BENCH MEASUREMENTS OF A MULTI-FREQUENCY PROTOTYPE CAVITY FOR THE FAST KICKER IN THE JLEIC CIRCULATOR COOLER RING*

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Abstract

A multi-frequency copper prototype cavity with 5 odd harmonic modes (from 95.26 MHz to 857.34 MHz) has been fabricated and bench measured at JLab. This quarter wavelength resonator (QWR) based deflecting cavity is a half scale prototype of the five-mode cavity (from 47.63 MHz to 426.67 MHz) in the QWRs group developed for the ultrafast harmonic RF kicker in the proposed Jefferson Lab Electron Ion Collider (JLEIC, formerly MEIC). With this prototype cavity, several RF measurements were performed and the results showed good agreement with the simulation results.

INTRODUCTION

A group of quarter wavelength resonator (QWR) based deflecting cavities have been developed to generate 10 harmonic modes for an ultrafast harmonic RF kicker in the proposed Jefferson Lab Electron Ion Collider (JLEIC, formerly MEIC) [1-3]. To validate the electromagnetic characteristics of the cavity from numerical simulation, a half scale copper prototype cavity with 5 odd multiple harmonics of 95.26 MHz has been fabricated and measured. Fig.1 shows the copper prototype cavity with its cross section cut CAD view.

SOME FABRICATION DETAIL

The outer conductor was fabricated from a commercial copper water pipe line. The inner conductor, five tuner pipes, five tuning stubs, one input coupler pipe, two beam pipes and all flanges are all made from oxygen free copper. All the welding processes were performed with the electron beam welding (EBW) including joints of those pipes to the outer conductor, the inner conductor to the end plate where the RF current is the strongest. The electric end flange with the pickup port is welded together and its flange is bolted to the cavity body which makes it possible for further near-beam structure optimization and a replacement with other end structures to reduce the multipole fields and longitudinal impedance. Fig.2 shows the cavity components before the final welding of the end plate to the outer conductor.

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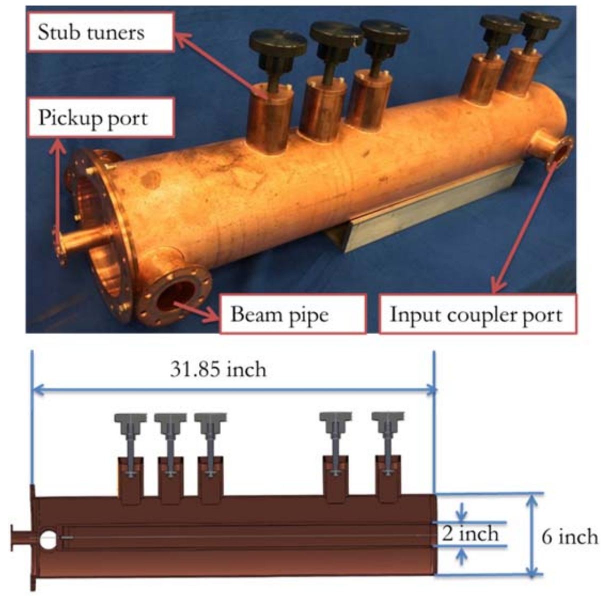

Figure 1: The copper prototype cavity with five odd multiple harmonic modes of 95.26 MHz (top) and the cross section view of this prototype (bottom).

Figure 2: Cavity components before the final welding of the end plate to the outer conductor.

In the first round of measurements (without RF fingers installed in the tuner ports), the harmonic frequencies with stub tuning process, unloaded Q factors and bead–pulling measurements were performed. Then the mode combination experiments were carried out. All of them have shown good agreement with the simulation results. Then the cavity was sent to the machine shop to repair the tuning stubs and finally all RF fingers were installed for a better RF contact and Q factor.

BENCH MEASUREMENTS

After the cavity was finally assembled, the resonant frequencies of each mode were checked with a network analyser by measuring the transmission parameter S21 and reflection parameter S11, as shown in Fig.3.

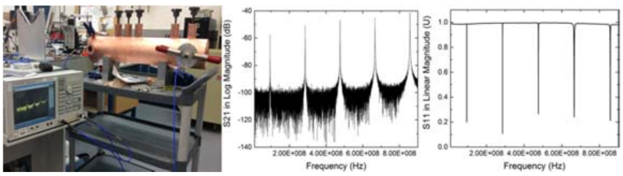

Figure 3: Cavity bench measurement set up (left), the transmission coefficient between the input coupler and the pickup (middle), and the reflection coefficient at the input coupler (right) as a function of frequency.

The input loop coupler and pickup antenna used in the measurement are shown in Fig.4. The coupling strength of all modes can be adjust to be near critical at the same time by carefully adjust the size, position, and rotation angle of the loop.

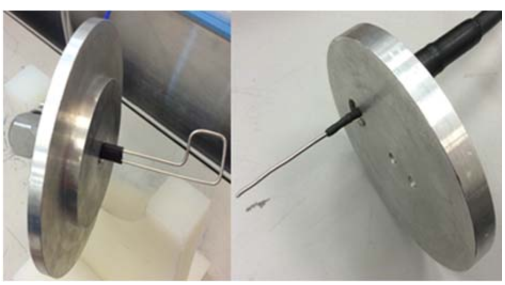

Figure 4: The input loop coupler and pickup antenna used in the measurement.

The fabrication errors on the natural frequencies for all modes were less than 0.2%, and could be tuned to the target values with only four iterations of the stub tuner settingss, as shown in Fig.5.

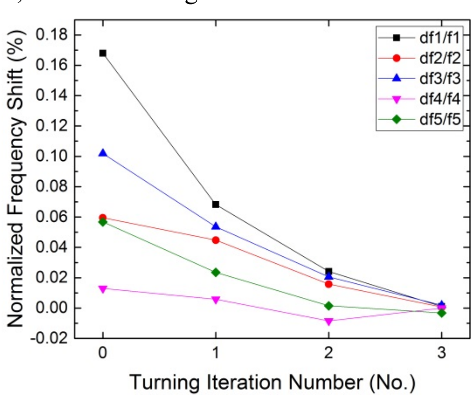

Figure 5: Tuning process to achieve the target frequencies by solving the tuning matrix equation and adjusting the stub tuners three times in the first tuning measurement.

The manual stub tuner used here is similar to a CEBAF waveguide stub tuner. The tuning resolution is 0.05 inch/turn, set by the chosen threaded rod (1/2-20). Bearings are used to minimize friction between the stubs and tuner ports. Fig.6 shows the details of the stub tuner and Fig.7 shows the iteration scheme how to get the target frequencies by adjusting the stub tuners in a convergent process.

Figure 6: Stub tuner part detail.

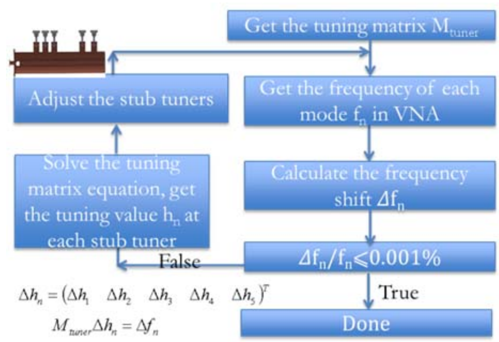

Figure 7: iteration scheme to get the target frequencies by adjusting the stub tuners several times.

After the tuning process, the unloaded quality factors of the five harmonic modes were measured and compared with the CST simulation in Table 1. The unloaded Q factors are lower than the design value for all modes and especially the highest modes. The Q-drop may be caused by the imperfection of the outer conductor copper material, poor RF contact at the tuner pipes due to the absence of RF fingers, coupler losses, or leakage out of the beam ports. The measurement results should be better when the RF finger is installed.

Table 1: Comparison of the Unloaded Quality Factors From the Simulations and Measurements

Mode(MHz)	CST	Measurement	Error (%)
95.26	5665	5301	-6.43
285.78	9770	9277	-5.04
476.3	12531	11282	-9.96
666.82	14834	13152	-11.34
857.34	17109	14095	-17.62

The electromagnetic field distribution and mode orientation in the cavity were obtained by a bead-pull technique, as set up in Fig.8.

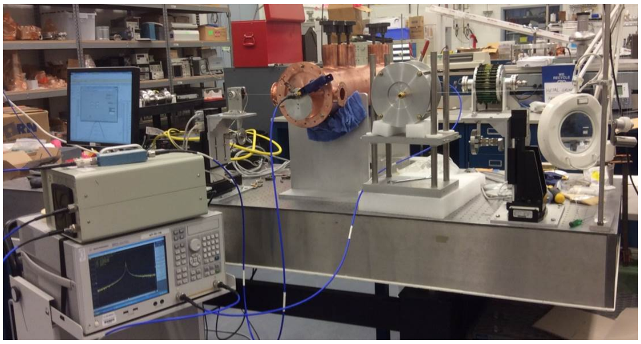

Figure 8: Complete bead pull measurement setup.

By pulling a dielectric (Teflon) bead through the beam axis, the electric field along the string can be measured, and with a metallic (brass) bead, both the electric and magnetic fields will be detected. The measurement results with both beads are shown in Fig. 9 and compared with the simulation results. The dominant field component in the cavity is the transverse electric field. The longitudinal electronic field and the transverse magnetic field in the beam path are too weak to be separated out from the bead-pulling signals. The form factors of both beads were carefully calibrated with a TM010 pillbox in order to get the best agreement.

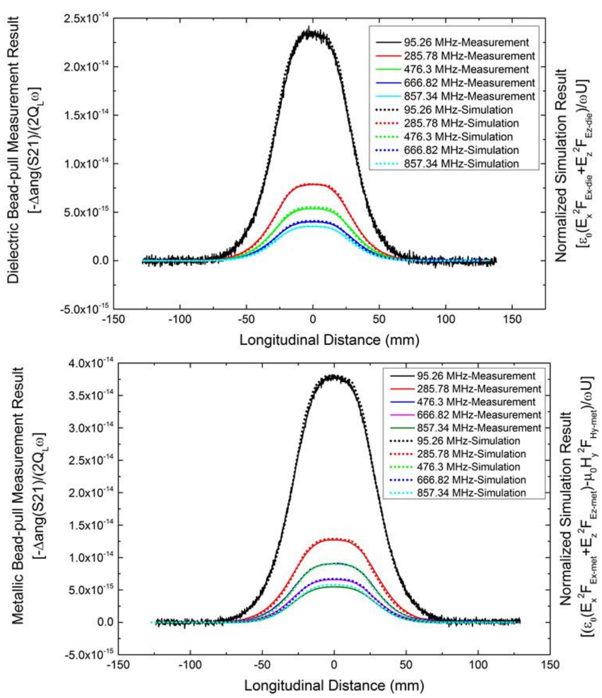

Figure 9: Result of the measurement with the dielectric (top) and the metallic (bottom) bead, and the comparison with the CST simulation result.

A simple mode combination experiment was also performed on this prototype cavity. With five signal generators, five harmonic modes with independent amplitude and phase controls were generated. Then these harmonics were combined in an RF combiner and fed into the cavity through the input loop coupler. A pickup probe in the pickup port was used to sample the combined signal, and the synthesized waveform was recorded by an oscilloscope. Fig.10 shows the complete setup of this experiment, and Fig.11 shows the comparison of the 5-odd harmonics combined pulses captured from the oscilloscope display with the ideal simulation result. The agreement is excellent.

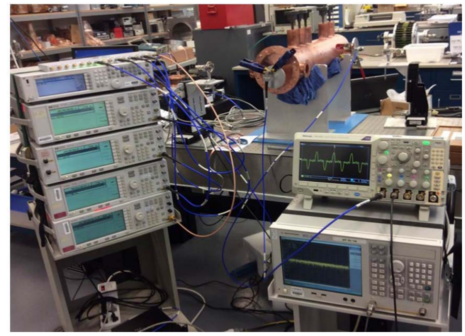

Figure 10: Complete setup of the mode combining experiment.

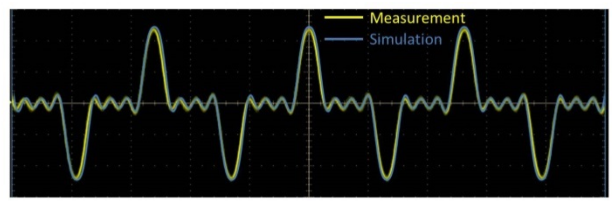

Figure 11: Comparison of the 5-odd harmonics combined pulse captured from the oscilloscope display with the simulation.

CONCLUSIONS

First RF bench measurements on the half scale prototype harmonic kicker cavity show a good agreement with the design simulation results. Real vacuum compatible cavities are to be designed and fabricated in the near future to measure the actual kicking effect on the electron beam bunch train.

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REFERENCES

[1] S.Abeyratne *et al.,* “Science Requirements and Conceptual Design for a Polarized Medium Energy Electron-ion Collider at Jefferson Lab”, arXiv:1209.0757 [physics.acc-ph], 2012.

[2] S.Abeyratne *et al.,* “MEIC Design Summary”, arXiv:1504.07961 [physics.acc-ph] 2015.

[3] Y.Huang, H.Wang, R.A.Rimmer, *et al*., "Ultra-fast harmonic RF kicker design and beam dynamics analysis for the ERL-based electron circulator cooler ring of JLEIC". *Phys. Rev. ST Accel. Beams 19*, 084201, 2016.