

# ON-LINE PERFORMANCE OF THE LNL MECHANICALLY DAMPED SUPERCONDUCTING LOW BETA RESONATORS

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## Abstract

7.1 MV/m at 7 W is the average accelerating field of the four bulk niobium, 80 MHz quarter wave resonators recently installed in the first cryostat of the low- $\beta$  line of ALPI, the superconducting linac at Laboratori Nazionali di Legnaro. The maximum peak electric field reached by all cavities in cw operation is about 50 MV/m and the maximum peak magnetic field is about 1100 G. The total energy gain produced by the cryostat is above 5 MeV/q at the design cryogenic power of 28 W. The cavities are equipped with mechanical dampers that increase considerably their stability against strong environmental vibrations; these dampers are a valuable alternative to electronic fast tuners.

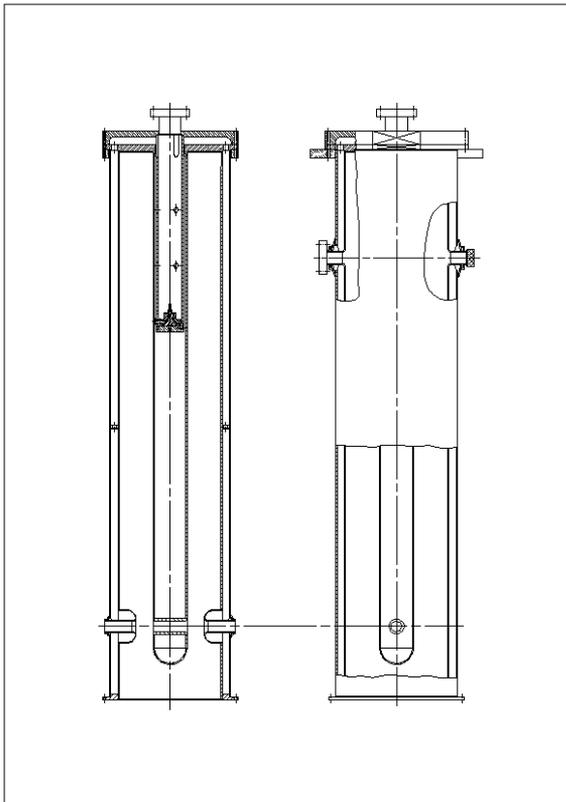


Fig. 1 The  $\beta=0.055$  niobium resonator equipped with a mechanical damper

## 1 INTRODUCTION

The development of bulk niobium quarter wave resonators at Laboratori Nazionali di Legnaro started in 1989 [1] with the goal of producing high performance cavities for low velocity ions at moderate cost. A highly symmetric design, which simplified considerably the construction procedure, was studied in such a way that the resonator optimum velocity could be modified over a wide range by simply modifying the resonator length and frequency [2]. A set of  $\beta=0.055$ ,  $\beta=0.11$  and  $\beta=0.165$  resonators was constructed and successfully tested with promising results [3]. The considerable effort of LNL in developing copper-lead and copper-niobium cavities, however, limited this bulk niobium program to the large size  $\beta=0.055$ , 80 MHz resonators [4][5], to be developed with moderate human and logistic charge to the laboratories. The cavities described in this paper were produced and tested since 1994, but they could be properly installed and tested in the LNL superconducting linac only this year.

## 2 CONSTRUCTION FEATURES

The rf and cryogenic characteristics of the LNL bulk niobium resonators have been widely described elsewhere [1-5]. It should be reminded that the resonators are made of bulk niobium, except for the lead-plated OFHC copper removable tuning plates (Fig. 1). Even if a high temperature treatment is possible, and it was tried and tested in the past, we did not find it necessary in these cavities. We have never observed any Q-disease, even after very slow cooling processes taking more than 24 hours. Since no clean room was available to mount the resonators in the cryostat, we had to set up a procedure which prevented the resonators internal surfaces to be contaminated by dust.

The resonator alignment was performed, during their mechanical construction, by properly machining the aluminum holders used to connect them to the cryostat, and the alignment of the cryostat internal holding bars was done by means of dummy cavities; the resonator alignment, then, can be automatically obtained.

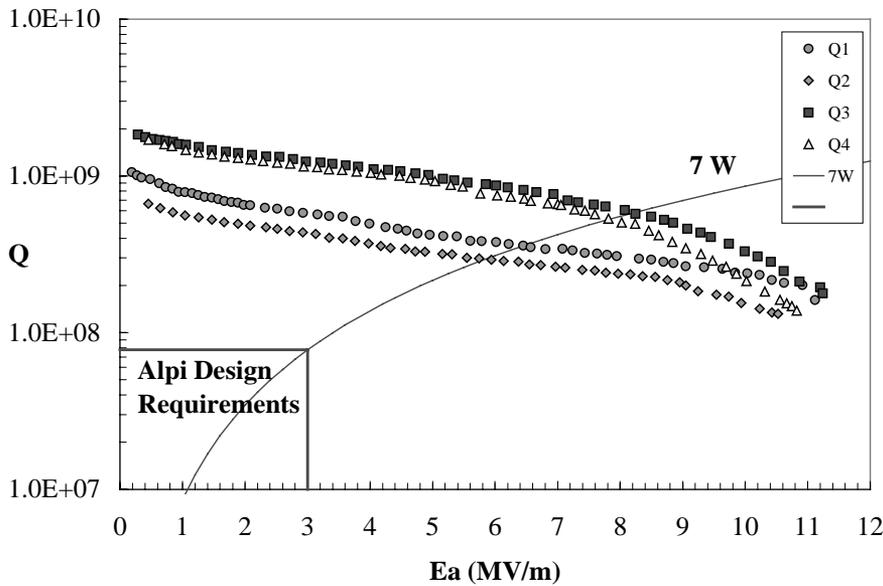


Fig. 2 On-line rf test results of the low $\beta$  cryostat installed in ALPI.

The resonator surface treatment, after the chemical polishing, consisted of a high pressure rinse with 80 liters of deionized water at 100 bar, followed by a final rinse with 2.5 liters of ethanol. The cavities have then been closed with a polypropylene disk to avoid the contact of ethanol with the lead plated surface of the original tuning plate. During this operation, all the resonator apertures have been kept closed. After about 1 hour the polypropylene plates have been replaced by the original tuning plates, the resonators have been installed and the cryostat closed. We started pumping slowly but immediately, so as to make any exposure to atmosphere as short as possible, since any gas, even if clean, could transport residual dust particles from the cryostat walls to the interior of the cavities.

After a few weeks storage the cryostat was installed in ALPI. The resonators were baked at 350 K for about 48 hours. The multipactoring conditioning took about 12 hours.

### 3 ON-LINE RF TESTING

At first the resonators have been tested before any rf or helium conditioning. In these cavities we usually had a low-field quality factor around  $2 \times 10^9$ ; in this measurement, cavities n. 1 and 2 have shown a lower  $Q_0$ , due probably to contaminations happened during the many tests performed, without any further chemical polishing, during the previous years. All cavities, however, reached from the beginning an accelerating field between 5 and 6 MV/m at 7 W, much higher than the ALPI design requirement of 3 MV/m. Moreover, the cavity n. 1 did not show any significant field emission up to above 11 MV/m, corresponding to about 50 MV/m peak electric field.

After helium conditioning, applied for about 1 hour on each cavity with 150 W pulsed rf power, all resonators reached a field between 6 and 8 MV/m at 7 W and about 11 MV/m at maximum power (Tab. 1 and Fig. 2). To

confirm the field calibration, an ion beam was accelerated by the cavities and we measured its energy gain.

These rather good results are in a substantial agreement with those previously obtained in the test cryostats.

| $\langle Q_0 \rangle$ | $\langle E_a \rangle$ 7W<br>MV/m | $\langle E_{max} \rangle$<br>MV/m | $\langle E_{peak} \rangle$<br>MV/m | $\langle H_{peak} \rangle$<br>G |
|-----------------------|----------------------------------|-----------------------------------|------------------------------------|---------------------------------|
| $1.3 \times 10^9$     | 7.1                              | 10.9                              | $\cong 54$                         | $\cong 1100$                    |
| $\pm 0.5 \times 10^9$ | $\pm 0.1$                        | $\pm 0.3$                         | $\pm 1.4$                          | $\pm 30$                        |

Tab.1 Average values measured on the four resonators.

### 4 MECHANICAL DAMPING TEST

The cavities were equipped with a dissipator [6][7] to prevent the setting up of mechanical resonances induced by environmental noise. We could test, for comparison, also the behaviour of a similar resonator installed on the same line without dissipator. We recorded, by means of a spectrum analyzer, the spectra of the residual phase error signal of the phase-locked cavities: this signal is related to their mechanical vibrations. The response to the background noise was relatively weak in all cavities, but stronger in the damped resonator; this enhancement was expected, since the dissipator lowers the mechanical quality factor of the cavity and widens its acceptance bandwidth. The following measurement was done while inducing vibrations by means of a mechanical oscillator connected to the cryostats and driven by the spectrum analyzer. At higher vibration levels the damped cavities have shown a much more stable behaviour than the undamped one. The effect of the dissipator in the linac cryostat, although significant especially around the frequencies of the resonators mechanical modes (Fig. 4), was not as good as in the test cryostat, since new resonant modes appeared as a result of the new mechanical system (see Fig. 3). This is specially clear in resonator Q1, equipped with our old model dissipator [6]: Q1 is very stable around the dangerous 50 Hz but, when combined

with the linac cryostat, it shows a new resonance at 22.5 Hz which appears also in the undamped cavity B1.

The new model dissipator [7], even if the behaviour of resonator Q4 suggests an improper installation in this particular cavity, gives a significant stabilization at high noise level.

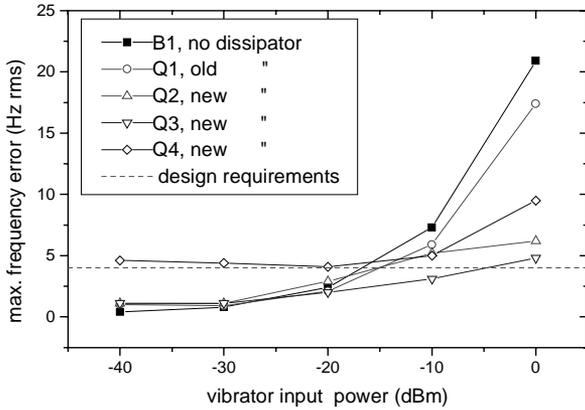
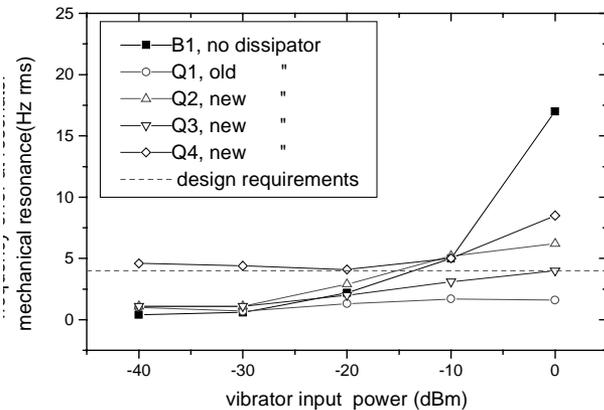


Fig. 3 Maximum frequency error induced by a mechanical vibrator operated in the range 5-150 Hz. In B1 and Q1 the largest vibration is at 22.5 Hz.

Fig. 4 As in Fig. 3, vibrator operated in the range 40-60 Hz, around the resonators mechanical eigenfrequency of 42 Hz.



At present, the main problems in operating the resonators come from fast helium pressure instabilities (more than 100 mbar/minute) which show up from time to time in our cryogenic system. The resonators response to pressure changes varies from  $\approx 0$  to  $\approx 1$  Hz/mbar; our mechanical tuner, driven in a feedback loop by the residual phase error of the resonator, can compensate for changes within about 10 Hz/minute. When our cryogenic system is in stable operation, and this situation can be maintained for days, our cavities can be locked reliably. However, sudden changes of the helium pressure, appearing as a result of fast changes of the cryogenic load, can cause cavities unlocking. We are presently working to eliminate the causes of these fast pressure jumps.

## 5 CONCLUSIONS

The very high field reached by these operating cavities, built by using a technology which can be purchased from industry at a relatively moderate cost, demonstrates that the design goal of 7 MV/m at 7 W can be considered a reasonable standard for this kind of resonators: this is more than two times higher than the low- $\beta$  heavy ion linac ALPI design requirements. A 54 MV linac, the final goal of ALPI, would need only 11 such cryostats (about 7.6 m of resonators) instead of the planned 25, dissipating only 300 W of rf power at 4.2 K instead of 700. This development can reduce significantly (to about one half) both the linac and the cryogenic plant size of future machines, as well as their construction and maintenance cost.

The low frequency resonant mechanical modes, which are typical of superconducting cavities working below 100 MHz, can be strongly attenuated by a newly designed mechanical dissipator, which could eliminate the need of electronic fast tuners.

At LNL, eight more bulk niobium cavities are ready to be installed in the ALPI linac. Moreover, a  $\beta=0.047$  cavity of a similar type was constructed and successfully tested; this resonator, together with 7 more which are presently under construction, will be part of the new LNL linac injector PIAVE.

## 6 ACKNOWLEDGMENTS

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