SUPPRESSION OF MECHANICAL OSCILLATIONS IN QUARTERWAVE 106 MHZ RESONATOR

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Abstract

Analytical calculations and numerical simulations have been done for mechanical eigenmodes of quarter wave superconducting resonators with operating frequency of 106 MHz and 80 MHz. A possibility of frequency shift of mechanical modes in 106 MHz resonator has been estimated by application of the damper. We have optimized the damper's position for suppression efficiency. We have also compared the numerical and experimental results.

INTRODUCTION

Superconducting quarter wave resonators (QWR) are used very often in particle accelerators at relatively low particle velocities $\beta < 0.15$. They operate in frequency range from 70 to 160 MHz. The structure of commonly used superconducting QWRs is enough sensitive for mechanical vibrations because of their length of 0.5-1 m made from 2-3 mm thin sheets of Nb. Superconducting cavities inside of cryomodule affected by various factors such as vibrations from environment and vacuum pumps, instant impacts from valves, oscillations of liquid He pressure. Hence, a wide spectrum of mechanical oscillations is applied to the cavity and could excite mechanical oscillations deforming the cavity geometry and providing substantial deviations of resonant frequency. It causes instabilities in cavity operation. There are several ways to mitigate this problem:

- To keep mechanical resonances in higher frequencies region to be far away from strong industrial noise components of 50-60 Hz
- To make cavity structure more rigid to reduce sensitivity for vibrations
- To make operational bandwidth of the cavity higher than frequency deviation caused by mechanical vibrations
- To use mechanical damper [1] to dissipate energy of mechanical vibrations.

The most effective way of microphonics suppression is to develop mechanical dampers for the cavities.

This paper is focused on investigation of mechanical oscillations in 106 MHz [2] superconducting QWR with mechanical damper. The cavity design presented in Fig. 1.

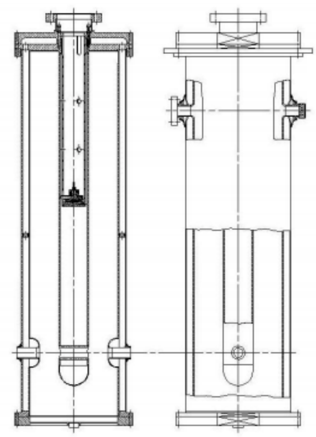

Figure 1: Design of the 106 MHz superconducting Nb QWR with mechanical damper.

ANALYTICAL CALCULATIONS

Inner conductor of the QWR is the most sensitive part to mechanical impacts. Frequencies of mechanical modes f_i of the inner conductor can be roughly estimated by using an approach of a thin-wall cylinder fixed at one edge [3].

$$f_i = \frac{\alpha_i^2 \cdot \sqrt{\dfrac{E \cdot I}{\mu}}}{2 \cdot \pi \cdot L^2} \qquad (1)$$

where E is Young's modulus; L = 685 mm is the length of the inner conductor; μ is the mass of the inner conductor per unit length; α_i is the intrinsic constant of oscillation (α_1 = 1.875, α_2 = 4.694 for the first and second modes, respectively); $I = \frac{\pi}{4}\left(r_o^4 - r_i^4\right)$ is the moment of inertia of a thin-wall cylinder with radii of r_i and r_o.

According to these formulae, the frequencies of the lowest mechanical modes are f_1 = 46.5 Hz and f_2 = 291.2 Hz for the resonator with an operating frequency of 80 MHz; and f_1 = 72.7 Hz and f_2 = 455.7 Hz for the resonator with an operating frequency of 106 MHz. According to [3], the frequencies of the first two modes of the inner conductor of 80 Hz resonator are f_1 = 45 Hz and f_2 = 284 Hz. The difference between results might be explained due to approximation of the theoretical model which did not take into account a complicated shape of the inner conductor.

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NUMERICAL SIMULATIONS

Numerical simulations of mechanical oscillations of the 106 MHz quarterwave resonator have been done with two codes: ANSYS [4] and Comsol Multiphysics [5]. The upper plate of the QWR (see Fig. 1) is fixed for assembly in the cryomodule and was treated as a fixed plane. The parameters of Nb used in simulations are presented in Table 1.

Table 1: Parameters of niobium used in simulations.

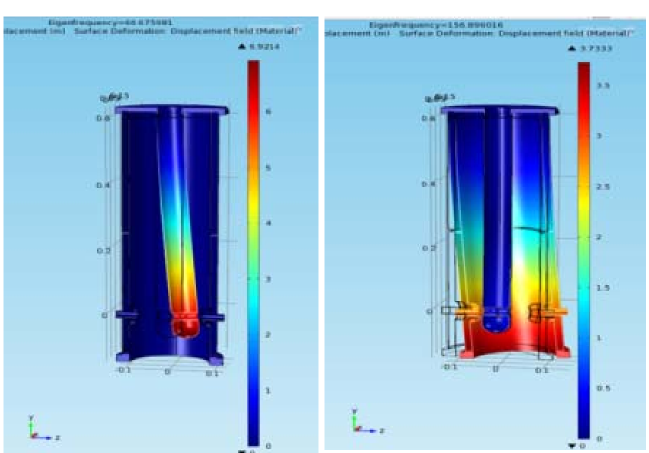
Material	Young's modulus, GPa	Poisson coefficient	Density, kg/m^3
Niobium	105	0.38	8570

Mechanical eignefrequencies of the first five lowest mechanical oscillations obtained from numerical simulations in ANSYS and COMSOL are very close and are presented in Table 2. Figure 2 shows damper deformations for the first two modes simulated in Comsol.

Table 2: Main mechanical modes in 106 MHz QWR

Mode	Frequency f_i, Hz	
	ANSYS	Comsol
1	66.85	66.68
2	157.2	156.89
3	429.5	415.19
4	431.8	431.22
5	552.6	544.4

The first and the fourth modes shown in the table appear to be the first and second modes of the resonator's inner conductor (Figure 2a), while the remaining ones correspond to the outer conductor (Figure 2b).



a) f_1 = 67 Hz *b)* f_2 = 157 Hz

Figure 2: Main mechanical modes in 106 MHz QWR.

Frequencies obtained from analytic and numerical simulations are in good agreement; the difference of 8-9% is due to the approximation of the cavity shape.

The simulation results for 80 MHz superconducting QWR are presented in Table 3. The frequencies of the first two modes for the inner conductor obatined numerically in ANSYS and compared to analytical calculations [3].

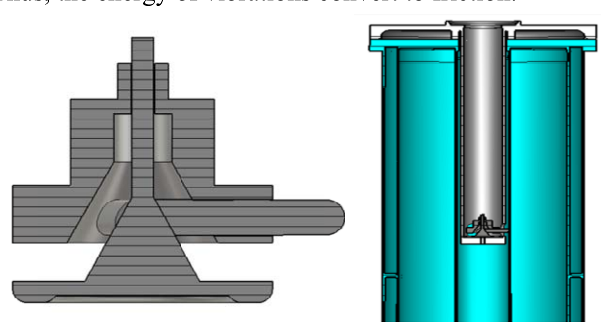
Table 3: Frequencies of the first two modes of the inner conductor

Mode	Frequency f_i, Hz	
	ANSYS	By [3]
1	44.76	45
2	281.20	284

The results are very close and the difference is less than 1%. The approximation works better for 80 MHz QWR rather than for 106 MHz QWR because the impact of cylindrical part of the geometry is dominating in the result.

DAMPER SIMULATIONS

Design of the mechanical damper for 106 MHz QWR is presented in Fig. 4. The damper [3] consists of the stainless steel cone on the stainless steel bottom, brass load is placed on the top of the cone and three fingers are used for contact between cone and the inner conductor internal surface. The finger's vibrations transfer to the inner conductor and to the cone. In the result the vibrations convert to damper's sliding on the bottom. Thus, the energy of vibrations convert to friction.



a) b)

Figure 3: Geometry of damper (a) and its position in resonator (b).

Mechanical model of the 106 MHz QWR inner conductor with damper was created for simulations in Comsol.

The first results of the numerical simulations of damper, integrated on the tube and assembled inside of the QWR inner conductor, show that the inner conductor frequency is of 75.5 Hz (Fig.5) which is 12% above the value of the first mechanical mode of the inner conductor without damper.

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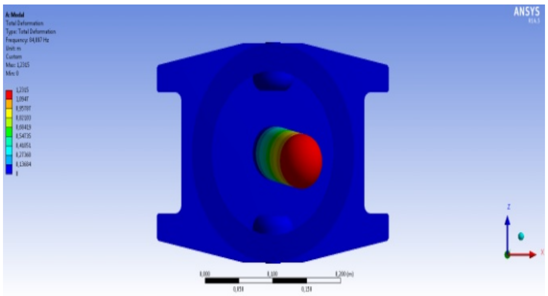

Figure 4. The lowest mechanical mode of the inner conductor with damper.

To achieve the maximum displacement of the lowest mode frequency, optimization of the damper's position, we have changed the length of cylindrical base of the damper. Simulations in ANSYS were done for the models with the damper's base lengths from 100 mm to 600 mm. Figure 6 shows the plot of the inner conductor first mode frequency as a function the length of the damper's base.

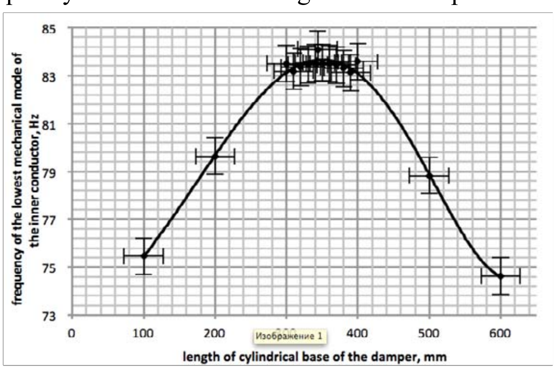

Figure 5: Plot of the inner conductor first mode frequency as a function of the length of the damper's base.

The hughest frequency of the inner conductor first mode was obtained for the damper's base length of 343.5 mm . It equals to 84.1 Hz which is 20.7% above the value of the frequency in the structure without damper application.

SUMMARY

Analytical and numerical simulations of the mechanical modes in 80 MHz and 106 MHz resonators have been done. The comparison of mechanical frequencies of 80 MHz resonator obtained using analytical calculations,numerical simulations and previously obtained data was done. The mentioned techniques provide the reasonable agreement. The highest frequency displacement of the first inner conductor mode o is achieved by the application of a damper. The studies will be continued for damper efficiency optimization.

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