ON LINE PERFORMANCE AND UPGRADING OF ALPI RESONATORS

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Abstract

The first 44 Pb/Cu, β=0.11 QWRs have been in operation for more than 5 years accelerating ion species ranging from ^{28}Si to ^{90}Zr. The resonators have been subject to many thermal cycles without showing any degradation (average Ea = 2.7 MV/m). The possibility to set automatically a He gas pressure of $5x10^{-5}$ mbar inside the cryostat during the RF conditioning, implemented in 1994, has been extensively used to recover and stabilize the resonator performance.

Other 12 (β= 0.055 bulk Nb) and 4 (β = 0.13 sputtered Nb/Cu) resonators have been installed. Both Nb and Nb/Cu resonators sustain more than twice the accelerating field of Pb /Cu resonators. The Nb/Cu resonators maintain the excellent frequency stability of Pb resonators. The sensitivity of the Nb cavities to changes of He bath pressure is successfully controlled by a computer program that adjusts continuously the mechanical tuner and an innovative mechanical damper allows their operation without a fast tuner.

Two cryostats, housing resonators in which sputtered Nb substitutes the Pb layer, have been installed during this year. Even if some difficulties arose because of the not perfectly suitable copper base, accelerating fields of about 4.5 MV/m could be obtained, thus suggesting a low cost program of ALPI upgrading.

1 INTRODUCTION

ALPI is the Superconducting booster of the 15 MV XTU Tandem of the LNL [1]. Its original design included 84 Pb on Cu accelerating QWRs of three different ion velocity (β), offering an optimized energy gain profile to tandem output beams. A positive ion injector, PIAVE, now under construction, was also foreseen to increase the beam current even in the case of the heaviest beams [2].

The first stage of ALPI, consisting of 44 medium β Pb on Cu resonator operating at 160 MHz, was completed in March 1994 [3] and the resonators have been used to provide beams for the users. In the meantime both bulk Nb and Nb on Cu sputtering technologies have been developed leading to very encouraging results. That has allowed the realization of the low β resonators in Nb [4] and the high β resonators in sputtered Nb on Cu [5].

The better performance in both cases allowed the reduction of the number of resonators while maintaining the foreseen energy gain.

Last year the possibility to substantially increase the resonator accelerating field by substituting the Pb layer of the medium β resonators with sputtered Nb film, allowed to set a maintenance program that foresaw the change of six cryostats in two years [6].

2 EXPERIENCE WITH ALPI CAVITIES

2.1 Pb/Cu medium β resonators

A total of 50 Pb on Cu QWRs were installed in ALPI, 44 used as accelerating units and 6, housed in three different cryostats, as buncher structures.

The resonator characteristics and the conditioning and operation procedures have been widely discussed in previous literature [7] and only the new evidences are presented here.

Most of the cavities (34) were installed without a preliminary laboratory test to have the fist linac section operating as soon as possible. This did not allowed to select out the low performance units and limited the average accelerating field of the resonator to 2.7 MV/m. The resonators were subject to many thermal cycles, especially in the first years of functioning, because of the difficulties arisen in the cryogenic plant [8]. The number of warming up to room temperature are becoming less frequent, nevertheless even this year we will have to warm up the resonators three times. After a thermal cycle the resonators performance usually recover by means of a few days conditioning using the installed amplifiers. These can provide up to 100 W forward power and the RF control system allows to pulse it (D.F. of about 25%, pulse length about 250 msec) to limit to 30 W its average value in the cryostat. We found very useful, during the conditioning process, to increase automatically the cryostat pressure to $5x10^{-5}$ mbar by He gas. The resonator accelerating fields, measured in July of this year (1999), are compared in fig. 1 with the values obtained in June 1995. As can be noticed the resonator performance is not

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deteriorated. Most of the resonators are operating at 7 W dissipated power near the limits determined by the superconducting surface resistance and the performances are not expected to improve.
During beam operation the resonators showed to be extremely stable in frequency. A slight overcoupling (about 15 W forward power) is more than sufficient to allow the resonator locking to the reference linac frequency. This condition allows limiting the power travelling in the RF input lines and makes the cryogenic load due to RF power dissipation in the cryostat cables negligible with respect to the cavity power consumption.
Once set to the correct frequency and coupling, resonator unlocking is extremely unusual. It can happen once or twice during a weekly beam run while all the resonators are on. Setting again the lock condition usually does not take more than a couple of minutes.

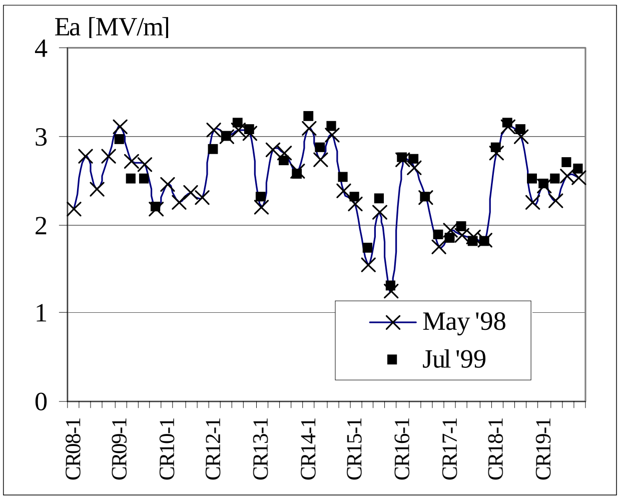

Figure 1: Performance of ALPI Pb/Cu resonators. They do not show any deterioration

2.2 Low β bulk Nb resonators

In 1998 the first cryostat housing four low β resonators was installed in the beam line after maintenance.
The resonator characteristics, the construction and treatment procedures, have been described elsewhere [4].
The resonators reached even better performance on the beam line than in laboratory. After an hour of He conditioning, using 150 W pulsed power, they could sustain an average accelerating field of 7.1 MV/m at 7W.
The resonators were equipped with the mechanical damper developed at Legnaro [8] that strongly reduces the sensitivity, typical of low frequency structures, to mechanical vibrations.
The resonator locking to the linac reference frequency is made more reliable by a computer program that monitors the variations in frequency induced by pressure changes on the liquid He cooling bath and controls the tuner movement to compensate them. In this way the resonators could be reliably kept locked at 6 MV/m for more than 24 hours without any fast tuning device.
These cavities were used only once to deliver beam to the users. It was chosen to limit the acceleration field at 3.5 MV/m even though the cavities could have been locked at 6 MV/m. The cavities are not routinely used, up to now, to accelerate beams, because of some difficulties in providing reliably liquid He to the low energy branch of the linac.
The second low β cryostat was installed in March of this year, the remaining one is completed and it will be mounted on the beam line at the end of November when there will be possibility to get access in ALPI. Putting these new cryostats into operation will increase significantly the ALPI equivalent voltage.

2.3 High β Nb/Cu resonators

The only cryostat housing high β resonators was installed in ALPI in 1998. The resonators are very similar to the medium β ones and are housed in the same type of cryostat [9].
These resonators can combine the good Nb superconduting characteristics with the thermal stability and insensitivity to change of He bath pressure of Cu resonators. They can be reliably locked to the reference frequency without any fast tuner or necessity of continuous adjusting of the resonant frequency. The installed resonators show accelerating fields higher than 6 MV/m even though the performance on line is slightly lower that measured in laboratory.
Since the installation they are routinely used, without any problem, at the maximum field sustained at 7 W of dissipated power when it was necessary to reach the required beam energy.

3 ACCELERATED BEAMS

In table 1 the beams provided to the users in the last two years are presented.
The number of used cavities (N), the input and output β and the average energies delivered per charge state and per cavity to the beam are also presented. The number of the resonators used in each run is defined by the beam energy required by the users. The cavities were sequentially turned on, at 7 W accelerating field value, up to the required beam energy.
The average energy gain per charge and per cavity is about 0.4 MeV depending on the accelerating field sustained by the used cavities and on their TTFn value at the beam velocity in the cavity position. It is possible to notice that the average energy gain is improving.

Table 1: Beams accelerated in ALPI in the years 1998 and 1999. N is the number of used resonators**,** βin is the linac input β and βout is the linac output β. In the last column the average energy gain per charge state and per cavity provided to the beam is given.

Date	**Ion**	**N**	**βin**	**βout**	**Energy gain /charge /cavity [MeV/ch./cav.]**
25Feb98	$^{32}S^{12+}$	38	0.104	0.151	0.393
11Mar98	$^{48}Ti^{10+}$	23	0.081	0.103	0.387
26Apr98	$^{58}Ni^{15+}$	29	0.082	0.109	0.346
2May98	$^{37}Cl^{9+}$	15	0.087	0.104	0.423
11May98	$^{48}Ti^{10+}$	25	0.081	0.104	0.372
12Jun98	$^{58}Ni^{14+}$	33	0.082	0.113	0.355
18Jun98	$^{58}Ni^{14+}$	43	0.082	0.121	0.351
25Jun98	$^{28}Si^{9+}$	27	0.104	0.134	0.389
4Jul98	$^{74}Ge^{12+}$	32	0.073	0.095	0.338
26Nov98	$^{62}Ni^{11+}$	38	0.076	0.105	0.363
6Dec98	$^{32}S^{9+}$	34	0.092	0.128	0.395
14 Dec98	$^{28}Si^{11+}$	42	0.109	0.163	0.415
4 Feb99	$^{32}S^{10+}$	21	0.100	0.128	0.413
25 Feb98	$^{62}Ni^{11+}$	41	0.075	0.109	0.394
1 Mar99	$^{58}Ni^{11+}$	26	0.077	0.099	0.359
3 Mar99	$^{58}Ni^{11+}$	38	0.077	0.108	0.373
17May99	$^{58}Ni^{11+}$	37	0.077	0.110	0.405
15Jun99	$^{90}Zr^{12+}$	35	0.069	0.097	0.473
23Jun 99	$^{32}S^{11+}$	25	0.100	0.127	0.365
25Oct 99	$^{58}Ni^{12}$	25	0.081	0.118	0.449

4 CRYOSTAT MANTEINANCE

The thermal cycles, to which the cryostats were subject, have not deteriorated the accelerating field, but they begin to have some consequences. We have a cavity out of operation because a coupler movement line stuck, other two resonators could not reach the right frequency this year because of unscrewing in mechanical tuning mechanisms.

The most serious problem, arisen in the last two years, was the opening of a leak in the cryogenic valve used to commute between resonator pre-cooling and He tank filling in two cryostats. In one case the leak opened during the cooling down procedure, in the other case when the He tank was 50% full. In the latter case the cryostat connection to the He inlet was close and the valve control circuit (16 bar) depressurized before the cryostat pressure increase to 10^{-3} mbar. The possibility of a vacuum accident in the cryostat which could lead to a fast He evaporation and to a overpressure in the 100 liters He tank, is the reason why its liquid He content is limited to 50 l. In this way even in the worst hypothesis of very fast cryostat pressurization, a maximum of 9 bar could be reached in the He tank. In case of tank rupture the gas will expand into the cryostat vacuum (1 to 10 volume ratio) where the cryostat flange, left free to lift up 3 cm, will act as safety valve. A third cryostat was removed from the beam line because of a cold leak developed after 4 years in a connection of the liquid He. One of these cryostats was repaired and installed on the beam line equipped with medium β sputtered Nb resonators, another is now under maintenance, the third will be removed within this year.

The cryostat maintenance program foresees the repairing of leaks, if present, the replacement of the Pb superconducting layer of the resonators with sputtered Nb and the Cu replating of the stainless steel input RF line. Moreover pins are added to fix all the connections of the mechanical lines that drive the coupler and tuner movement.

Other two minor inconveniences were discovered. The first is the leaking of the viton sealing of the cryostat valves on the beam line. This it is not a problem during operation, but it asks for the warming up of the cryostat to avoid cryopumping when the beam line has to be pressurized, as for example in case of removal of nearby cryostats.

The leaking was connected with viton deterioration evident in the sealing looking toward the inside of the cryostat. The damage was found compatible with loosing of elasticity, which leads to fissuration, due to radiation dose delivered by field emission electrons, coming from the resonators, and scattered toward the seal. Stainless steel rings located just in front of the valve reducing the beam bore diameter to 30 mm, are now inserted in front and behind the input valve and in front of the output valve to prevent electrons and halo beam impingement. Tantalum protections are now inserted on the contour of the thermal shield beam holes of the cryostat where the aluminized mylar, used to reduce the emissivity, and its fixing tape, were found damaged, still by radiation.

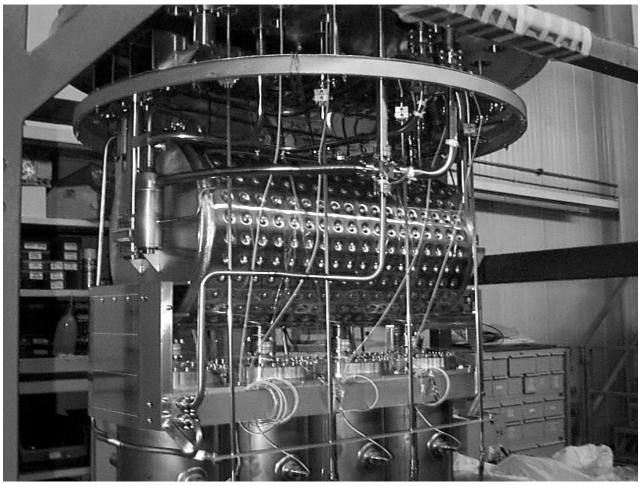

Figure 2. Upper flange of a low β ALPI cryostat. The cryogenic valve is on the top of the LHe reservoir

5 FROM PB TO NB: A PROGRAM OF ALPI UPGRADING

Once good performance, high β, sputtered resonators were obtained and installed on the beam line, it was preferred to suspend the research of better performance and look for a way to sputter the medium β resonators installed in ALPI. The main point of concern was, at the start of the program, the presence of beam ports penetrating inside the cavity body, but it was possible to find a way to obtain a good sputtered film on that area without any modification in beam port shape. The flat shorting plate (fig. 3) is instead a crucial point, that can not be modified for lack of thickness, and a sufficient good film quality must be obtained looking for a compromise in the sputtering parameter setting.

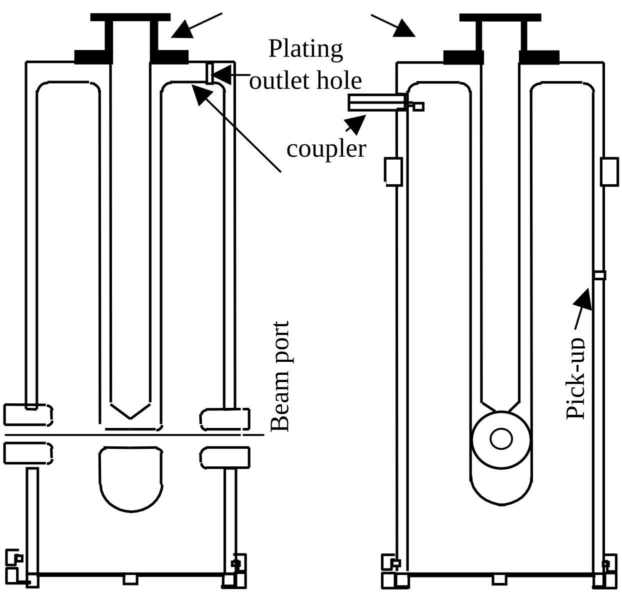

Figure 3: ALPI medium β resonator.

Moreover the sharp holes, located in the resonator high current area, are difficult to be covered with a sufficient thick film and have to be smoothed. Other difficulties come from the copper substrate. If small defects or impurities can be sustained in Pb plated resonators, they can instead spoil the performance of Nb resonators in which the surface resistance can be 10 times lower. In ALPI we have installed all the resonator bases that were produced by standard OFHC copper. In some of them the copper presents small bubbles that can open during chemical process: in such a case the Nb sputtering cannot offer an improvement in the results. A further critical point is moreover the presence in some resonators of cavities trapped during the brazing process in the outer resonator surfaces, especially in the Cu to stainless steel transition.

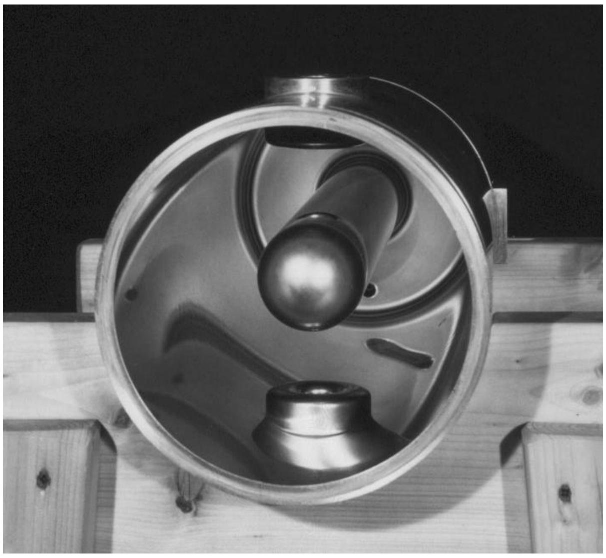

Fig.4. A medium β resonator obtained by Nb sputtered on Cu

Their opening during the sputtering process can compromise the film quality so that they have to be open. Losses negligible at low Q resonators can be more important for high Q resonators, therefore an extension, sputtered together with the cavity, was added to the coupler hole to allow the electromagnetic field to decay before meeting normal conduction surface. The cost to modify each cavity, extension included, was 250$. All this difficulties make impossible to obtain the same performance of suitable designed resonators, but certainly an improvement was expected when the Pb coating was replaced with a sputtered Nb layer. Eight sputtered medium resonators (fig. 4) were installed in two resonators that went into maintenance this year. Their Q curves, measured on the beam line, are presented in fig. 5 and 6 for the resonators respectively housed in the cryostat CR7 and CR10.

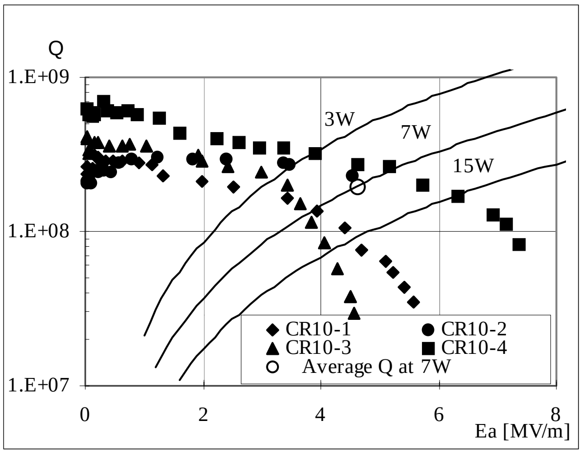

Figure 5: On line performance of Nb sputtered QWRs housed in cryostat CR10. The resonators are now working at an average field of 5 MV/m at 7W.

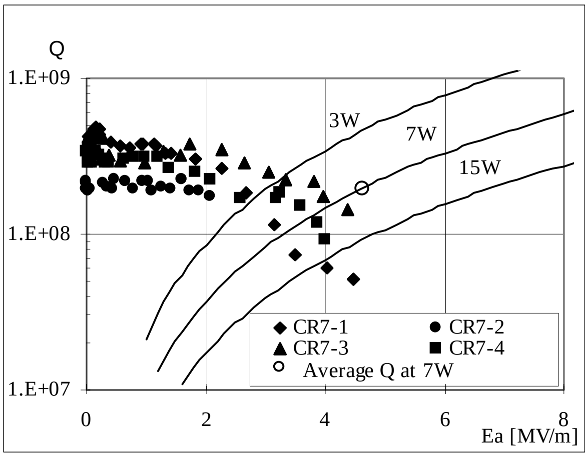

Figure 6: On line performance of Nb sputtered QWRs housed in cryostat CR7. The resonators are now working at an average field of 4.6 MV/m at 7W.

6 ACKNOWLEDGEMENT

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