallel graph, on the right side presents the accelerating field sustained by the cavities. Note that the legend of each Q-curve indicates the cavity position, resonator type and number, data of the first laboratory test (performed just after the cavity production). The further letter, present in cryostats CR8, CR9, CR10, CR13, indicates the treatment the cavity had when the relative cryostat was recently uninstalled for maintenance [9]. R means HPWR only, N stays for newly sputtered resonator. CR8, CR9, CR10 and also CR7 were opened to air before 2004, without however substituting or rinsing the cavities.

As it is possible to notice, two cavities of CR15 present the worst performance. In 2000, when we had to repair that cryostat in emergency, we put inside the only cavities then available, whose performance where badly influenced by the substrate (PP1) from Cu quality and bad plate contact (2). A further cavity in CR15, FC03, was produced before the systematic opening of the volumes under the brazed joint. This also happened for the CR7 cavities. In both cases the film contamination during the sputtering process can be responsible for the results. All the CR8 resonators sustain accelerating fields of about 5MV/m @ 7 W, which were reached after the cavities were rinsed only in the last cryostat maintenance cycle (2008). Also the other medium β cryostats (CR10, CR12, CR13,CR18), which had their cavities HPW rinsed after sputtering, present now average accelerating fields @ 7W of about 5MV/m . Only CR9, which had to be vented after resonator rinsing, operates limited to 4.4 MV/m in average. The cavities of cryostats CR16, CR17 still present strong field emission; it limits their performance to 4.6 and 4.4 MV/m respectively. Both these cryostats were vented after having installed the resonators and surely this introduced contaminations difficult to process.

Notice that some cavities had further conditioning after the shown Q-curves. The performance at 7 W presently sustained can be found on the right plots together with the performance of the last years. Pay attention that in case of cavity substitution, the value refers to the resonator previously installed in that place.

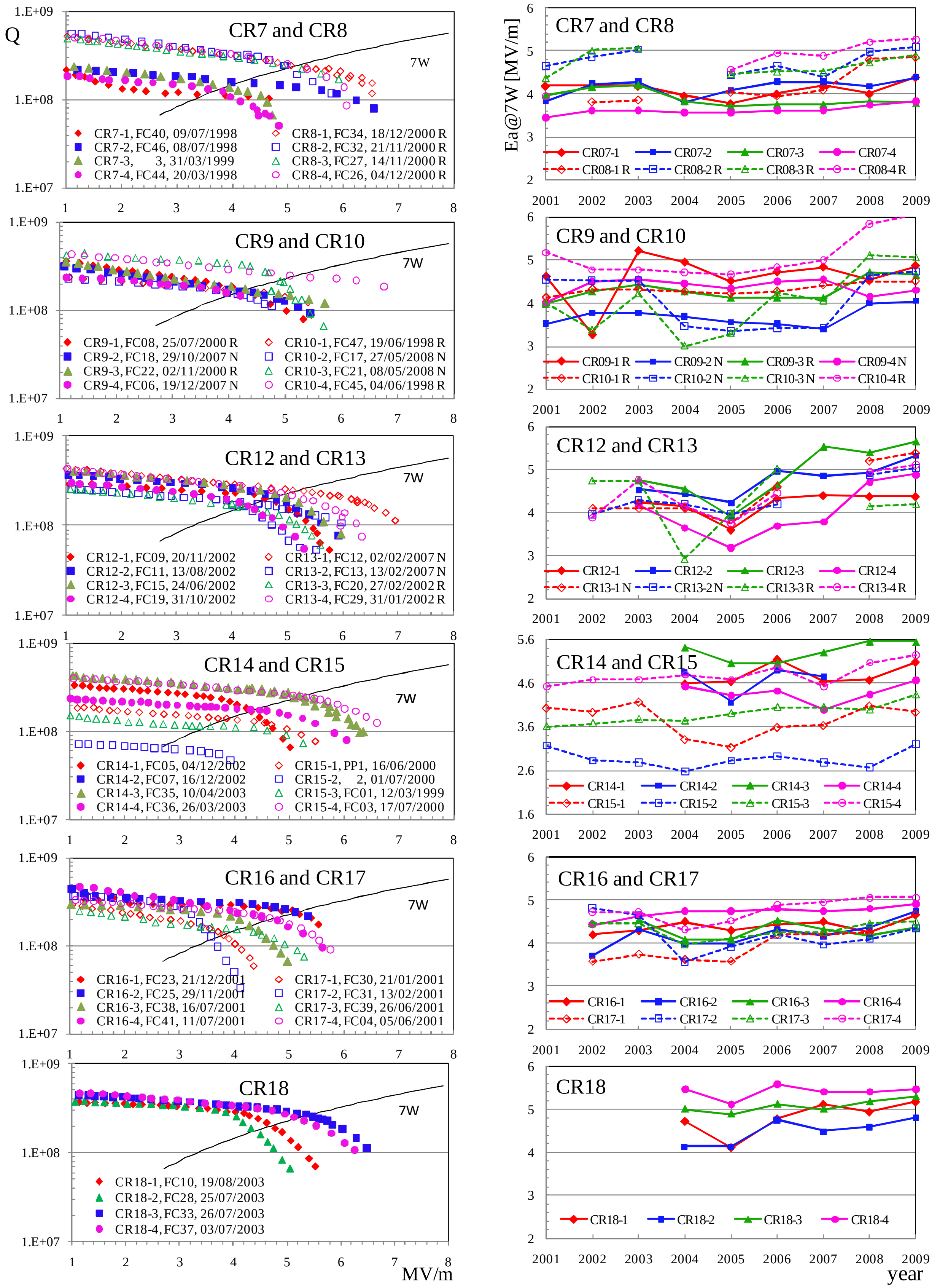

Figure 4: Q curves (left) and performance in the last years (right) of the medium β resonators installed in ALPI cryostats. See text for comments.

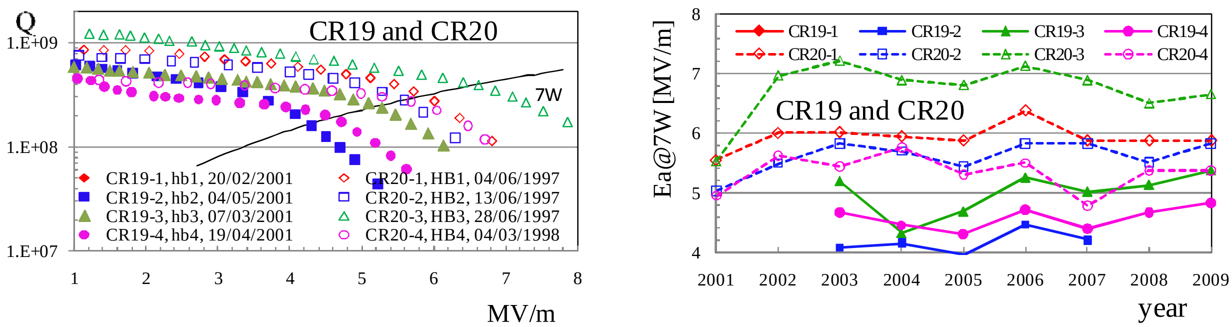

Figure 5: Q curves (left) and performance in the last years (right) of high β resonators installed in ALPI cryostats. See text for comments.

The Q-curves of the high β resonators are shown in Fig. 5. The cavities in CR20, built without any brazing joint, present better results than the cavities in CR19, whose construction technology is similar to the medium β resonators. The Q_0 value of CR20 cavities are about $1x10^9$, except HB4, whose Q-curve presents a Q-switch, not visible in the graph, which decrease the Q-value from $7x10^8$ to $4x10^8$. The average accelerating field that they can presently sustain is about 6 MV/m @7W.

Cavities of CR19 have Q_0 around $5x10^5$ and should reach accelerating fields higher than 5.5 MV/m when full conditioned. However this is not the case because, as it happened also for the other high β resonators, they were often kept turned off, and not conditioned long enough, being their contribution not generally required for reaching the scheduled beam energy.

We are going to uninstall the CR19 both to repair the rf line of hb1 and to adjust the frequency of cavity hb2. In that occasion we plan to perform HPWR in the resonators which should reduce their field emission.

CONCLUSION

The sputtered high β cavities have been in operation for more than 10 years maintaining their performance and always showing high reliability [9].

The accelerating field of medium β resonators @ 7 W is now approaching 5 MV/m, in average twice higher than the value they had when Pb plated [10]. The renewing of medium β resonators by Nb sputtering substantially increased the ALPI gradient and was performed without interfering with operation at a negligible cost. The cavities are still improving their performance, but they are now very close to the maximum value reachable by the old substrates. We could obtain accelerating field exceeding 6 MV/m also in medium β resonators only by sputtering on new substrates. Recently we had the possibility to develop and to sputter four of them and plan their installation in ALPI very soon [10].

The reliability and simplicity of operation of Nb sputtered cavities is clearly shown in ALPI where they steadily operate in spite of pressure instability in liquid He cooling bath [11].

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