MICROPHONICS MEASUREMENTS IN RIA CAVITIES

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Abstract

Phase stabilization of the RIA drift-tube cavities in the presence of microphonics will drive the RF power requirements for the RIA driver linac. Microphonics measurements on the ANL β=0.4 two-cell spoke cavity have been performed many at high fields and using a new "cavity resonance monitor" device developed in collaboration with JLAB. Microphonics tests on the fully jacketed two-spoke cavity operated under realistic conditions are the first ever on a multi-cell spoke geometry and indicate exceptional performance in this regard with no low-lying mechanical modes which couple to the cavity RF fields. Rather, at useful accelerating fields of E_{ACC}=7-8 MV/m most of the modest frequency jitter (~5 Hz RMS) is due to relatively slow pressure fluctuations in the helium bath due to pool boiling. The issue of microphonics is being addressed at Argonne in three ways: (1) construction of piezoelectric and magnetostrictive tuners, (2) cavity design to reduce the pressure sensitivity and (3) reducing the source of helium pressure fluctuations.

INTRODUCTION

The 300 superconducting (SC) cavities needed for the RIA driver linac [1] and spanning the velocity range 0.02< β<0.84 will require a method of fast tuning of the cavity eigenfrequency regardless of the detailed cavity type. This is because all proposed RIA cavities, being constructed of thin wall (~3 mm) niobium, will have eigenfrequency fluctuations caused by microphonics comparable to or larger than the beam loaded bandwidth.

Presently operated heavy-ion SRF linacs use one of two techniques for fast tuning in the presence of microphonics. The VCX tuner, first used more than 25 years ago, now constitutes a highly developed and reliable technology for frequencies up to 145 MHz [2]. VCX technology would, however, require further development for cavities running at frequencies above 145 MHz. A second established method uses overcoupling together with phase and amplitude feedback and would be suitable for all of the RIA cavity frequencies. However, this method would require many kilowatts of addition RF power for most of the RIA cavities. A third promising design uses a fast piezoelectric transducer to directly compensate for vibration induced frequency shifts. This, of course, has the advantage that it would require no additional RF power. A piezoelectric tuner has recently been demonstrated on a low-β quarter-wave cavity [3].

TEST HARDWARE

Microphonics measurements in production quality cavities tested in a realistic accelerator environment are necessary to establish fast tuning requirements. Important considerations include the frequency of cavity vibrational modes, the likelihood for excitation of the modes and the stored RF energy in the cavity. Cavity microphonics together with the beam dynamics requirements are the inherent considerations for tuner design. Present specifications for the RIA cavity fields call for an RMS phase error $\Delta\phi < 0.3^o$ and an RMS amplitude error <0.5%. Microphonics measurements consistent with this level of accuracy require that careful attention be paid to measurement techniques.

ANL has developed a set of electronics for the measurement of cavity microphonics. A pair of "cavity resonance monitor" (CRM) devices have been built and operated [4]. The devices directly compare the frequency of the cavity RF pickup to an external RF signal from of a low-noise generator. The output sensitivity of the CRM is 1 V per 100 Hz of cavity frequency shift and the device has an operational bandwidth for cavity vibrations ranging from DC to 1 kHz. As a reference, a pair of Agilent models 8665B and 8664A were used each in low noise mode and each having less than 1 Hz rms frequency jitter for modulation frequencies from 0 to 1 kHz. This set of hardware was used to measure, for example, the two-spoke Lorentz transfer function shown in Figure 1 (see also Section 3).

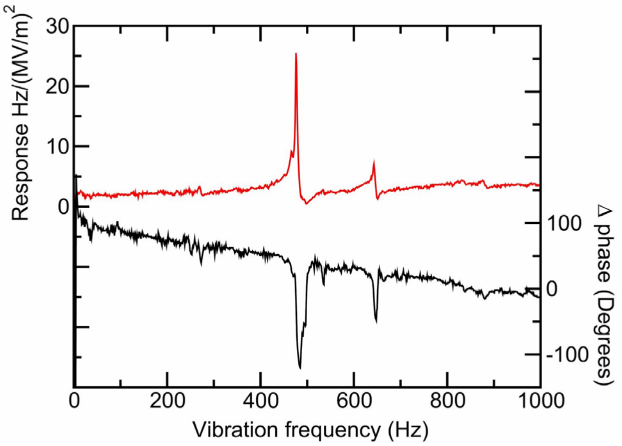

Figure 1: The measured Lorentz force transfer function for the two-spoke cavity. Top – amplitude response. Bottom – phase response. There are no low lying mechanical modes that couple to the RF fields.

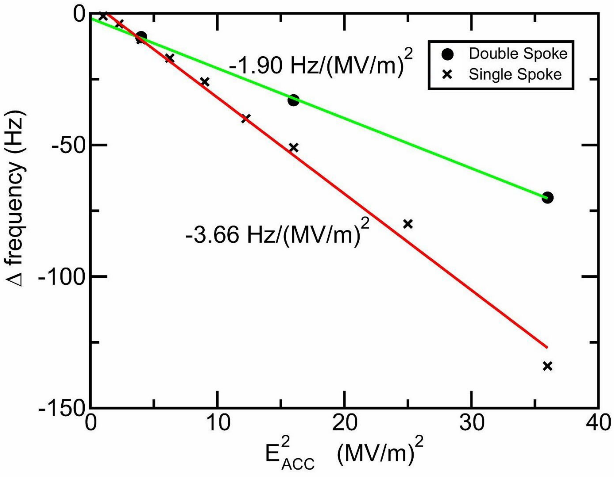

Figure 2: Static field Lorentz force detuning for the single spoke cavity (crosses) and the two-cell spoke cavity (circles) as a function of the square of the accelerating gradient. All ports are unconstrained.

A new set electronics used to lock the cavity field to an external master oscillator has been built and is housed in a single 19” rack mount chassis. The components include a self-excited loop and separate feedback loops to lock both the phase and amplitude of the cavity field. Together with the ANL high-power variable RF coupler and a 7 kW RF transmitter, these electronics have been used to stabilize the phase and amplitude of the two-spoke fields at realistic operational field levels.

RESULTS

Lorentz Force Transfer Function

The mechanical response of the cavity to a modulation of the cavity RF field is referred to as the Lorentz force transfer function and indicates which cavity vibrational modes may lead to shifts in the cavity RF eigenfrequency.

Transfer function data shown in Figure 1. were obtained by modulating the amplitude of the cavity RF drive with a peak input power of 15 Watts and a 10% modulation factor. The upper curve in Figure 1. shows the frequency response of the cavity as a function of the frequency of the amplitude modulation. The lower curve is the phase difference between the RF field modulation and the cavity eigenfrequency modulation. Cavity field amplitudes and modulation phases were measured with a crystal detector while the cavity eigenfrequency response was measured with the cavity resonance monitor device.

The data demonstrate that there are no low lying mechanical modes in the two-spoke cavity which couple to the RF fields. This is in contrast to typical thin wall quarter-wave and elliptical-cell geometries which typically have mechanical modes at ~100 Hz or less. Perhaps most importantly the frequencies of cavity vibrational modes lie well above nearly the entire observed microphonics spectrum. This presents an opportunity to damp these low frequency (nonresonant) microphonics with a mechanical transducer without exciting mechanical modes of the cavity. The inadvertent excitation of cavity mechanical modes had been problematical in similar efforts to damp microphonics performed much earlier.

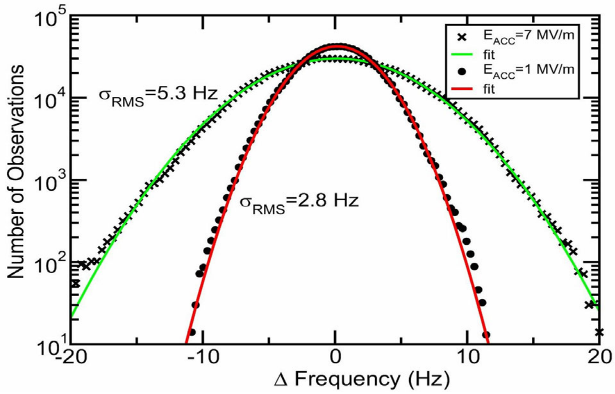

Figure 3: Probability density for double spoke eigenfrequency deviations for CW operation at E_{ACC}=7 MV/m (crosses) and E_{ACC}=1 MV/m (circles).

Microphonics Levels

The probability for cavity eigenfrequency shifts due to microphonics is shown in Figure 3. for the two-spoke cavity. Data was collected using the cavity resonance monitor for both low and high values of E_{ACC} at T=4.2 K. Each data set contains 100 seconds of data sampled at a rate of 10 kHz. The measurement at E_{ACC}=7 MV/m corresponds to a peak surface electric field in the two-spoke of E_{PEAK}=24 MV/m and represents a realistic operational field for drift-tube cavities in the RIA driver.

The observed 3 Hz RMS frequency jitter (Figure 3. - circles) at E_{ACC}=1 MV/m is typical of the jitter observed at low fields with the two-spoke cavity mounted in the horizontal test cryostat. The additional 2.5 Hz of frequency jitter at E_{ACC}=7 MV/m (Figure 3. – crosses) is due to low frequency vibrations induced by pool boiling in the 4.2 K helium bath. The corresponding heat load into the bath is ~15 Watts.

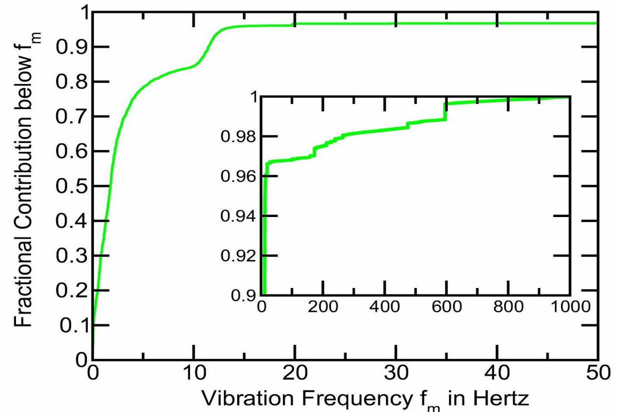

Figure 4: Fractional contribution to the total microphonics below the frequency f_m. The inset shows the same curve extended to vibrational frequencies up to 1 kHz.

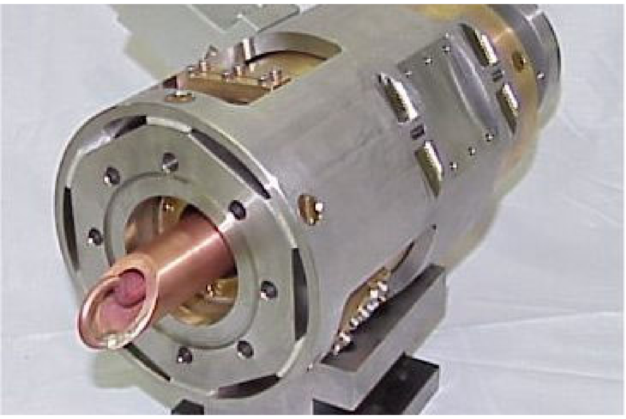

Figure 5: A high-power RF coupler for the two-spoke cavity designed for 5 kW CW power at 350 MHz and recently tested with up to 2 kW CW fully reflected.

The predominance of very low frequency vibrations compared to the total spectrum is shown in Figure 4. Here roughly 95% of the frequency jitter comes from vibrations with frequencies below 15 Hz. These rather low frequencies make the prospects for a mechanical transducer such as a piezoelectric stack quite promising as discussed below.

Phase and Amplitude Stabilization

The use of overcoupling to achieve phase and amplitude lock for the RIA two-spoke cavity has been demonstrated using a new high-power variable RF coupler designed for the RIA prototype cavities. The device is shown in Figure 5. In addition to providing for separate cavity and cryogenic vacuum spaces and clean assembly, the coupler is designed to operate with 5 kW of RF power fully reflected at a frequency of 350 MHz. For this series of measurements 2 kW of RF power was sufficient to achieve phase and amplitude lock.

Figure 6. shows the first phase error data collected for the field-locked two-spoke cavity using a peak incident power of ~1 kW. The coupler has been adjusted for an external $Q_{EXT}=1.3\text{x}10^7$ and the cavity field has been locked for a value of E_{ACC}=6.5 MV/m. The stored energy at this field is 6.2 Joules. The phase error distribution is well described by a Gaussian with a standard deviation $\sigma_{RMS}=0.58^{\circ}$ indicated in Figure 6. It is anticipated that optimization of the electronics alone will reduce the phase error substantially. Additional tests are planned at higher power and field levels and with different values of Q_{EXT}.

Fast Tuning

A pair of fast tuners based on two types of mechanical transducer is under development for the RIA cavities and will be tested first on the two-spoke cavity. The proposed placement on the two-spoke housing is indicated in Figure 7. Options for transducers are a piezoelectric stack or a magnetostrictive device. This device may be used either separately or in conjunction with the overcoupling technique.

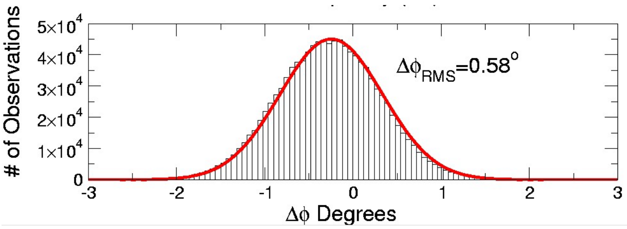

Figure 6: Phase error distribution for the two-spoke cavity at E_{ACC}=6.5 MV/m locked in both phase and amplitude to an external master oscillator.

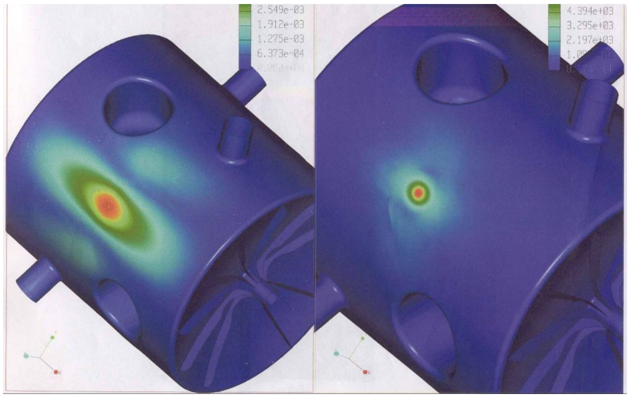

Figure 7: Deflection of the outer niobium housing due to a point load calculated using ProEngineer. The resulting tuning sensitivity is 14 Hz/micron of deflection.

OUTLOOK AND CONCLUSION

Based on results presented here for the two-spoke cavity, specifically, the high frequency of the cavity mechanical modes (>400 Hz) and the relatively low frequency of the observed microphonics from helium boiling (<20 Hz), the use of a mechanical transducer to damp low frequency microphonics looks promising. A pair of transducers, one based on a piezoelectric stack and the other on a magnetostrictive device is currently under development and will be tested on the ANL two-spoke cavity.

ACKNOWLEDGEMENTS

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