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MEASURING THE ELECTRICAL CENTER AND FIELD FLATNESS OF 704 MHz DEFLECTING CAVITY FOR LEReC WITH WIRE STRETCHING SYSTEM

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Abstract

704 MHz deflecting cavity was designed for the Low Energy RHIC electron Cooling (LEReC) project. The cavity will serve as a major component in diagnostic line. In LEReC project the requirement on the energy spread of the electron beam is extremely high (better than 1e-4) and the diagnostic system has to to be designed accordingly. The 704 MHz transverse deflecting cavity provides the vertical kick to the beam after it passes through the dispersion dipole so that we can measure the time correlated energy spread of the the bunch. Traditional way of determining the electrical center of the cavity involves the needle pulling and integration of the signal which is prone to the cumulative error. We used the wire stretching method here for the electrical center measuring since it is much more efficient and accurate compare to the bead/needle pulling method. There was also a high requirement on the kick strength flatness (1%/cm) of the cavity. We demonstrated the field mapping method with the wire stretching system and measured the field flatness of the cavity to meet the specification. Both simulation and experimental results are shown in this paper and the further plan is discussed at the end.

INTRODUCTION

In LEReC project the energy spread is one of the most demanding parameter on the beam quality. For the cooling experiment only the energy spread of the core portion of the bunch matters. However, due the relatively low energy of the electrons, the total energy spread caused by the space charge effect can be disguising if we only look at the image generated by a single dipole. Therefore we need to introduce a deflecting cavity after the dipole magnet in the diagnostic line in order to get the time domain information and measure the slice longitudinal emittance. In this paper we first present the cavity design parameters. After that we will give the simulation and experimental results of the wire stretching method for the cavity electrical center measurement. Finally we will discuss the application of wire stretching method on the field flatness mapping of this cavity.

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CAVITY DESIGN

The shape of 704 MHz deflecting cavity for LEReC diagnostic line morph from the Cornell ERF 1.3 GHz deflecting cavity [1]. The cut view of the cavity is shown in Figure 1.

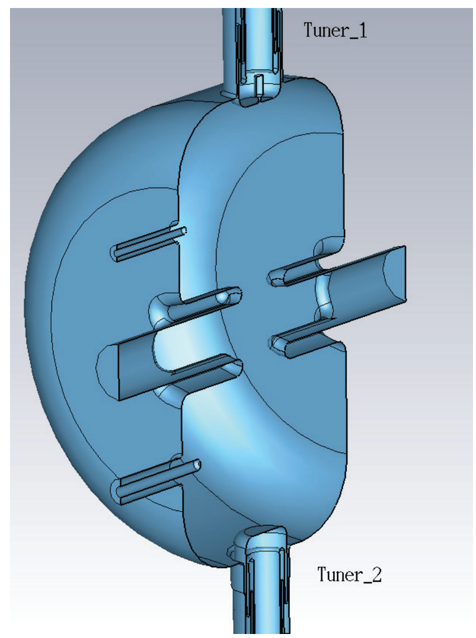

Figure 1: Cut view of the 704 MHz deflecting cavity. Adopted from the Cornell ERL 1.3 GHz four plates cavity. With BNL designed folded coaxial tuners.

The design parameter of the cavity is shown in Table 1.

Table 1: Design Parameters of Cavity

Parameter	Value	Unit
Frequency	704	MHz
$\frac{R_t}{Q}$	1500	Ω
Q_0	13000	NA
R_{sh} (Acce. Def.)	19.5	MΩ

This design has a relatively large $\frac{R_T}{Q}$ that potentially can save decent amount of power if we'd like to operate the cavity for higher energy particles in the future or for other project. And since this cavity is after the last dispersive

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components in the diagnostic line, the relatively high HOM impedance is not a problem for the energy spread measurement.

FINDING THE ELECTRICAL CENTER OF THE CAVITY

The cavity was fabricated by RI and shipped to BNL towards the end of 2017. After checking the quality factor, frequency and tuning range, one very important measurement was to determine the electrical center of the cavity. The traditional way of doing this was to pull a bead or a needle (large aspect ratio object) through the cavity with various starting and ending point at two ends of the cavity. Then by integrating the field strength along each path, one can iteratively approach one path that gives the minimum integrated longitudinal field. This path is the path that goes through the electrical center of the cavity. This method, as one can imagine, is quite time consuming since we might need to go through tens of, if not hundreds of paths before the results converge. On the other hand, this method is also prone to cumulated error since we can taking hundreds of points along each path and the value interested is the integrated number from all these measurement. Therefore we decided to use the wire stretching method proposed by Haipeng Wang from Jefferson Lab [2]. The basic setup of the method is shown in Figure 2. When a metallic wire goes through the electrical center of the deflecting cavity, due the the symmetry of the EM field of the deflecting mode, the coupling between the propagating mode of the wire and the cavity mode is zero. Therefore, if we sent an RF signal from one end of the wire down to the cavity and measure the S21 from pickup port there should be no signal except the crosstalk between the wire and antenna if the wire goes trough the electrical center of the cavity.

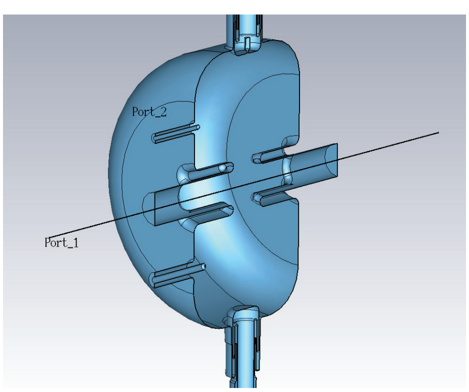

Figure 2: Conceptual view of the wire stretching measurement. RF signal was sent trough port1 and measured from port2.

Figure 3 shows the simulated results of S21 between the wire and pickup port given by CST. We can clearly see the curve evolves with the rotation angle of the wire. In this simulation we put a wire trough the electrical center of the model and intentionally rotated the wire in vertical plane around the center of the cavity. By doing this we were able to change the coupling between the cavity and the wire. As expected, the NULL signal was obtained when the wire goes through the electrical center of the cavity.

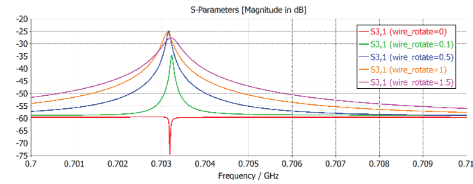

Figure 3: Simulation results of S21 between the wire and pickup port for different rotation angle of the wire with respect to the center of the cavity.

Figure 4 shows the wire stretch system we built in BNL. The system consists of two XY stages each mounted on its own frame. The stage can drive the end of the wire in two direction with resolution better than 20 μm in the range of $\pm$15 cm.

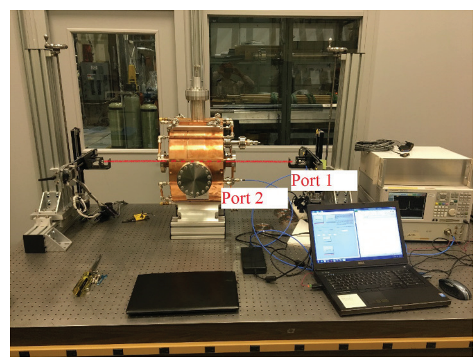

Figure 4: Wire stretching system at BNL. The XY stages that drive two ends of the wire can provide better than 20 μm linear resolution.

With the help of an automated Labview App, we were able to locate the electrical center of the cavity by the gradient decedent algorithm within a couple of hours. The selected measured result of the S21 curves are shown in Figure 5.

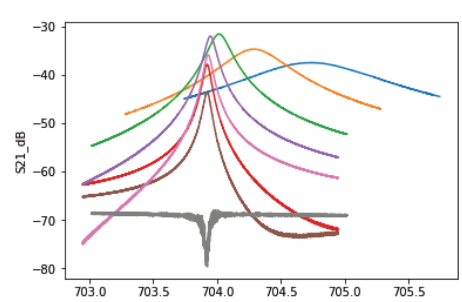

Figure 5: The measured S21 signal from the wire to the pickup port. The gray curve shows the signal of the final stage and other curves shows intermediate stages.

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The wire stretching method allowed us to successfully locate the electrical center of the cavity in a much faster and more accurate fashion compare to the traditional bead/needle pulling method. We expect more application of the system on future transverse cavities.

MAPPING THE FIELD OF THE CAVITY

Another important parameter of this deflecting cavity is the flatness of the vertical kick along horizontal plane. The requirement given by beam dynamic simulation is that in order to measure the real core energy spread we need the kick strength uniformity to be better than 1%/cm along horizontal plane. Again, we could use the traditional bead pulling technique to map the transverse kick strength but the efficiency and accuracy is not ideal. Therefore, we decided to use the wire stretching method again to map the kick strength.

The idea is straight forward: From the Panofsky-Wenzel theorem, the transverse kick strength is proportional to the transverse gradient of the longitudinal kick. If we use the long wire to perturb the field in the cavity, it will only perturb the longitudinal field due to the large aspect ratio of the wire [3]. Therefore, we only need to measure the frequency shift at different wire location and calculate the gradient of $\sqrt{\Delta f}$ to get the relative strength of the transverse kick. The simulation results from CST S-Solver showed frequency shift of the cavity as expected, see Figure 6. We noticed some deviation from the quadratic curve due to the noise caused by mesh resolution but for the prove of principle this give enough confidence to continue. On the other hand, we calculated the kick strength directly from the CST Eigen solver by setting different integration path in post-processing and got the uniformity of the deflecting strength to be better than 1%/cm in center region. Then we used the same system measured the frequency shift of the cavity due to the perturbation of the wire. The result is shown in Figure 7. As we can see, the kick strength measured by the wire stretching system is better tan 1% within ± 5 mm range along horizontal plane.

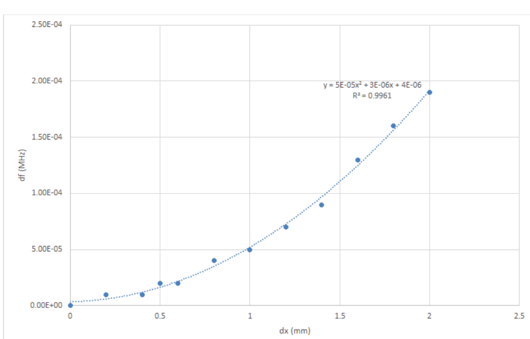

Figure 6: Frequency shift of the cavity frequency due to the perturbation of wire at different locations.

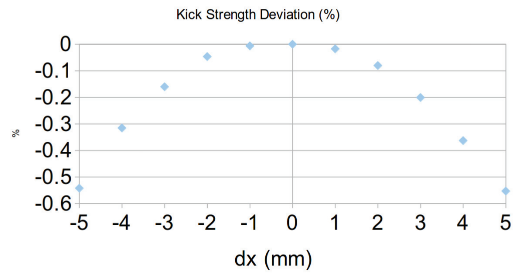

Figure 7: Measured kick strength uniformity along horizontal plane.

CONCLUSION

In this paper we presented the simulation and measured result with the wire stretching system on the 704 MHz deflecting cavity for the LEReC diagnostic line. One of the application of the wire stretching system was to find the electrical center of the cavity. Compare to the traditional bead pulling method, this method is much more time efficient and accurate. Another application system is to map the transverse kick strength of the cavity. The first measurement on the deflecting cavity showed a better than 1% kick strength uniformity which was consistent with the simulation results. Further work is on going with the system which includes improving the resolution of the mechanical system, reducing the noise from environmental vibration, shielding the wire to provide better boundary condition and improving the impedance mismatch.

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