MICROPHONICS MEASUREMENTS IN SRF CAVITIES FOR RIA

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Abstract

Phase stabilization of the RIA drift tube cavities in the presence of microphonics will be a key issue for RIA. Due to the relatively low beam currents (≤ 0.5 pmA) required for the RIA driver, microphonics will impact the rf power required to control the cavity fields. Microphonics measurements on the ANL β=0.4 single spoke cavity and 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. Tests on a cold two-cell spoke are the first ever on a multi-cell spoke geometry. The design is essentially a production model with an integral stainless steel housing to hold the liquid helium bath.

INTRODUCTION

The 400 superconducting (SC) cavities needed for the RIA driver linac[1] and spanning the velocity range 0.02< β<0.84 will require a method for compensating for the rf eigenfrequency shifts induced by microphonics. A solution for cavities with frequencies up to 97 Mhz has operated for years in the form of the VCX (Voltage Controlled Reactance). Another established technique overcouples to the cavity using the rf drive probe and uses negative phase feedback to control the cavity fields[2]. Recent results from DESY using a fast piezoelectric tuner[3] suggest that the effects of microphonics may be compensated for without detuning the cavity, possibly resulting in much reduced rf power requirements.

These tests represent the first microphonics measurements on a realistic production model RIA drift-tube cavity. Two-spoke tests were performed horizontally with separate cavity and insulating vacuum spaces, a fully integrated stainless steel jacket for the helium bath and a variable rf power coupler. An understanding of microphonics will be crucial for the proper choice of slow and fast tuner design.

RF INSTRUMENTATION

Microphonics in the single-cell β=0.4 spoke cavity and the two-cell spoke cavity have been measured using two techniques based on largely independent sets of electronics. One method uses a standard phase-locked loop (PLL) circuit where the phase of an external signal generator is locked in quadrature to the cavity rf phase by means of a feedback or "error" signal. In the second method the cavity is run in a self excited loop and the cavity rf frequency is compared directly to that of a low noise external generator using a device developed together with JLAB and referred to as a cavity resonance monitor[4] (CRM).

It is critical that such measurements be performed with a low phase noise signal generator since noise in the generator is difficult to distinguish from microphonics. Measurements here were performed with an Agilent 8665B in low noise mode and having less than 1 Hz rms frequency jitter for modulation frequencies in the range of interest. All results here are for the cavities in cw operation, though the CRM may be used during pulsed operation since it is designed to be insensitive to the input signal amplitudes.

MEASUREMENTS

Probability densities for rf eigenfrequency shifts are shown in Figure 1. for the two-cell spoke cavity at T=4.2 K and E_{ACC}=1 MV/m. Each data set contains 100 seconds of data. Measurements were first performed based on the phase-locked loop (PLL) error signal and then for comparison performed 5 minutes later using the cavity resonance monitor (CRM). Consistently good agreement between the PLL and CRM measurements is seen. The rms frequency jitter shown here at low field levels is 2.8 Hz.
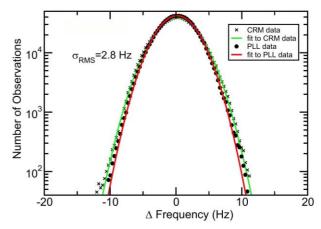

Figure 1. Two methods for measuring rf eigenfrequency shifts (see text) in the two-cell spoke cavity due to microphonics.

The present baseline design for the RIA driver linac calls for operation of the drift-tube cavities at a peak surface electric field 21 MV/m. This corresponds to 6 MV/m accelerating field in the two-cell spoke cavity. Measurements of microphonics levels in the two-cell

spoke cavity have been performed at fields equal to and above this design value.

Figure 2. compares a low field measurement together with a measurement performed at an accelerating field of E_{ACC}=7 MV/m. The input rf power for the two cases is 300 mWatts and 15 Watts respectively. The increase in eigenfrequency excursions by roughly a factor of two for the high-field case is due mostly to low frequency vibrations below about 15 Hertz and may be related to heat dissipation in the helium bath.
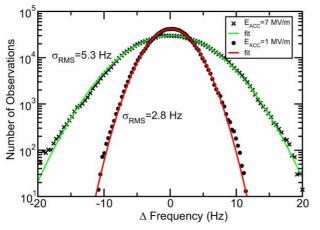

Figure 2. Probability density for double spoke eigenfrequency deviations for cw operation at E_{ACC}=7 MV/m (broad curve) and E_{ACC}=1 MV/m (narrow curve).

The Fourier spectrum of the error signal for the data where E_{ACC}=7 MV/m is shown in Figure 3. The x-axis gives the cavity vibration frequency while the y-axis gives the peak frequency shift in the cavity resonant frequency due to cavity vibrations.
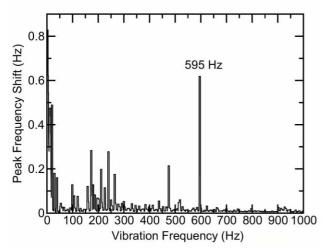

Figure 3 . Frequency spectrum for vibrations in the two-cell spoke cavity running cw at E_{ACC}=7 MV/m.

The peak in Figure 3. at a vibrational frequency of 595 Hz represents the largest contribution to eigenfrequency shifts due to excitation of a natural mechanical mode of the cavity, however, it contributes less than 0.5 Hz rms to the 5 Hz rms total shake. This compares favorably elliptical-cell structures even when structurally reinforced

which typically still have mechanical modes lying well below those observed here. Further analysis of the natural cavity modes using accelerometer measurements and additional finite element analysis calculations is being performed.

Based on measurements like those shown in Figure 3. most of the remainder of the 5 Hz rms cavity shake at E_{ACC}=7 MV/m is due to relatively low frequency oscillations likely from the coupling of pressure changes in the helium bath to the cavity rf eigenfrequency. The dominance of low frequency (helium) vibrations is clearly demonstrated in Figure 4. which shows the integrated total vibration below a given vibrational frequency[*]. The curve has been normalized to unity for high vibrational frequencies. Clearly 95% of the total amplitude for eigenfrequency excursions is due to vibrations at frequencies below 15 Hz. The two-cell spoke cavity sensitivity to pressure changes in the helium bath has been measured to be +65 Hz/Torr so that the corresponding pressure changes in the helium bath giving rise to the 5 Hz rms shake are likely of the order of 10-100 mTorr. Additional measurements to measure the bath pressure fluctuations directly will be performed.
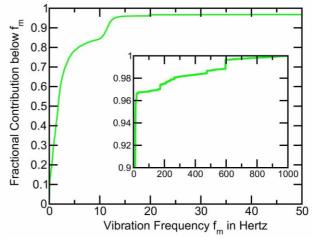

Figure 4 Fractional contribution to the total cavity shake from vibrations at and below the frequency f_m. The inset shows the same curve extended to vibrational frequencies up to 1 kHz. The result is based on the same data as used for Figure 3.

Measurements of the static field Lorentz detuning of the single-cell and two-cell spoke cavities have also been measured as a function of accelerating field gradient as shown Figure 5. Measurements for the spoke cavities were performed with all ports unconstrained and give detuning coefficients of –2 and -3.5 Hz/(MV/m)^2 for the double and single-cell cavities respectively. This indicates that the spoke geometry is roughly an order of magnitude more rigid with respect to Lorentz detuning than a typical unconstrained elliptical cell structure constructed from similar thin wall niobium.

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[*] Note that Figure 3. is an amplitude spectrum and must be converted to a power spectrum before integration.

The lower detuning coefficient for the two-cell cavity compared to the single spoke is probably due to the added stiffness of the stainless steel jacket in the former. A given amount of deformation in the end wall of the two-cell cavity will also tend to shift the frequency less than in the single spoke cavity because of the relatively higher stored energy. The single spoke is a bare niobium cavity. Indeed, the frequency shifts induced in the two cavities from pressure changes in the helium reservoir ($\Delta f/\Delta p$) also differ by a factor of two although the shifts are in opposite directions. The values are +55 kHz/atm. and –120 kHz/atm. for the double and single spoke cavities respectively. The difference arises primarily from the different reinforcements on the cavity end walls.
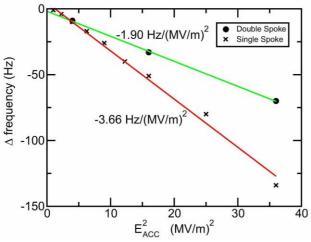

Figure 5 Static field Lorentz force detuning for the single spoke cavity (crosses) and the two-cell spoke cavity (circles) as a function of the square of the accelerating gradient. All ports are unconstrained.

DISCUSSION

The two-cell spoke resonator forms a section of the baseline RIA driver linac where beam loading requirements will already require fairly large rf amplifers. For example, assuming the two-cell spoke is operating at E_{ACC}=7 MV/m and with an effective accelerating length of 39 cm then each cavity provides nearly 3 MV of accelerating potential. The RIA driver baseline proposal calls for 0.5 mA of protons implying beam loading of roughly 1.4 kW per cavity.

Beam loading power may be compared to the additional amount of rf power required to control the cavity fields by overcoupling and assuming the same microphonics levels observed here. An estimate of that

power is given by the expression $P = \delta\omega \cdot U$, where $\delta\omega$ is the required tuning window and U is the stored energy of the cavity at the operating field. Assuming σ_{RMS}= 5 Hz and allowing a window of $\delta\omega$ = 6 x σ_{RMS} then the power required required for phase stabilization is roughly 1.4 kW based on the measured cavity stored energy of U_o=0.146 J at E_{ACC}=1 MV/m. In this case rf power requirement needed to compensate for microphonics would roughly double that needed due to beam loading alone.

It is likely that a further reduction in the cavity frequency response to pressure will be achieved through fairly minor design revisions. Even for the present case it will be possible to phase stabilize the cavity fields with presently available rf power of several kilowatts. Such tests will be performed shortly.

CONCLUSION

Microphonics tests on the first multi-cell spoke geometry have been performed in a realistic accelerator conditions on a two-cell spoke cavity with full helium jacket and movable coupler all in a horizontal test cryostat. Results show that the spoke geometry is rigid with respect to microphonics showing only 5 Hz rms shake at an accelerating field of E_{ACC}=7 MV/m. Vibrations of the natural mechanical modes contribute very little to the shake which is due mostly to low frequency pressure changes in the helium bath.

ACKNOWLEDGEMENTS

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