RESULTS OF NEW MEASUREMENTS ON THE 80 MHZ BULK-NIOBIUM RESONATOR

***A. Facco and +*J.S. Sokolowski**

* *INFN-Laboratori Nazionali di Legnaro, via Romea 4, 35020 Legnaro (Padova), Italy.*

\+ *The Weizmann Institute of Science, Department of Nuclear Physics, Rehovot 76100, Israel.*

Abstract

A series of new measurements was performed on the 80 MHz, $\beta_o = 0.056$ bulk niobium resonator developed at Laboratori Nazionali di Legnaro. The standard resonator surface preparation was modified by including a rinse with high pressure (100 bar) deionized water; in the rf test we observed a drastic reduction of the surface residual resistance, that reached 8 $n\Omega$ (compared with 70 $n\Omega$ measured after the standard treatment). As a consequence, the resonator Q (theoretical BCS limit 5.4×10^9) was 1.4×10^9, almost constant up to $E_a = 4$ MV/m. A sudden breakdown appeared when we tried to reach higher field values in cw mode; the reasons of this breakdown will be further investigated. We have searched for the mechanical resonances of the cavity and tested its mechanical stability at 4.2 K, as well as the capability of the ALPI rf controller to phase and amplitude lock the resonator in noisy conditions. The resonator, controlled in the standard ALPI configuration, remained phase and amplitude locked in a very noisy environment (purposely induced mechanical disturbances, LN_2 transfers, liquid helium transfers and pumps operating). Using a powerful vibrator connected to the cryostat we discovered only one mechanical resonance at 42.7 Hz. This frequency, applied continuously, would unlock the resonator; however, short-time disturbances were still managed by the controller. We measured also the resonant frequency shifts due to variations of the cooling helium pressure and the resulting phase shifts when the resonator was locked to an external reference. The results seemed to demonstrate that our system would be compatible with pressure fluctuations expected in ALPI. This type of resonator will be used as the accelerating element in the low-β section of ALPI.

1. Introduction

The bulk niobium resonator program at LNL[1] included the development of an 80 MHz, $\beta_o = 0.056$ resonator for the low-β section of the ALPI linac. The main purpose of the measurements described in this paper was preparation of final data before embarking on production of such resonators. The two basic questions to be answered were whether the resonator, in spite of its length, could be kept amplitude and phase locked in noisy mechanical environment and whether we could overcome the limit of 4 MV/m discovered during the previous measurement[2], caused most probably by a hot spot on the superconducting rf surface.

We were hoping to get rid of the breakdown noticed in the previous test by applying the high pressure rinsing[3];we have tried this procedure already on our 240 MHz cavity[2] and the breakdown point moved to a higher field.

The mechanical stability test was crucial to the production program; if the resonator would prove unstable we would have to introduce changes in its structure. Improving the maximum achievable field, which was already beyond the planned operating point of the resonators, was not critical; however, it would be of great interest for us to be able to eliminate the breakdown point or at least to know its origin.

2. Resonator preparation for the test

It should be noted that prior to this run of measurements the resonator has undergone some other preparations and traumas in the following order:

1. Chemical treatment.
2. Firing at 1300°C with titanium gettering.
3. Resonator collapse due to cryostat overpressure accident.
4. Mechanical straightening of the collapsed region of the resonator without rewelding or any heating operations.
5. New chemical treatment and rf test.

After the last test[2] the resonator was stored in a vacuum tank for 6 months; during this time nitrogen flushings as well as vacuum deterioration due to power breaks could not be avoided. Just before the preparation for this test the cavity was kept for one week in open air.

The preparation consisted of rinsing with 100 l of high pressure (100 bar) deionized water during 10 minutes, followed by a short rinse with 2.5 l of ethanol. We employed in-house redistilled ethanol which was previously used for similar rinsing. No nitrogen drying was used, the identically treated bottom plate was attached to the wet resonator and the cavity was subsequently mounted in the test cryostat. After closing the cryostat a 48 hour pumping period was followed by 36 hour heating in vacuum at 370 K. After the standard multipactoring conditioning at room temperature and at liquid nitrogen temperature the resonator was ready for testing.

3. Testing sequence

As mentioned before, we have had only some specific tests in mind, namely;

A. Mechanical stability of the resonator
   a. frequency change between room temperature and 4.2 K
   b. frequency dependence upon the helium pressure change
B. Phase and amplitude lock using the standard resonator controller
   a. in normal laboratory conditions
   b. in presence of strong mechanical disturbances
   c. in presence of induced mechanical vibrations at various frequencies
   d. in presence of induced helium pressure changes
C. Tuning range of the tuning mechanism with niobium sputtered copper bottom plate
D. Effect of the high pressure rinsing on the resonator performance: did the procedure remedy the breakdown previously observed above 4 MV/m?

Since our main objective was a long sequence of measurements for studying the mechanical stability of the cavity and since we had the pickup calibration factor from the previous measurement, only at the end of the experiment we decided to check the quality factor of the resonator, assuming wrongly that it could not improve as a result of high pressure rinsing after the long and incorrect storage of the cavity.

4. Experimental procedure and results

We measured the change of resonant frequency of the phase locked cavity in self excited mode, as a function of the cooling helium pressure. This pressure, in ALPI, is expected to fluctuate between 1.2 and 1.3 bar. The frequency shift in the range from 1.0 to 1.5 bar is shown in fig.1. This shift was not negligible but could be managed, in the range of interest, by overcoupling the resonator.

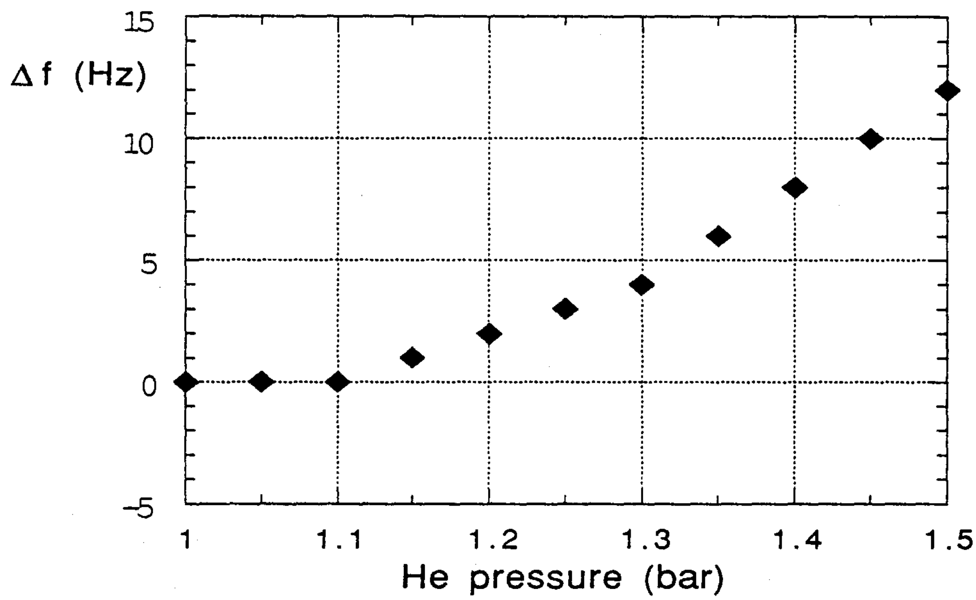

Fig.1 Frequency shift vs He pressure

We were able to amplitude- and phase-lock the resonator to the standard frequency source easily. We did not notice any unlocking of the strongly overcoupled resonator neither due to the mechanical ambient noise, nor to purposely induced mechanical transients. We measured the phase error due to helium pressure changes; we tuned the resonator to the external rf source when the helium pressure was 1 bar.

It should be noted that, due to the fact that we underestimated the resonator Q, we were working with a very strong coupling at a field value below 1.3 MV/m; we intend to repeat these measurements at less favourable conditions. Changes from 1 bar to 1.4 bar at 1 MV/m were within the controller locking capabilities (maximum phase error of 0.05 degree) using a maximum forward power of 70 Watts (see fig.2a and 2b).

In order to test the mechanical resonances of the cavity, a Brüer&Kjaer model BK 4808 powerful vibrator was coupled to the cryostat tank (by means of a stainless steel bellows attached to one of the valves) and the frequency range of 1 up to 1000 Hz was scanned. Only one resonant frequency of the resonator was detected (42.7 Hz, 0.2 Hz bandwidth); at this frequency short pulses would not be able to unlock the cavity, even at a rather high amplitude of vibrations. Only applying vibrations at this frequency for an extended period of time would unlock the resonator; given enough time the cavity would get out of lock even at low amplitude.

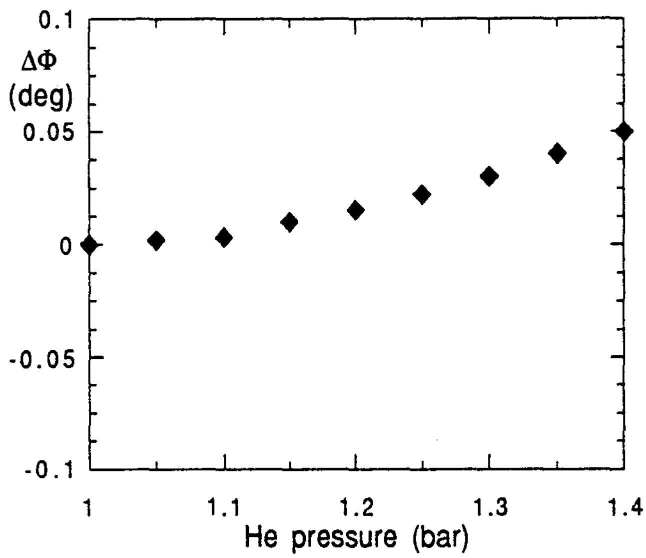

Fig. 2a Phase shift vs Helium pressure of the resonator locked to an external frequency

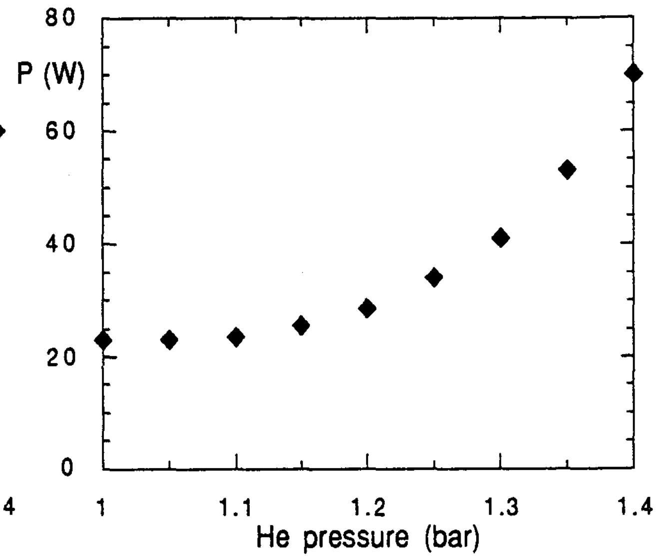

Fig. 2b Forward power vs Helium pressure of the resonator locked to an external frequency

We have measured the tuning range of the tuner, it was $\Delta f = 13.475$ kHz ($\Delta f/f = 1.7 \times 10^{-4}$) which would be satifactory for the resonator.

After having completed all the measurements needed for initiation of the production process we have concluded the tests by the Q *vs.* E_a measurements. The results were beyond our expectations. The low power Q of the resonator had increased to $Q_o = 1.42 \times 10^9$; it corresponds to the surface residual resistance of 8 $n\Omega$ as opposed to 70 $n\Omega$ of the previous measurement. The theoretical (BCS) maximum Q-value for a niobium resonator of this shape and frequency is 5.4×10^9. The complete Q versus E_a curve is shown in fig.3. The Q droop was very slow; at 4 MV/m Q was still 1×10^9 and the power dissipated in the cavity was less than 1 W. The breakdown which was previously observed above 4 MV/m reappeared; power and helium conditioning with 300 W peak power did not cause any significant improvement.

5. Conclusions

The resonator is mechanically stable, no reasonable noise could get it out of lock, at least in our strong overcoupling operating point. The 42.7 Hz mechanical resonance would be dangerous only in case of a CW source working in the vicinity of the resonator at this particular frequency. If this unfortunate situation could not be avoided, a special fast tuner would have to be installed.

Reasonable pressure excursions (from 1.2 to 1.3 bar) during the operation of the linac can be accomodated by the rf controller.

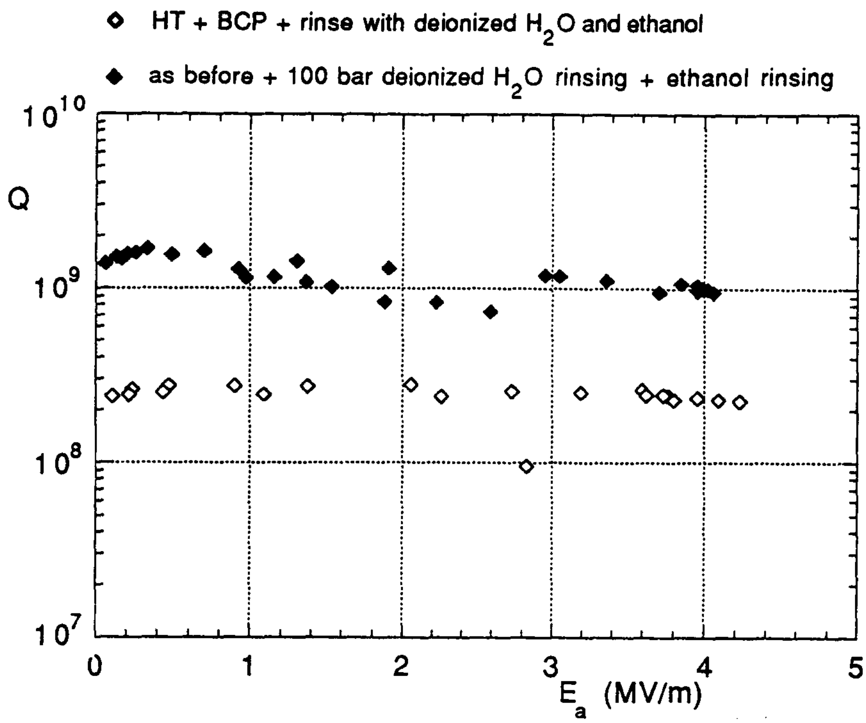

Fig. 3 Q vs. E_a curves, before and after high pressure rinsing.

The existing tuning mechanism is suitable for the resonator and should be used without any changes.

The Q measurement shows that neither the coupler nor the pickup location, suspected to introduce significant rf losses, prevented the resonator reaching high Q - therefore no change should be made in their position or design.

In comparison with the previous rf measurements of the same resonator, the Q curve is shifted up by about a factor of five; it seems reasonable to attribute this rather spectacular improvement to the high pressure water rinsing. One should do more testing in order to establish whether indeed the rinsing was the cause of Q-value improvement.

The 4 MV/m limit is still unclear; we shall continue looking for the clue.

6. Acknowledgments

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References

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