FIRST RESULTS WITH THE FULL NIOBIUM SUPERCONDUCTING RFQ RESONATOR AT INFN-LNL

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Abstract

A full-Nb superconducting RFQ was completed and tested at liquid helium temperature at INFN-Laboratori Nazionali di Legnaro. Two superconducting (SC) RFQ resonators will be the very first accelerating elements of PIAVE, the very low velocity injector of the heavy ion linac ALPI.

The paper briefly reviews the main construction steps of the resonator, in the context of the completion of the full injector, and fully describes the SC tests showing that the design requirements are met.

An outlook is also given on the electromechanical stability issue and on the measures taken to face it, as well as a description of the status in the development and construction of the second SC RFQ.

1 INTRODUCTION

Two 80 MHz superconducting RFQs follow an ECR source – located on a 350 kV platform - and precede a series of eight SC QW-resonators in the beam-line of PIAVE [1], the new being built injector of the SC-booster ALPI.

The purpose of the new injector is that of making ALPI capable of accelerating up to the heaviest ion species, overcoming the present limitation of A ≤ 100 given by the Tandem injector. In general, it is also expected that larger currents will be made available for experiments also at A < 100.

Both the ECR on the HV platform [2] and the low-energy beam transport line (LEBT) [3] have been completed and commissioned. The eight QW-resonators were also built and tested [4] and are ready to be assembled in the dedicated cryostats. It took longer to develop and build the SC-RFQ resonators, which are the really novel elements on the beam line. The paper reviews the latest test on SRFQ2 in SC regime, while the completion of the construction of SRFQ1 is expected in summer 2001. The construction of the SRFQs cryostat also started recently and is expected to be implemented by the end of 2001 together with the cryogenic plant dedicated to the whole injector.

Table 1 summarises the main features of the RFQ-part of the injector.

SRFQ1 is nearly twice as long as SRFQ2 and closely follows the design of SRFQ2. It is less demanding in terms of stored energy, i.e. easier to be controlled versus mechanical vibrations, and the specified peak surface field is smaller: hence the proof of principle on SRFQ2 should hold true also for SRFQ1. Fig.1 shows the completed SRFQ2 structure mounted in the test-cryostat.

Table 1: The main design parameters of the SC-RFQs are shown. The design assumes 315 kV for the ECR platform and the design ion is $^{238}U^{28+}$.

	SRFQ1		**SRF2**		
	In	**Out**	**In**	**out**	
Energy	37.1	351.3		585.4	**KeV/u**
	8.82	83.61		139.33	**MeV**
Beta	0.0089	0.0275		0.0355	
Voltage	148.0	148.0	280.0	280.0	**kV**
Length		**138.9**		**74.4**	**cm**
N of cells		43		13	
m	1.2	2.8	2.7	2.8	
a	0.7	0.4	0.8	0.8	**cm**
R_0	0.80	0.80	1.53	1.53	**cm**
ϕs	40.0	18.0	12.0	12.0	**deg**
$E_{p,s}$		**24.**		**25.5**	**MV/m**
U		**1.8**		**3.5**	**J**

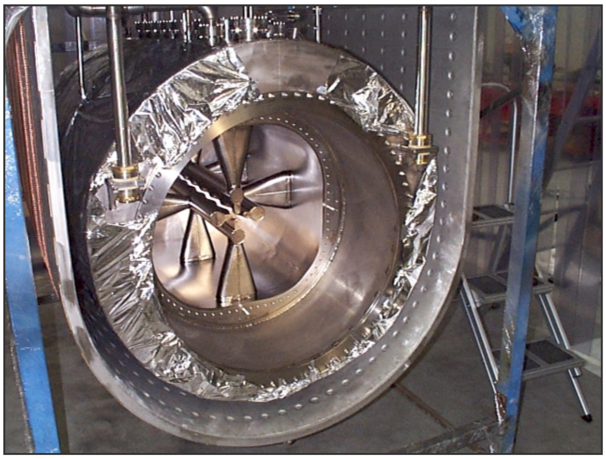

Fig.1: SRFQ2 mounted in the test cryostat.

2 CONSTRUCTION HIGHLIGHTS

The construction of SRFQ2 was preceded by the construction of a full size stainless steel model, by which it was possible to optimise the details of the construction sequence (machining, electron-beam welding of components and rough frequency tuning to the desired resonant frequency) [5]. Moreover it was possible to assess the frequency change that the resonator would undergo when put under vacuum, chemically polished and cooled down to cryogenic temperatures. The mechanical construction of the niobium version of SRFQ2 followed exactly the same sequence. Only, given the meanwhile acquired experience, even better results in terms of electrode alignment could be achieved.

Room temperature assessment of the relative positioning of the four electrodes was done via the bead-pulling technique [6]. The voltage unbalance among the four quadrants was measured to be within 0.4 %, consistent with a frequency splitting between the two dipole modes of about 0.8 %. In fact the two dipole modes were identified at $f_{d,1}$ = 100.15 MHz and $f_{d,2}$ = 100.70 MHz ($\Delta f/f \sim 0.55$ %).

The dipole mode splitting at 4.2 K was found to be even smaller ($\Delta f/f \sim 0.34$ %), showing that the cool-down well preserves the quality of the alignment: these measurements imply that the positioning precision of each electrode at 4.2 K is within ±75 µm. We believe this conclusion to be extremely relevant. A precision better than ±75 µm had also been measured at room temperature at the end of the mechanical construction one year earlier.

The fundamental issue which can be derived is that annealing of electrodes+stems - done at DESY, Hamburg, see fig.2 - and annealing of the Ti stiffening jacket – done at INFN-LNL prior to its welding onto the Nb tank – are sufficient steps to prevent mechanical distortions during cool-down.

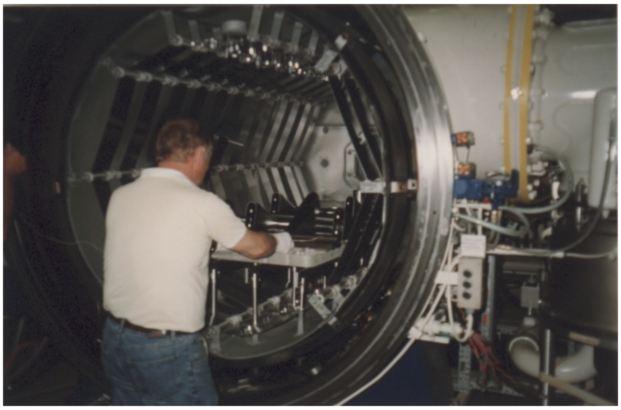

Fig.2 Annealing of the internal parts of SRFQ2 in the DESY HV-furnace, prior to their welding to the Nb tank.

3 RESULTS AT 4.2 K

Fig. 3 shows the present Q-curve, which describes the performance of SRFQ2 at 4.2 K. It can be seen that the design specification of a peak surface electric field $E_{s,p}$ = 25.5 MV/m at P_{cav} = 7 W is met. A quality factor Q = $5\div8\text{x}10^8$ remains basically constant up to 21÷22 MV/m, where it starts to drop because of residual field emission (the drop is in fact correlated with X-ray emission). A maximum value of 29 MV/m can still be reached in CW operation, at the expense of a much higher dissipated power. A peak surface field exceeding 40 MV/m could be reached when feeding the resonator by 10 ms pulses at a 1 Hz repetition rate.

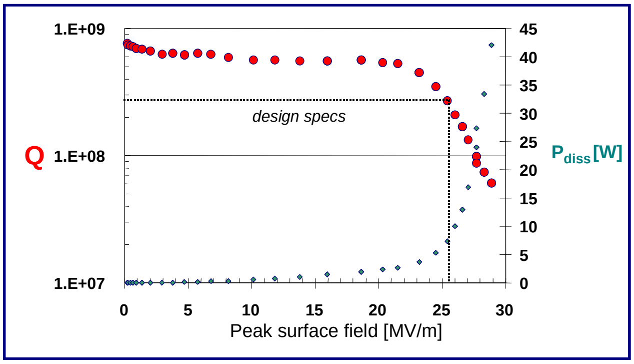

Fig. 3: The present performance of SRFQ2 is shown, which exactly matches the design specifications of PIAVE (the inter-electrode voltage at 25.5 MV/m is 280 kV as required for the $^{238}U^{28+}$ reference case).

Conditioning of multipacting levels (ranging between 0.01 and 0.4 MV/m) could be accomplished mostly in the normal conducting (NC) regime, after filling the cryostat intermediate shield with liquid nitrogen and at a base pressure of ~ $5\text{x}10^{-7}$ mbar. The whole treatment required less than 24 hours and was done after 48-h bakeout at 70 °C. A very last multipacting level (at the much higher field $E_{s,p}$ = 10 MV/m) could be treated, in a few hours, only in SC regime.

Non-resonant electron loading (or field emission, FE) was quite severe and took quite long before it could be processed up to the specified field (see fig. 4).

It should be noted, however, that the cavity had to be exposed to air for days in a not properly clean environment during the time elapsed between the last rinsing and the final tests: dust particles were probably sitting on the electrodes during the herein described tests.

Additionally, the resonators seems to require a higher-power amplifier than the available one ($P_{amplifier}$ ~ 1.5 kW) for a thorough FE processing.

Finally, the siphon system which removes the gaseous helium formed in the lower electrode [7] is very effective, even under field emission conditions, but only up to ~ 40 W average dissipated power. Beyond this threshold, the lower stems are rapidly filled by gas and the cavity temperature tends to rise quite abruptly.

For the next test session, foreseen in early Fall this year, we plan to implement a higher power RF line, to double the gaseous He delivery capability of the siphon system and to carefully rinse the resonator just before putting it under vacuum.

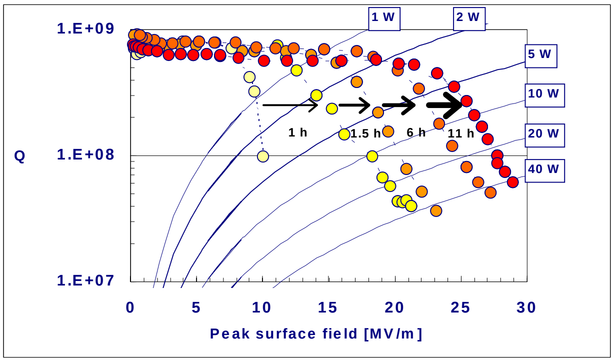

Fig. 4 The improving performance of the Q-curve under FE conditioning is shown

The RF-calibration of the peak surface field was checked, by means of a NaI detector and associated Multichannel Analyser, looking at the Bremsstrahlung spectrum of the photons created by the electrons travelling between oppositely biased electrodes under strong FE conditions. The maximum of the photon energy spectrum corresponds to the total energy acquired by the electrons in the process and hence to the inter-electrode voltage. Very good agreement was found between the two methods, which were compared at a peak surface field $E_{s,p}$ = 39 MV/m (duty cycle ~ 1 %).

Finally, it is worth mentioning that the RF-joint between the Nb-sputtered end plates and the full Nb resonator carries no gasket at all.

4 PRELIMINARY LOCKING TESTS OF SRFQ2

It might be not straightforward to be able to lock in amplitude and phase a SC resonator featuring a stored energy as high as 4 J. The item is however of crucial importance for a cavity which has to be kept synchronous with the beam during accelerator operation.

The natural bandwidth of an 80 MHz cavity at Q = $8x10^8$ is 0.1 Hz. Presumably the smallest mechanical vibrations would cause EM-eigenfrequency jitters significantly larger than 0.1 Hz.

Several measures were considered, foreseen or checked in order to control the effects of mechanical vibrations.

First of all, the cavity design includes a very robust Ti stiffening cage - welded onto the Nb tank – which shifts the lowest vibration eigenmode frequency beyond 120 Hz, i.e. far beyond the most noisy environmental range of mechanical excitation (up to 50÷60 Hz) [8].

Second, by strongly overcoupling the resonator with a 1 kW-power amplifier we should be capable of broadening the cavity bandwidth up to Δf ~ 20 Hz.

Third, we intend to equip both SC RFQ resonators with fast tuners [9], which are being developed in collaboration with Argonne National Laboratory.

We were able so far to test the phase and amplitude locking of SRFQ2 with a 700 W class A amplifier, and with a controller similar to those which are routinely used on the QW-resonators of the ALPI SC booster [10].

In strong overcoupling mode, the resonator could be kept locked up to ~ 12 MV/m (with 400 W from the amplifier), whereas at 16 MV/m the locking test was not successful due to a trivial RF-fault outside the resonator. The test was rather successful and we do not see any fundamental reason, within the available RF power, why the method should not work as long as there is no FE (hence up to about 20 MV/m peak surface field for the moment). Where the Q-curve drops, electron loading would probably cause too large and sudden frequency jitters to be able to control them with this method.

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