MECHANICAL PROPERTIES OF SPOKE RESONATORS*

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Abstract

This paper reports an investigation of the electromagnetic and mechanical properties of spoke-loaded intermediate-β superconducting (sc) cavities being developed for both cw and pulsed operation. These structures are of interest in new linacs such as the proposed RIA driver linac and the 8 GeV FNAL proton driver. Results characterizing the interaction between the electromagnetic and the mechanical structure will be presented. This study focuses on microphonics, Lorentz detuning, and mechanical fast tuners.

DYNAMIC FREQUENCY VARIATIONS

SC spoke cavities are highly sensitive to mechanical deformations due to the small loaded bandwidth of some sc rf applications. Variations in the cavity rf eigenfrequency that are a large fraction of the loaded cavity bandwidth result in rf field phase and amplitude errors. Two sources of these frequency variations are microphonics, and the Lorentz force detuning. Microphonics refers to the mechanical vibrations of the cavity due to externally driven mechanical vibrations. Lorentz detuning refers to the change in rf eigenfrequency due to mechanical distortion of the cavity caused by the rf electromagnetic field.

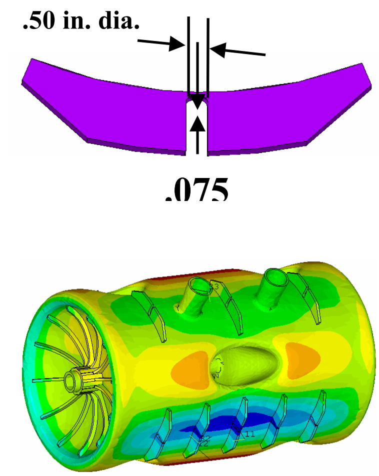
Two examples of these frequency variations are found in the proposed RIA Driver linac and the proposed FNAL 8 GeV proton driver upgrade. For the cw RIA driver linac the loaded spoke cavity bandwidths range from 50 to 250Hz and microphonic induced frequency variations are expected to be around a few tens of Hz. The proposed pulsed FNAL 8 GeV proton driver upgrade employs β = 0.5 325 MHz triple spoke cavities with loaded bandwidths of 800Hz. For a similar β = 0.5 triple spoke cavity being developed at Argonne National Laboratory (ANL), as is discussed below, the expected Lorentz detuning due to pulsing the cavity rf accelerating field to 10MV/m is ~730Hz.

During cold tests of double and triple spoke cavities, the dynamic variation of the rf eigenfrequency was measured, including microphonics, Lorentz detuning, and the characteristics of two different fast tuning systems. This work is described below.

Microphonics

The microphonic behavior of the β = 0.42 double spoke and the β = 0.5 triple spoke cavities has been previously reported [1, 2]. In both cases the rf eigenfrequency variations resulting in significant phase error (>0.3^{o}) occur only at low frequencies. The β = 0.5 triple spoke cavity was designed to minimize the total rf eigenfrequency shift due to changes in the He bath pressure (df/dp) by adding support ribs to the end walls and the cylindrical wall of the cavity. The support ribs stiffen the cavity walls but are not intended to reduce df/dp simply by stiffening. Rather, the ribs are intended to reduce df/dp by balancing deflections of the cavity wall in areas with high magnetic fields with deflections in areas with high electric fields. In actual construction, some of the ribs were made slightly oversize to allow for post-construction fine-tuning by cutting away part of each rib.

After the initial construction a residual df/dp = -12.4 Hz/torr at 4K was measured and the FEA design guiding the rib placement predicted a shift of -10.5 Hz/torr [2, 3]. After modifying the support ribs, the rf eigenfrequency shift was measured to be 2.2 kHz over 680 torr whereas the modeled result predicted a 3.7 kHz shift (Figure 1) [3].



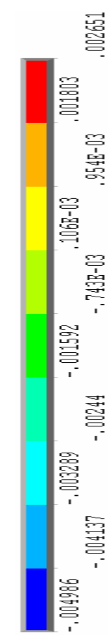


Figure 1: Pro-E model of the β = 0.5 triple spoke cavity with support ribs after modifications. Displacements in inches.

Lorentz Detuning

In order to characterize the dynamic Lorentz detuning, we have measured the Lorentz transfer function for several spoke cavities. The Lorentz transfer function correlates an rf amplitude modulation with the consequent Lorentz-force-induced frequency modulation. This was accomplished by exciting the cavity accelerating rf eigenmode, amplitude modulating the forward power, and measuring the phase and amplitude of the rf eigenfrequency modulation simultaneously with the rf eigenmode amplitude modulation. The initial measurement of the β = 0.42 double spoke cavity Lorentz transfer function is shown in Figure 2 [1]. The initial measurement of the β = 0.5 triple spoke cavity Lorentz transfer function is shown in Figure 3[2].

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The transfer functions display several encouraging features. Firstly, there are very few mechanical modes excited by the dynamic Lorentz force. Secondly, these modes are at high frequencies and do not couple to the ambient vibration caused, for example, by LHe bath bubbling.

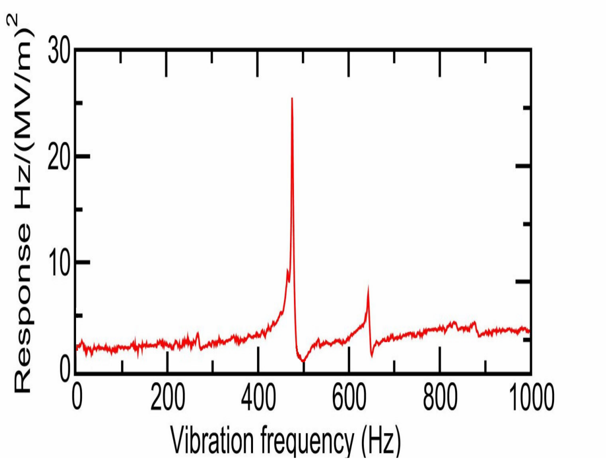

Figure 2: Amplitude of the β = 0.42 double spoke resonator lorentz transfer function when excited in the 348MHz mode

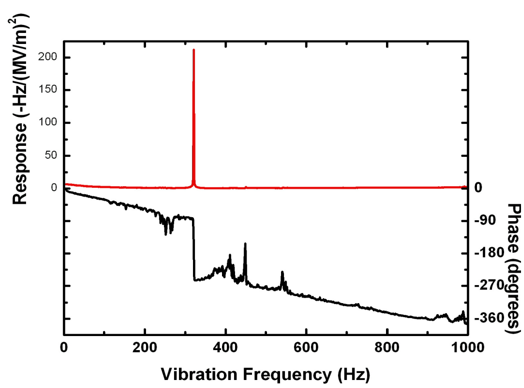

Figure 3: Amplitude and phase of the β = 0.5 triple spoke resonator lorentz transfer function when excited in the 345MHz mode.

The transfer function can be used to predict the cavity rf eigenfrequency response to pulsed fields. This is displayed in Figure 4 for the β = 0.5 triple spoke cavity and indicates that the cavity will ring at 320Hz the modulation frequency at which the Lorentz force excites a cavity mechanical mode. This result will be experimentally tested once a source of sufficient (>8kW) rf power is procured.

Fast Mechanical Tuners

In order to characterize the fast tuner performance, we have measured the tuner transfer function for several cavities and fast tuners. The tuner transfer function correlates the amplitude and frequency of the tuner drive signal with the cavity rf frequency modulation. This was done by sweeping the frequency of the signal driving the fast tuner and simultaneously recording the phase and amplitude of the resulting cavity rf frequency modulation.

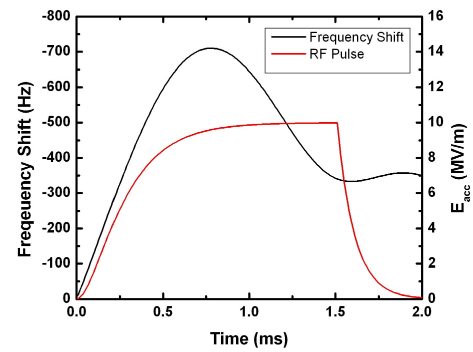

Figure 4: Predicted rf eigenfrequency response of the β = 0.5 triple spoke cavity due to pulsing the rf fields.

The fast tuners were mounted on the spoke cavities by bolting the actuator assembly to a conflat flange on the integral stainless steel helium jacket described in [2, 3]. The fast tuners distort a small region of the cavity surface in a region of high surface magnetic field near the base of one of the spoke elements [4]. During operation the fast tuner actuator expands and contracts, pushing between the Nb wall of the cavity and the stainless-steel resonator housing.

Figure 5: The piezoelectric fast tuner assembly used during the cavity tests and the piezoelectric actuator.

The first mechanical tuner tested was a piezoelectric actuated fast tuner. The tuner utilized a Physik Instrumente type P-239.90 actuator mounted in an ANL-designed assembly. This assembly, shown in Figure 5, preloads, guides, and supports the piezoelectric fast tuner. The transfer functions for this tuner mounted on both the β = 0.42 double spoke cavity and the β = 0.5 triple spoke cavity are shown in Figure 6 and Figure 7 respectively.

The second fast tuner tested was based on a magnetostrictive rod actuator built by Energen Inc. under a SBIR contract [5]. The tuner utilized the Energen actuator encased in an ANL designed assembly. This assembly was designed to guide, and support the magnetostrictive fast tuner (Figure 8). The transfer function for this tuner mounted on the β = 0.5 triple spoke cavity is shown in Figure 9.

These transfer functions show that no low frequency mechanical modes of the mechanically coupled cavity and fast tuner are excited. This is promising for compensating the low frequency non-resonant noise below 100Hz due to LHe bath bubbling reported in [1,2]. In our work to date with these tuners development of a high mechanical frequency capability has not been the focus. Future designs will aim at higher-frequency capability to enable compensation of the dynamic Lorentz force detuning encountered during pulsed operation.

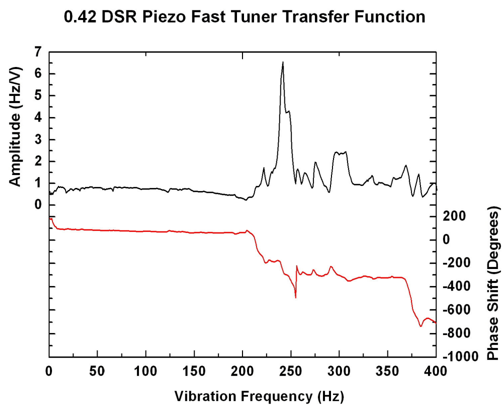

Figure 6: Transfer function amplitude and phase for the combined β = 0.42 double spoke resonator and piezoelectric fast tuner system.

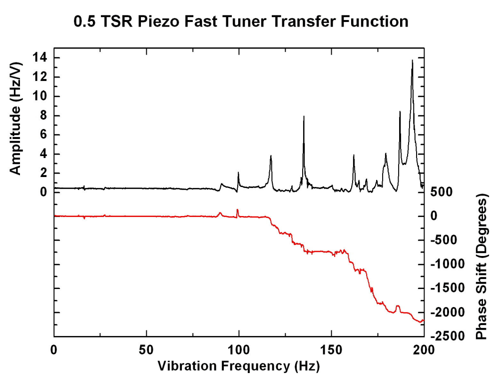

Figure 7: Transfer function amplitude and phase for the combined β = 0.5 triple spoke resonator and piezoelectric fast tuner system

CONCLUSIONS

We have measured the dynamic variation of the rf eigenfrequency of double and triple spoke cavities including microphonics, Lorentz detuning, and the characteristics of a piezoelectric and a magnetostrictive fast tuning systems. The mechanical fast tuner tests reveal that in their current state they are suitable for low frequency operation. However, they still need to be adapted to high frequency operation to compensate the high frequency ringing due to Lorentz detuning.

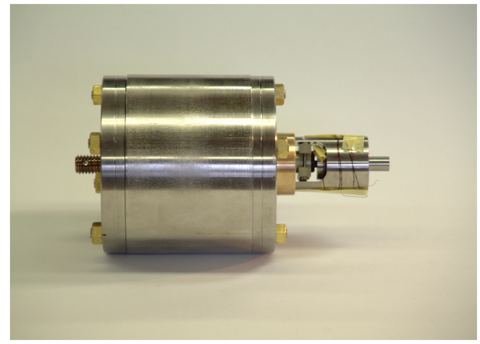

Figure 8: The magnetostrictive fast tuner assembly used during the β = 0.5 triple spoke cavity test.

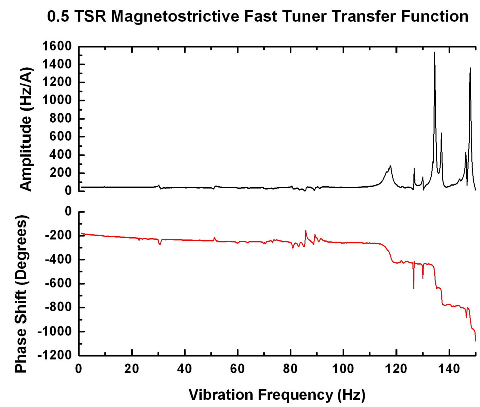

Figure 9: Transfer function amplitude and phase for the combined β = 0.5 triple spoke resonator and magnetostrictive fast tuner system.

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