SUPERCONDUCTING RFQ'S APPROACHING BEAM COMMISSIONING AT INFN-LEGNARO

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Abstract

Two superconducting (sc) RFQ's (SRFQ1 and SRFQ2), following an ECR source on a 350 kV platform and preceding superconducting quarter wave resonators, are being tested and getting ready for ion beam operation at INFN-Legnaro. The new ion injector will expand the mass range of accelerated projectiles in the laboratory up to the heaviest ones. The following experimental data on the SRFQ's are reported in this paper: curves of Q value versus accelerating field, frequency tuning, sensitivity to liquid He bath pressure, Lorenz force detuning, locking in phase and amplitude to a master oscillator

1 INTRODUCTION

The complete equipment of the heavy ion injector PIAVE [1] has been built at or delivered to INFN-LNL by now. The skew beam line from the ECR high voltage platform to the SRFQ's, including the low energy buncher, went through repeated tests, which proved the transverse emittance to be within specifications [2]. Measurements of the longitudinal emittance are being carried out.

The two SRFQ's are going through their final testing phase (reported in this paper): they resonate at 80 MHz, being about 0.8 m in diameter and 1.34 m and 0.74 m long, respectively. The cryostat which will house them on the beam line was received from the manufacturer (Budker Inst., Novosibirsk) and preliminarily assembled.

Characterization of the sc RFQ resonators will be completed as soon as they will be mounted on the final cryostat in the linac vault and connected to the cryogenic plant in its working refrigeration cycle.

Figure 1 shows the longer SRFQ1 resonator in the test cryostat. The resonator is immersed in the liquid He dewar, wrapped by a mylar foil and surrounded by the liquid nitrogen shield.

The last part of the beam line, matching the SRFQ's to the sc linac ALPI, includes 8 Quarter Wave Resonators (QWR), which have been already tested with success. The cryogenic plant was tested with a dummy load, showing the expected cooling capability.

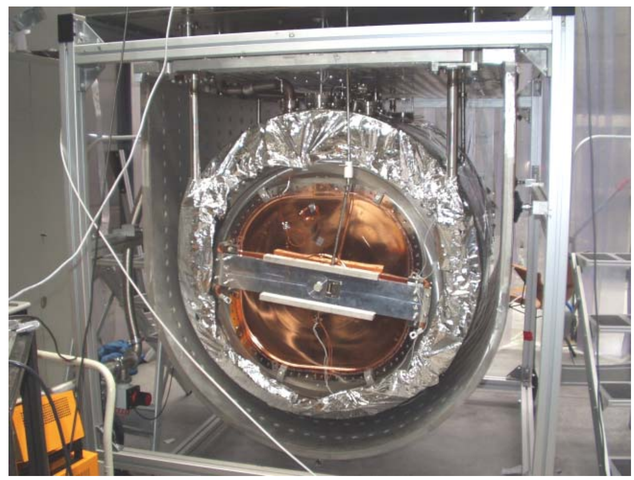

Figure 1: SRFQ1 in the test cryostat.

2 Q-VERSUS-$E_{P,S}$ CURVES

SRFQ2, the second on the beam line, was built first and its construction was completed in Fall 1999. Its test phase lasted till March 2002 when it was dismantled and stocked. Meanwhile, SRFQ1 was built and then assembled in the same test-cryostat: it is being tested at present. SRFQ1 is less demanding than SRFQ2 in terms of inter-electrode voltage and stored energy.

Three Q-curves of SRFQ2, among the many measured in the above mentioned period, are shown in fig. 2. Since July 2000, the design specifications ($E_{p,s}$ > 25.5 MV/m at 10 W) have been achieved on repeated occasions, while the rf and mechanical properties of the tuners and pickup and coupler lines were continuously improved and locking tests (reported in the next paragraph) started. The curve with the green bullets in fig. 2 is the best one obtained so far (in June 2001). In order to achieve it, it was necessary to: implement movable rf lines which would not release any dust onto the modulated electrodes; provide proper rinsing at each opening (by acetone, HPWR, ethanol and dry filtered air); last but not least, ensure sufficient pressure at the sc joint between the sputtered end-plates and the resonator.

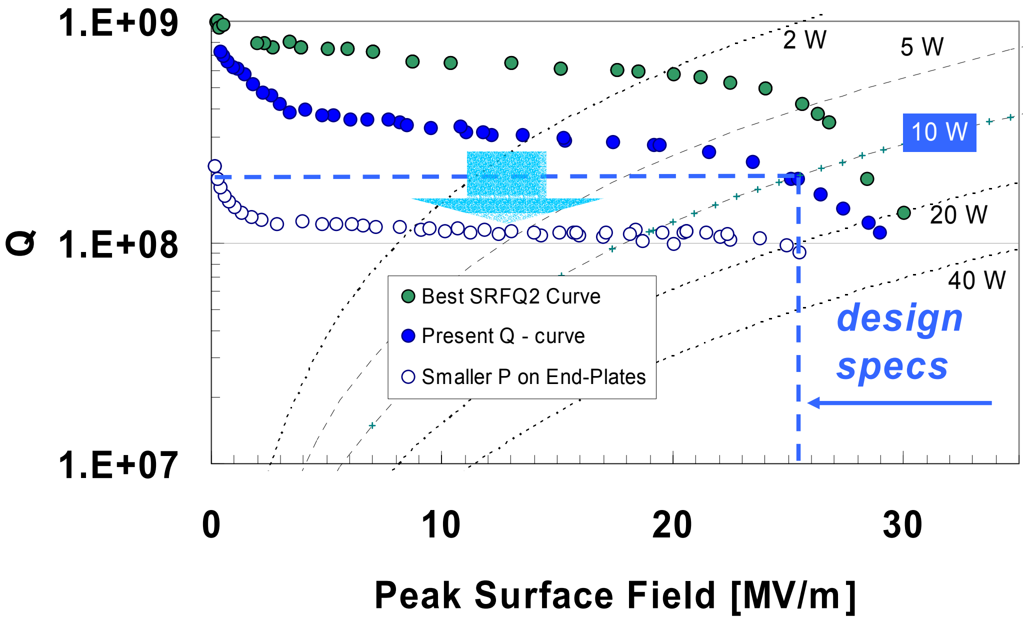

Figure 2: The final Q-curve (blue bullets) of SRFQ2 prior to mounting into the on-line cryostat is shown, together with the best ever measured one (green bullets). The lower curve shows the decrease in performance, if simply smaller pressure is exerted between the Nb/Cu sputtered end-plates and the full Nb resonator tank (white bullets).

The curve with the blue bullets was the last one measured, before SRFQ2 was dismounted and SRFQ1 mounted on the test cryostat in its place. The cause of the worse performance, with respect to the best one, was a discharge in the high power coupler cable, which sputtered a thin layer of Cu and stainless steel in the resonator over tens of cm^2 in a high current density region.

Since chemical polishing (CP, which we perform in collaboration with CERN) would have taken months, we attempted to simply remove the contaminated layer by means of 3M Scotch Brite lapping, followed by standard HPWR. After this treatment the flat part of the Q-curve, which had dropped to around $1x10^8$, recovered substantially, as shown on the graph. A new CP would clearly recover the Q-curve completely.

Another inconvenience occurred while trying to condition the last RFE level at $E_{s,p}$ ~ 10 MV/m [3]: during pulsed rf treatment of the resonator and after a few discharges, associated with increasing temperatures on a couple of sensors inside the modulated vanes, the Q curve dropped to the low 10^7 scale. It was not possible to recover it during the same shift. After warm-up and opening of the resonator, there were several scattered signs of discharge between the end-plate and one couple of electrodes. The damaged areas on the electrodes were treated by 3M Imperial lapping film, with Al_2O_3 abrasive of decreasing roughness; the Nb layer on the end-plates was stripped and sputtering remade. CP was again avoided in a first instance and only careful HPWR was made. The Q-curve recovered completely in this case.

The decision was taken to stop the experiments on SRFQ2 at this stage, being the Q-curve more than acceptable for typical ion beam operation, for which it is expected that the large majority of requested species will require more than 80% of the $E_{s,p}$ design value.

The importance of the above mentioned sc joint between the end-plates and the resonator tank is worth being emphasized. The end-plate to cavity joint bears no gasket, the surface magnetic field on its perimeter varying between 3 and 6 mT. Following the experience made at Argonne National Laboratory (ANL) with Split Loop Resonators [4], the end-plate joints of which feature knife edge niobium gaskets, it was chosen to exert the maximum possible pressure onto the joint of the SRFQ's, through mechanical levers distributed all along the plate perimeter. The white dots in fig. 2 show one of the cases in which this pressure was decreased by nearly a factor 2: the smaller pressure resulted in a Q drop of a factor ~3 along the entire curve.

3 FREQUENCY CONTROL AND LOCKING AT 4 K

A fundamental step towards the reliable use of sc RFQ's on a linear accelerator is the characterization of the resonator frequency (f) changes with respect to: changes in the He bath pressure (slow changes) and microphonics (fast changes) in a Lorenz detuning dominated regime.

A pressure increase in the He bath decreases the intervane distance, which makes f to decrease. The measured sensitivity (-39 Hz/mbar) is rather high.

However, it is expected to be compatible with the specifications of the cryogenic system, which will work at 1.2 ± 0.05 bar, with pressure drifts smaller than 2 mbar/min, that can be followed up by the SRFQs slow tuners. Slow tuning is provided by pushing/pulling both end-plates with respect to a stiff bar, through a stepping motor: the mechanism is visible in fig.1. The slow tuners were characterized in their total tuning range, at 4 K temperature, on both resonators: the range is around 300 kHz for SRFQ2 with a deformation of ±3 mm at the centre and about 160 kHz for SRFQ1 with a deformation of ±1.5 mm (see fig. 3). Their sensitivity is 0.5 Hz per step of the stepping motor with a backlash of ~500 steps.

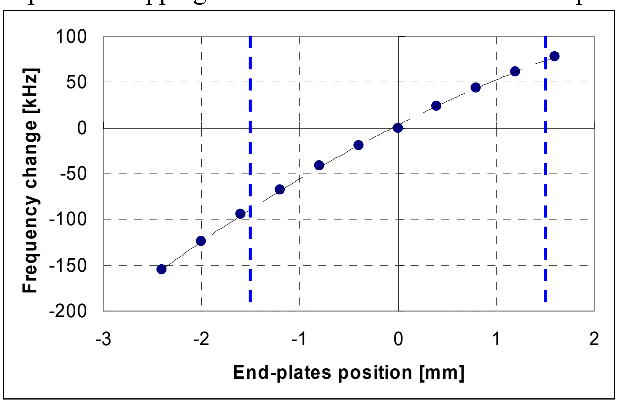

Figure 3: Tuning range of the newly built SRFQ1 resonator, measured at 4 K.

It was proven possible to use only one end-plate in the push-pull mode [5], in order to follow the slow variations of the resonator frequency during periods of several hours. Nevertheless, the total f-drift seems to amount to about a few hundreds Hz/day at most, as far as repeated recordings in the test cryostat have shown. It was hence possible to conceive a double end-plate tuning, where one end plate is always used in the pushing and the other in the pulling mode. The total f-shift is probably so small with respect to the overall tuning range, that it will not be necessary to revert their direction of motion during a beam time of a few days. In so doing, we believe that the resonator operation on the accelerator is made significantly easier. The double end-plate slow tuner will be tested on SRFQ1 in one of the latest tests before mounting both resonators in their final position.
Lorenz detuning makes the resonator f to decrease quadratically as a function of the inter-electrode voltage: the measured detuning amounts to

$$\frac{\Delta f}{\Delta E_{s,p}^{2}} \cong -0.9 \frac{Hz}{(MV/m)^{2}}.$$

Folding of both the resonance (fig. 4) and the related phase-frequency curves impose to work off-resonance on the stable part of the curves themselves.

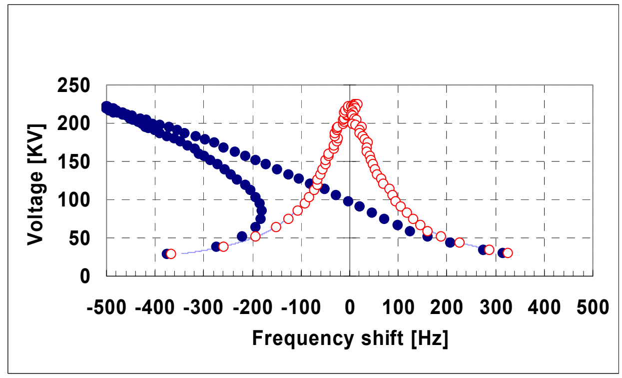

Figure 4: The measured resonance curve folded by the Lorenz force (blue bullets) is compared with the curve algebraically corrected for the measured detuning of around - *0.9 [Hz/(MV/m)^2]* (red bullets).

In the test cryostat, it was possible to lock SRFQ2 in these conditions in both amplitude and phase for periods of 1÷1.5 hours, at 80% of the specified $E_{p,s}$: microphonics do not seem to be a crucial issue in the working conditions of the test cryostat. The duration of uninterrupted locking is expected to increase with the backlash-free double end-plate slow tuner.
Tests of the fast tuner device [6] (acquired from ANL and just received at INFN-LNL), which should help resonator locking in operation, will be possible only in the on-line cryostat, which will house both SRFQ's on the beam line. In order to incorporate the fast tuner control with the existing resonator control system with minimum modifications, a Pulse Width Modulator was designed and tested.

4 CONCLUSION

The latest test with SRFQ2 provided Q values and accelerating fields which are definitely compatible with on-line operation. Investigations on the frequency stability in the test cryostat are rather encouraging.

5 ACKNOWLEDGMENT

The skilful contribution of L.Bertazzo, E. Bissiato, D. Conventi, S. Marigo and F. Stivanello was essential in the mechanical upgrades of resonators and test cryostat.

6 REFERENCES

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