ON-LINE MECHANICAL INSTABILITIES MEASUREMENTS AND TUNER DEVELOPMENT IN SC LOW-BETA RESONATORS

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Abstract

Bulk niobium, 80 MHz low beta resonators with mechanical damper have been installed since many years in the Legnaro superconducting linac ALPI, and similar cavities have been recently installed and commissioned in the PIAVE injector. We have measured, both in ALPI and in PIAVE during operation, the distribution of the low beta cavities frequency deviation induced by mechanical vibrations. We have developed a new, backlash-free high resolution tuner to improve the control system response to detuning induced by helium pressure fluctuations.

INTRODUCTION

ALPI includes a low-β section working at 80 MHz, to allow efficient acceleration of ions of all masses [1]. This section consists of 3 cryostats with a total of 12, β=0.055 bulk niobium quarter wave resonators. This linac section, in spite of the good performance of the first commissioning in 1998, was used rather sporadically after due to problems related to the ALPI cryogenic system; since it is necessary in order to allow injection in ALPI of the future PIAVE SC injector beam, however, the operation was restarted. PIAVE itself includes 2 similar low beta cryostats, with β=0.047.

The specified operation gradient in was 3 MV/m at 7 W per cavity, with a total power dissipation per cryostat of 35 W at 4.2 K; the rf system (amplifiers, lines and couplers) were dimensioned for this purpose and the standard LNL tuners had been used. After installation of the first cryostat, however, we found that the helium pressure fluctuations were sometimes much above expectations (sometimes above100 mbar/minute) and that it was possible to lock the resonators up to 6 MV/m when the cryogenic system was in stable operation [2].

To cope with mechanical vibrations the 80 MHz cavities are equipped with mechanical dampers [3]. To compensate detuning induced by helium pressure fluctuations, mechanical tuners are controlled in feedback by the residual phase error signal of the resonators locked to the reference frequency f_0. This signal is approximately proportional to f_c-f_0 (where fc is the cavity resonant frequency) if this value is within ±Δfc, the 3 dB rf resonance bandwidth. After proper calibration, this signal gives a direct measurement of cavity detuning, including the one caused by mechanical vibrations and the one caused by slow pressure fluctuations.

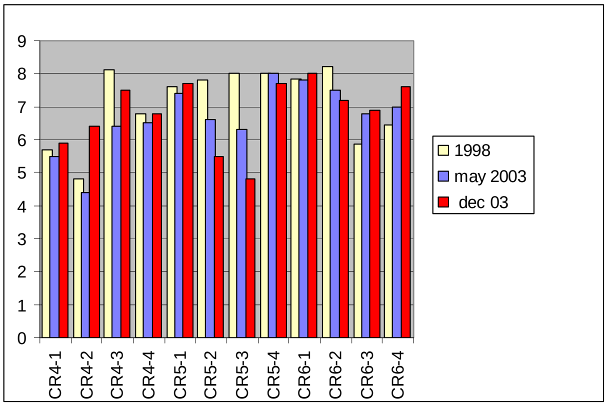

Figure 1. Gradient at 7 W in different periods of the ALPI 80 MHz resonators

ON-LINE TESTS

The resonators field could be checked and some Helium conditioning could be applied. Despite the changes observed, related to different rf conditioning time after cryostat warm-up, we found an average gradient of 6.8 MV/m at 7 W power, similar to the value obtained in 1998 by us and in 2003 by another team (Figure 1). The individual resonators performance at 7 W changed with time, but the average value did not show significant degradation.

Mechanical vibrations and pressure detuning

We have measured on line the frequency oscillations amplitude of the mechanically damped resonators caused by mechanical vibrations. We did a 24-hour test with the resonators locked in phase and amplitude. We have sampled the residual phase error signal in periods of 200 ms, we extracted the maximum oscillation amplitude and the average value in every period and translated them in frequency errors. We obtained the maximum amplitude of the frequency oscillations around the slowly drifting center frequency of the cavities. The distribution of the maximum frequency error in all cavities during the 24 hours of the test is shown in fig. 2.

We found that the oscillation amplitude, averaged over all cavities, is 4.5 Hz (approximately 3.2 rms). The best cavity had 1.2 Hz. Cavity 5-3 had by far the maximum value (14.4 Hz), more than twice the second most unstable one; we found later, after opening the cryostat for a vacuum leak, that the mechanical damper was sitting in a wrong position, that was eventually fixed.

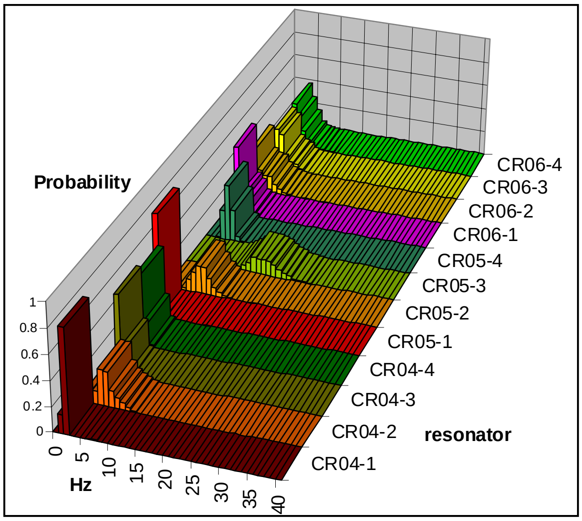

Figure 2. Distributions of the frequency oscillation amplitudes in a 24-hour record for all cavities.

Tuners response

We have monitored also the average frequency distribution of the locked resonators (see figure 3). The frequency changes are caused by helium gas pressure fluctuations; the frequency error depends on the response speed of the mechanical tuner controlled in a feedback loop. We found that the old standard tuners have in general a rather poor response, often with large and non-reproducible backlash, and sometimes with a non-monotonic behaviour. Nevertheless, tuners generally reach the reference frequency within 2 Hz if the pressure fluctuations are slow enough. However, for fast pressure fluctuations that in ALPI can exceed 100 mbar/minute, the delay in their response can cause temporary increase of the phase and amplitude error signal above the allowed values. This prompted us to develop a more suitable tuner for frequency tracking.

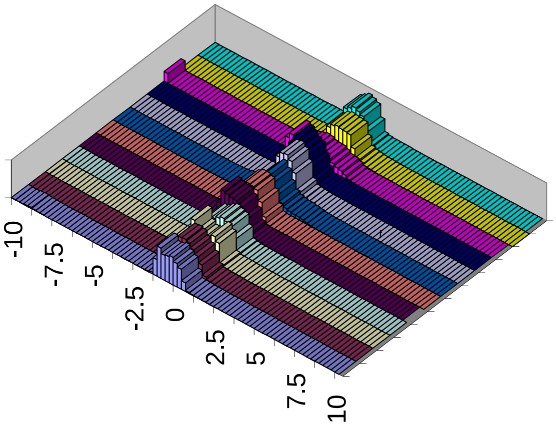

Figure 3. Average frequency error distribution in operation related to tuner resolution and delay.

Figure 4. The new tuner prototype #1, mounted on a 80 MHz resonator

THE NEW, HIGH RESOLUTION TUNER

We aimed to a backlash-free tuner for Quarter Wave resonators that could find applications to different geometries. Special requirements of the new tuners were:

1. Resolution ~0.33 μm or better; this corresponds to frequency resolution below 1 Hz.
2. Small and reproducible backlash in order to allow a fast frequency recovery.
3. Pushing and pulling force capability up to 1000 N on the 1 mm thick copper tuning plate.
4. No magnetic material in a significant amount.
5. No lubricants for vacuum operation.

The new tuner is based on 3.25:1 lever acting on the center of the tuning plate (fig. 4). The lever position is controlled by a screw-nut system mounted on a holder by means of oil-free ceramic ball bearings with amagnetic disc spring preloading. The holder is pivoted to a fixed support and free to follow the screw orientation for different positions of the lever.

We used the lever design of the TRIUMF QWR tuner [4] with commercial backlash-free joints [5]. We have designed the rest of the tuner in order to fit the existing ALPI cryostats and stepper motor control. The standard stepper motor, with 10:1 reduction on the top of the cryostat, moves the threaded rod through a straight stainless steel tube. We tried to avoid any element that could introduce backlash in the mechanical transmission; a bellows is mounted between tube and rod in order to account for thermal contraction and misalignment.

In addition to the C-FLEX joints, an AISI 304 helical spring eliminates the freedom of the threaded rod-nut

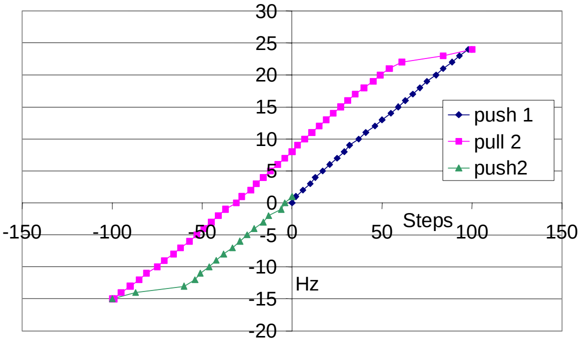

Figure 5: Frequency change vs. tuner step tested at 4.2K with an 80 MHz superconducting resonator

system.

We tried also to avoid as much as possible magnetic materials, that could affect the superconductor properties. However, the commercial backlash-free joints are slightly paramagnetic at a level that we expected to be tolerable inside the cryostat, where the earth magnetic field is shielded below 1 µT. The system is linear and its theoretical resolution on the tuning plate is 0.1 µm. This results in about 0.3 Hz tuning resolution for low-β quarter wave resonators, well suited for our application.

A test was done with an 80 MHz ALPI cavity in order to verify the performance and the resolution at 4.2K of the prototype, and to define possible final modification and adjustments. The new tuner has shown excellent resolution (~0.1 µm), linearity and reproducibility around the reference frequency, in the typical range used in operation (Fig. 5). The resonator had a quality factor $Q>10^9$, showing that the magnetic characteristics of the C-FLEX joints are compatible with high-Q operation. We have then started the production of tuners for all 21 low-β cavities of ALPI and PIAVE.

Figure 6. New tuners mounted in resonators ready for installation in the linac.

The need of replacing also the tuners of the PIAVE QWRs is not clear yet, however. Differently from the ALPI one, the PIAVE cryogenic system seems to be have only pressure jumps below 20 mbar/minute; in this situation the old tuners appear sufficiently reliable, causing negligible residual phase error (fig. 7). We decided to replace them anyhow, whenever the cryostats will be available for maintenance, in order to increase system reliability.

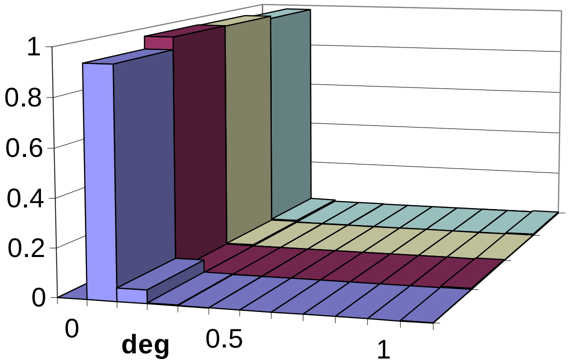

Figure 7. Phase error distribution recorded for 24 hours in the resonators of the PIAVE cryostat n. 1, locked at 5 MV/m with a rf bandwidth of about 7 Hz.

CONCLUSIONS

The on-line measurements of the ALPI low-beta resonators have shown, for cavities with mechanical dampers, an average frequency oscillation of 3.2 Hz rms. Most of the residual phase error is caused by poor response of the old mechanical tuner to fast helium pressure fluctuations, much more pronounced in the ALPI than in the PIAVE cryogenic system. We have developed a new tuner with 0.3 Hz resolution to allow frequency tracking in presence of fast pressure fluctuations.

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