# MECHANICAL STABILISATION OF SUPERCONDUCTING QUARTER WAVE RESONATORS

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*Abstract*

A device which is capable to reduce significantly the amplitude of mechanical vibrations in superconducting quarter wave resonators was designed, constructed and tested. This device can eliminate the necessity of fast tuners and related electronics in many superconducting cavities, resulting in a significant cost saving both in the construction and in the operation of superconducting low beta linacs.

## 1 INTRODUCTION

Mechanical stability is a very important requirement in superconducting cavities; their very small rf bandwidth, a consequence of their very high quality factor, makes very difficult to lock them to an external frequency, requiring a very accurate tuning. The resonator eigenfrequency can be modified by mechanical deformations, caused mainly by mechanical noise in the environment and by liquid helium pressure fluctuations. In some cases frequency shifts are caused also by radiation pressure [1]. Different resonators have different response to these external solicitations; while usually slow frequency changes can be compensated by slow mechanical tuning, fast vibrations, particularly when they act close to a mechanical eigenfrequency of a resonator, can cause very wide frequency changes, making the phase-lock to an external reference impossible. Overcoupling allow to increase the effective bandwidth; however, it requires an increase of the power flow through the rf lines and, consequently, larger rf power sources and more liquid helium consumption. This solution is often not sufficient and a fast tuning device, either an electronic or a mechanical one, is needed, at the price of a higher complexity of the system and of an increase in liquid helium dissipation [2].

## 2 THE LNL, LOW β CAVITIES APPROACH

The LNL low beta quarter wave resonators [3] are cylindrical coaxial cavities with very good rf performance; they have only one dangerous mechanical resonance at 42 Hz, related to the oscillation of the inner conductor with respect to the outer one. The mechanical quality factor $Q_M$ of this mode is about 2000 (decay time: ~8 s). The effect of this resonance can be observed by looking at the phase error signal when the resonator is phase-locked at 80 MHz: hitting cryostat can induce an oscillation which persists for many seconds. The high mechanical $Q_M$ prevents a fast setting up of the oscillation in the case of white noise; on the other hand, when a 42 Hz mechanical vibration is applied for a long enough time, the frequency error can reach such an amplitude that the phase-lock system capabilities are exceeded. In the ALPI linac cryostats this condition can appear, for a few minutes, almost everyday; this could make the operation of many resonators at the same time problematic. We have exploited a new approach to this problem: we have added to the resonator a mechanical dissipator, capable to absorb energy from the dangerous mechanical mode and, consequently, to reduce its amplitude. One problem in this approach is the difficulty of building a device with a linear, or at least smooth, response at liquid helium temperature; another problem is that new resonant modes could be easily introduced by adding to the resonator new parts. To be acceptable, the dissipator must fulfill also the following requirements: it must damp efficiently even very small oscillations, it must be simple and reliable, it must not affect the good rf performance of the resonator; moreover, it should be possible to add the dissipator to the existing resonators without modifying them.

## 3 DISSIPATOR DESIGN

The dissipator that we have developed consists of two main parts: an enforcing tube, welded to the stainless steel flange connected to the top of the resonator, protruding inside the inner conductor and terminated with a disk, and a load which is tightly connected to the inner conductor and oscillates together with it. Load and disk are in contact and any oscillation of the inner conductor make them slide with respect to each other (see figure n.1). The device can be mounted and dismounted without any difficulty.

*3.1 The enforcing tube*. The enforcing tube, a stainless steel cylinder, must be as rigid as possible and its lower resonance must be higher than 150 Hz which is believed to be a tolerable frequency ; its length and its outer diameter (48 mm) result from a compromise which guarantees a high enough resonant frequency and proper cooling of the inner conductor. Holes along the tube allow liquid and gas helium flow. The bottom disk can be made of different shapes and materials; after examining the the static and the dynamic friction coefficients for different coupling materials our choice was a flat, brass disk.

*3.2 The load*. The load is made of stainless steel parts; it is designed to sit automatically in the right position, move together with the inner conductor and slide over the bottom disk. The lower surface of the load is of 40 mm radius spherical, convex shape. Three pins are pushed by the load onto the inner conductor in order to provide the contact. Due to the low temperature, it is impossible to use springs and any contact at a desired pressure must be provided by gravity.

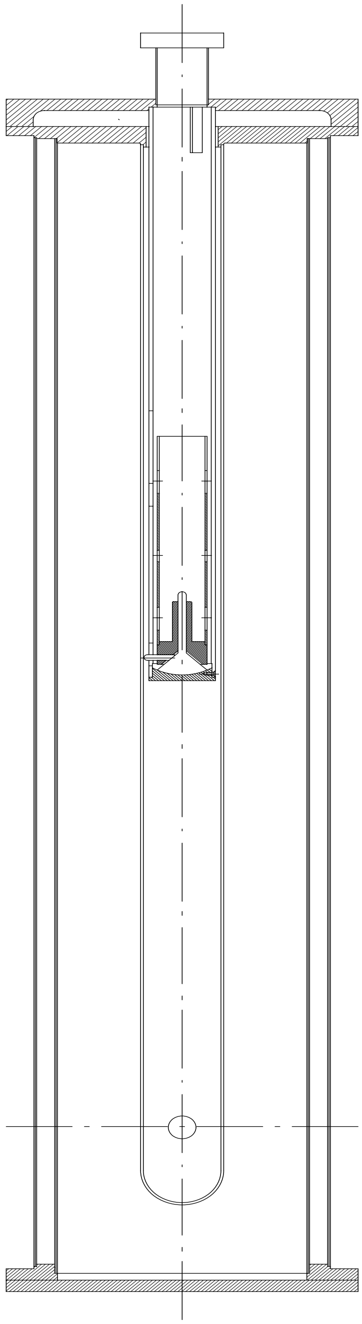

Fig. 1. Schematic of the mechanical damper inserted in a quarter wave resonator

*3.3 Theory*. A simple model allows us to calculate the main parameters of the device. We will assume that the inner conductor (of length $l_C$ and mass $M_C$ ) and the enforcing tube (of length $l_T$ and mass $M_T$ ) are connected to the same rigid plane (see fig. 1). The mechanical eigenfrequency of the inner conductor without dissipator is $\omega_C=\sqrt{(k_C/m_C)}$, where $k_C=(8/5)E_C I_C l_C/l_T^4$ , $E$ is the Young modulus of the material, $I$ is the geometrical moment of inertia of the tube and $m_C=(1/5)M_C(l_C/l_T)^4$ . The dissipator load of mass $m_D$ is located at the end of the enforcing tube and slides over the brass disk when the inner conductor oscillates. The load mass will change this frequency to $\omega_{CD}=\sqrt{(k_C/(m_C+m_D))}$. In a similar way we can calculate the enforcing tube eigenfrequency: $\omega_T=\sqrt{(k_T/m_T)}$ where $k_T=(8/5)\ E_T I_T/l_T^3$ and $m_T=(1/5)M_T$ . For very small oscillations the two tubes will move together, coupled by the static friction force between load and disk, at a frequency $\Omega_{CM}=\sqrt{\{(k_C+k_T)/(m_C+m_D+m_T)\}}$. If the oscillation amplitude at the top of the inner conductor , $x_0$, is sufficient to overcome the static coupling force, i.e. if

$$x_0=\{m_D gs/(\omega_T^2-\omega_C^2)\}\{(m_C+m_D+m_T)/[(m_C+m_D)m_T]\}(l_C/l_T)^2 ,$$

the two tubes will oscillate independently and the dissipator will slide on the brass disk; assuming a rigid enforcing tube the power dissipated will then be

$$P=\{(m_C+m_D)\omega_{CD}^3/(2Q_M)\}(l_T/l_C)^4 x_0^2+\{2\omega_{CD}m_D dg/\pi\}(l_T/l_C)^2 x_0$$

where g=9.8 $ms^{-2}$, $Q_M$ is the mechanical quality factor of the mode in absence of dissipator and s, d are the static and the dynamic friction coefficients between brass and stainless steel. For small oscillations the rf frequency error induced by this deformation is proportional to the displacement of the top of the inner conductor: $\delta f=\eta\ x_0$ . These formulas allow us to choose the main parameters of the device.

## 4 CONSTRUCTION AND MEASUREMENTS

We have built a few prototypes: the main differences were the length of the enforcing tubes (36 and 50 cm), the shape of the bottom disk (flat or spherical) and the disk material. For our particular case a flat disk is sufficient; however, a parabolic surface $y=\alpha x^2$ would introduce an additional term $P=\{8\omega_{CD}m_D dg\alpha/(3\pi)\}(l_T/l_C)^6 x_0^3$ in the power dissipation formula which would damp strongly at higher amplitudes. Measurements were done at room temperature to compare various prototypes; a test was done also at liquid helium temperature to verify that the device would not affect the resonator performance.

We have connected to the resonator a mechanical vibrator (Brüer & Kjaer mod. 4808) driven by a spectrum analyser HP 4195A which was reading at the same time the phase error signal, proportional to the frequency error for small oscillations, of the resonator locked to an external reference. We have calibrated our system in order to have a frequency error signal of 1 mV/Hz. We have verified the linearity between the applied vibration and the the frequency error up to about 200 Hz; then we have connected the dissipator and measured its effects. We have detected the peaks of the common mode oscillation resonance and explored their evolution at different vibrator amplitudes. We have done our test sweeping the frequency of the vibrator and in steady state mode. The test in superconductive regime was done after mounting a 50 cm long enforcing tube with a spherical surface stainless steel disk.

## 5 EXPERIMENTAL RESULTS

The results of our test are summarised in fig.2, where the maximum frequency error versus the vibrator input power is plotted in three different cases: for the resonator without dissipator, for the short and for the long tube dissipator, respectively. In the absence of dissipator the frequency error at the mechanical resonance is proportional to the square root of the vibrator power, as expected: this means both that our vibrator is linear and that the frequency error is proportional to the amplitude of the inner conductor oscillation.

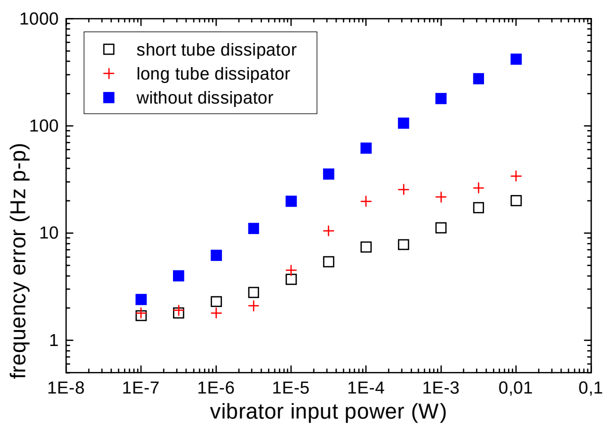


Fig. 2. Frequency error vs. vibrator input power.

The effects of dissipators are rather strong; the best results were obtained with a 36 cm long enforcing tube and a brass disk: this configuration starts working well even at very low level of external vibration and its response is very smooth. No new strong resonances were introduced, except for the expected common mode vibration at about 48 Hz, very weak in comparison with the original 42 Hz one. The attenuation of the frequency error is very significant and increasing with the external vibration amplitude; instead of being proportional to the frequency error amplitude, the power losses seem to increase with the fourth power of it. This means that other dissipation mechanisms are active in addition to the load sliding. At the maximum vibration level the frequency error, originally at 400 Hz, is being attenuated down to 20 Hz. We have mounted a dissipator with a spherical surface stainless steel disk and a 50 cm enforcing tube inside a low beta niobium resonator of the ALPI type. During this test we have verified that the good resonator performance were preserved by this addition and that the resonator could be locked to an external reference in the presence of vibratior noise. However, during the measurement we could not disconnect the dissipator for a comparative measurement. The common mode vibration was present but it seemed always to be well within the rf controller capabilities.

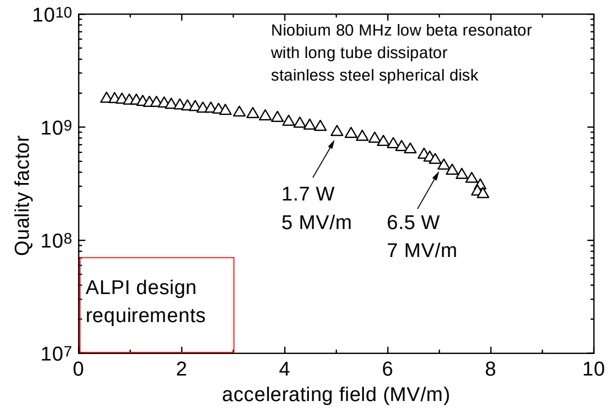


Fig. 3. Quality factor vs. accelerating field measured in the cavity equipped by a dissipator.

## 6 CONCLUSIONS

Mechanical dissipators appear to be an interesting alternative to electronic fast tuners in superconductive quarter wave resonators; they can attenuate the frequency error induced by environmental vibration by at least one order of magnitude and they seem not to present drawbacks. Their construction cost is very modest and they have no operation cost; it seems reasonable to install them even in resonators equipped with a fast tuner: the effective tuning range of the system would be increased significantly or, in alternative, the original fast tuner could be changed with a less demanding one. In our resonator, which is supposed to work with a 8 Hz bandwidth, the dissipator that we have tested is equivalent to a 100 Hz fast tuner. Particular attention must be paid to the design parameters in order to avoid the introduction of new mechanical resonances or setting up of high $Q_M$ common mode oscillations; other models using the same principles could be developed for superconducting resonators of different geometries. Further developments are foreseen in the next future at LNL to optimise the dissipator characteristics and to verify the behaviour at 4.2 K; we planned to equip all low beta cavities with these devices.

## 7 ACKNOWLEDGMENTS

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