RESULTS ON INFN-LNL NIOBIUM RFQ RESONATORS

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Abstract

Two superconducting RFQs, following an ECR source and preceding superconducting quarter wave resonators, are now installed in their common cryostat at INFN-Legnaro. The cavities have been thoroughly and successfully characterized on a test cryostat with respect to: Q versus accelerating field, frequency tuning, Lorenz force detuning, locking in phase and amplitude, sensitivity to liquid He bath pressure. The new ion injector will expand the mass range of accelerated projectiles in the laboratory up to the heaviest ones.

INTRODUCTION

The PIAVE injector [1] has been nearly completed, with the exception of the two superconducting RFQs. These were fully characterized off line in a test cryostat and, since April 2003, they are being assembled in their final cryostat. Fig.1 shows one superconducting RFQ in the final rinsing procedure, before being sealed in the final cryostat. This assembly phase is being particularly critical, both because of some annoying manufacturer's errors which had to be fixed and because of the extreme alignment precision, which is required from beam dynamics to the two big resonators once they are on the beam line and cold.

Figure 1: SRFQ1 during high pressure water rinsing, before being assembled into the final cryostat.

The two superconducting RFQs [2] (called SRFQ1 and SRFQ2) have been performing beyond specifications in the test stand. The Q vs. E_a curves, and the present limitation in the so far reached Q values, are discussed in the following paragraph, together with some findings on the resonators alignment at 4 K. The rest of the paper is devoted to the series of tests aimed at investigating the phase and amplitude locking of both resonators, with respect to slow and fast changes of the electromagnetic frequencies. For the sake of completeness, the resonator responses to both environmental (i.e. pressure induced) and artificial changes of the electromagnetic resonance (induced vibrations as well as various patterns of modulation of the master resonator frequency) were carefully studied.

PERFORMANCE OF THE TWO SRFQS

As shown in figure 2, both SRFQ1 and SRFQ2 exceeded the design specifications both in Q value and accelerating field. However, as expected, it is advisable to operate them below the Q-slope gets steep, i.e. before electron field emission starts causing undesired field jitters.

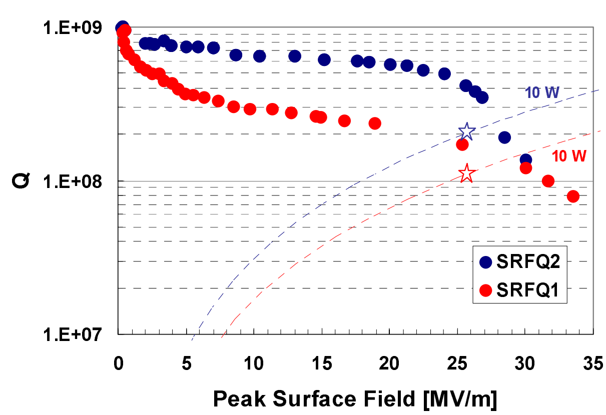

Figure 2: Q-curves of SRFQ1 and SRFQ2 exceed the design specifications (25.5 MV/m at 10 W)

The present limits to the Q values were confirmed to be any sort of looser or imperfect contact between the Nb-sputtered end-plate and the full Nb cavity (B_S at the joint is as large as 3.6 mT)[2]. A tight mechanical contact plus the differential contraction between 300 and 4 K make the Cu-based plate and the full Nb cavity to get well pasted together.

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Figure 3 shows the case where a mushroom shaped machining of the end-plate had to compensate for the 100 mm step induced during buffer chemical polishing (BCP): the step was located on the Nb cavity, at the position of the viton joint during the BCP process.

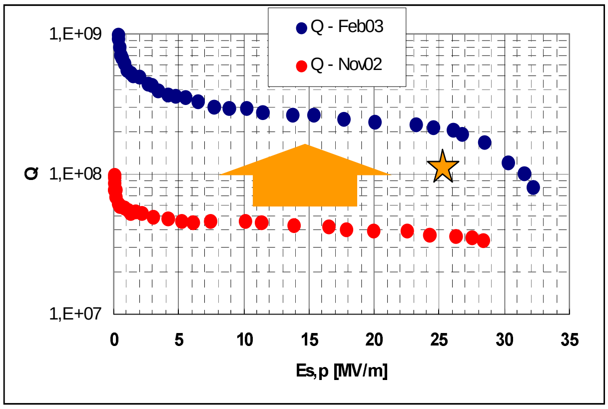

Figure 3: The Q curve recovered, after making the shape of the Nb sputtered end-plate to follow the shape of the Nb cavity (0.1 mm step induced by BCP)

Last but not least, the delicate issue of electrode alignment deserved special care. Positioning of each electrode was specified to be ≤ ± 100 μm on each axis: this was achieved during construction (checked with a theodolite). Perfect alignment gives a degeneration of the 2 dipole modes above the quadrupole one: a splitting of the modes can hence be correlated to average positioning error between electrode couples. Moreover, dipole mode splitting is the only alignment diagnostics from 300 to 4 K. The dipole mode frequencies measured at the operation temperature were 90.071 and 90.509 MHz for SRFQ1, 100.15 and 100.70 MHz for SRFQ2 (none worsened from 300 to 4 K): both splittings are consistent with a mispositioning of each electrode < 70 μm.

PHASE AND AMPLITUDE STABILITY

The test cryostat offers slow and fast periodic changes on the liquid He bath pressure (typical pattern shown in fig. 4), as natural excitations of the resonator frequency.

The slow component of the frequency change can be compensated, by deforming both end-plates: one is only pushed, the other pulled, thus virtually killing any mechanical backlash. At the rate of ~ 1 kHz/day in the test cryostat and a full range of 75 kHz (150 kHz for SRFQ2), the direction of motion must be inverted every 2÷3 months: this should leave around a factor of 100 possible larger rate, for still reasonable performance in real operation (one inversion of motion per day).

As far as the velocity of the mechanical tuner is concerned, the following should be noted. With the pressure sensitivity of 40÷50 Hz/mbar shown in figure 5, and the maximum pressure excursion specified for the cryogenic plant (2 mbar/min), the mechanical tuners must change the resonator frequency more quickly than 1.33 Hz/s: they were demonstrated to be as fast as 2.5 Hz/s experimentally.

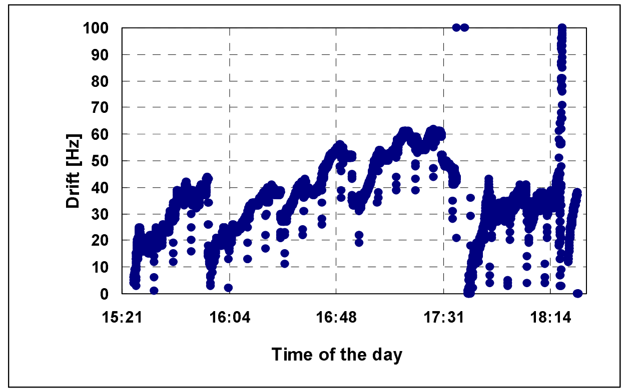

Figure 4: Natural excursions of unlocked SRFQ2 resonator frequency in a few hours time span; fast drifts are linked to the behaviour of the dryers of the lab cryogenic plant (around ±30 Hz/s), seen by the cavity through the gaseous He recovery line

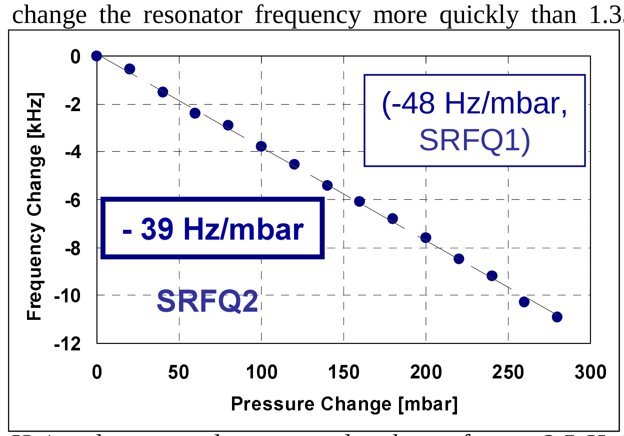

Figure 5: Measured frequency sensitivity to P changes of the two SRFQ's

Concerning fast drifts, the cavity can be operated both in strongly over-coupled mode (a 700 W amplifier makes it possible to broaden the frequency bandwidth from 0.1 Hz to around 20 Hz) and with VCX fast tuners [3], by which a window of 200 Hz around the reference frequency can be controlled. Only the former was available in the test cryostat, since the latter can be implemented only in the cryostat mechanics of the final cryostat.

Since the cavities are strongly detuned by the Lorenz force (see folded resonance curves in figure 6), we can expect only one side of the curve to give stable conditions for locking purposes. This is in fact proven to be the case. Figure 7 shows the average phase error, versus the chosen value of phase of the self excited loop (SEL) of figure 6: only the blue part of the curve is associated with stable behaviour of the SEL control system. Once the correct loop phase has been chosen, however, the Lorenz

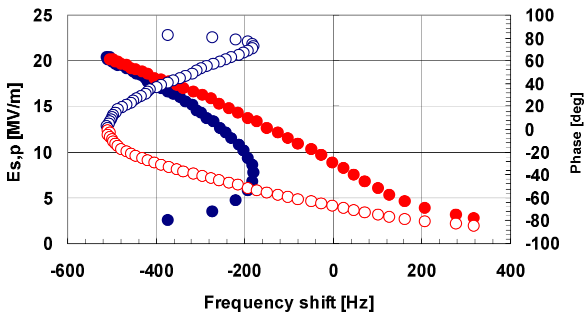

Figure 6: Folded resonance curves of the Lorenz detuned resonators: blue bullets correspond to the stable part of the curve, red bullets to the unstable one.

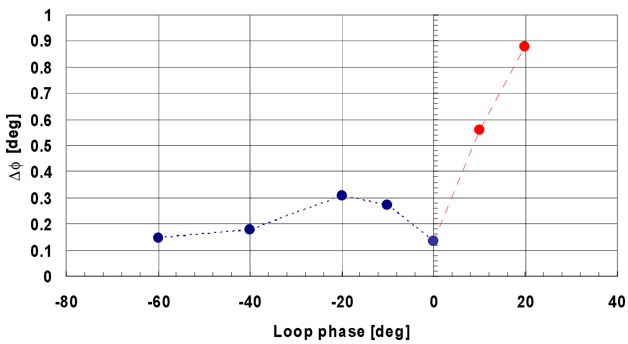

Figure 7: Average amplitude of the phase error of SRFQ1 versus the chosen value of the SEL loop phase of figure 6.

detuned resonator stability poses no particular problems, as can be expected from their CW operation.

In particular, the cavity control system can keep the phase and amplitude errors within given thresholds, which were set at ± 0.4° during the tests: when these values are reached, either one or the other tuner is moved, so as to compensate for the corresponding frequency change. Figure 8 shows a typical pattern of phase and amplitude error versus time: both cavities could be kept locked in this way beyond the design accelerating field values. These experiments showed also that only pressure change events (both fast and slow) were the cause of frequency changes in the test cryostat: clear correlations between P and Δϕ could be observed at all times.

The test cryostat was clearly in a reasonably quiet environment, with respect to what can be expected from the refrigeration cycle of the TCF50 cryogenic plant (although specified to give slow pressure changes, as mentioned above). Therefore we decided to artificially induce resonant frequency changes of both a "slow" and a "fast" nature, so as to better investigate possible thresholds of the control system.

Concerning slow changes (i.e. to be controlled with the mechanical tuners), we decided to modulate the master oscillator frequency with sine, square and saw tooth functions of various periods and amplitudes. Figure 9 shows the example of one such sine function modulation and the corresponding phase error response. It was thus shown that the mechanical tuners can follow up to a frequency change rate of ~ 2 Hz/s, i.e. ~ 50 % more than what should be induced by the cryogenic system, according to its specifications.

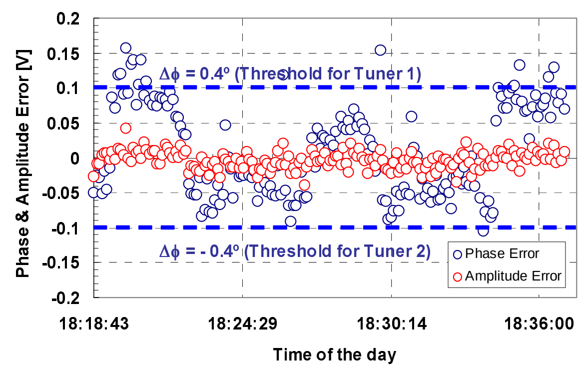

Figure 8: Typical excursions of phase and amplitude errors in the SRFQ's in the test cryostat: the phase error values, at which the mechanical slow tuners are moved, are shown.

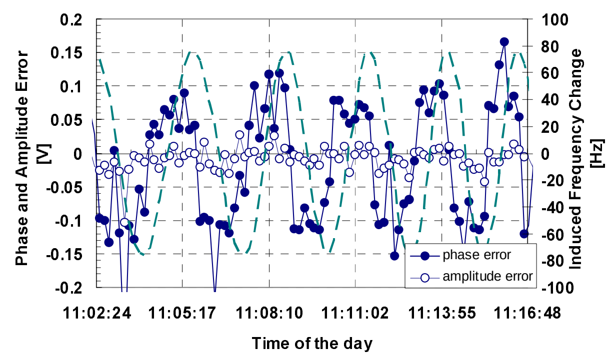

Figure 9: Sine function modulation of the master oscillator frequency, introduced to check the threshold velocity response of the mechanical tuners

Concerning fast changes, we excited the mechanical structure of the test cryostat both through a powerful frequency-swept shaker (at a cavity bandwidth of ~30 Hz) up to 1 kHz and through the strokes of a heavy hammer (white noise). Figure 10 shows the frequency change induced by the latter method. It can be seen that, beside a ~200 Hz change of the fundamental frequency, no vibrations seem to be triggered by the event (the resolution was 250 ms). This speaks in favour of the mechanical stiffness of the resonator geometry.

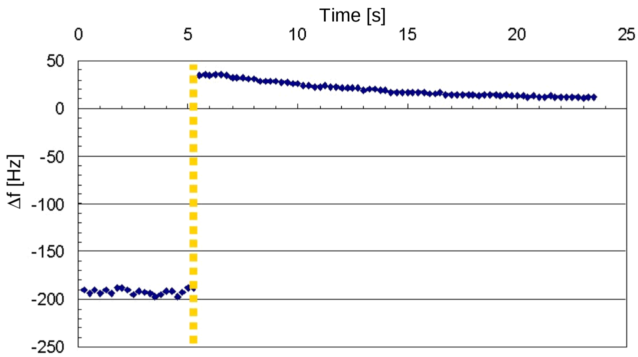

Figure 10: Typical frequency change induced in the SRFQ1 resonator by a heavy hammer stroke on the test cryostat outer vessel: however, no vibrations seem to have been induced (the resolution is 250 ms).

REFERENCES

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