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DEVELOPMENT OF 650 MHz β=0.9 5-CELL ELLIPTICAL CAVITIES FOR PIP-II*

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Abstract

5-cell 650 MHz elliptical cavities are being developed for the Proton Improvement Plan II (PIP-II) of Fermilab. The cavities are designed to accelerate protons of relative group velocity β=0.9 at the high energy part of the linear particle accelerator. In this paper, we report on the status of these cavities and summarize the results of the quality control measurements performed on four initial prototypes.

INTRODUCTION

Fermilab is proceeding with the Proton Improvement Plan PIP-II, which will revamp Fermilab's accelerator complex to meet future needs of Megawatt high intensity proton beam. PIP-II relies on replacing the current 40 years old 400 MeV normal conducting injector linear accelerator with an 800 MeV superconducting one with higher average beam current [1-2].

Two types of elliptical superconducting cavities are employed in the proposed superconductor Linac to accelerate the beam at relatively higher energies; specifically at a relative group velocity of 0.6 and 0.9 [2]. Both types of cavities consist of 5-cell and are operating at 650 MHz. Four prototypes of the 650 MHz β=0.9 5-cell cavity were fabricated by Advanced Energy Systems (AES) and were received at Fermilab. Prototype cavities passed the typical quality control process at Fermilab from visual inspection, and Coordinate Measurements (CMM). Meanwhile, RF measurements have been also performed on the prototype cavities.

In this paper, we report on the latest RF measurements results carried out to assess the spectrum, field flatness, and existence of trapped modes in the prototype cavities. In addition we present some of the latest simulations and analyses carried out to improve the performance of the 650 MHz β=0.9 5-cell cavity.

MICROPHONICS AND LFD DETUNING

We have studied both the frequency sensitivity to pressure fluctuation df/dP, and Lorentz Force Detuning LFD in the 650 MHz β=0.9 5-cell cavity dressed with helium vessel (HV) using Comsol Multipysics [3]. Upon coupling the electromagnetic problem to the solid mechanics one, we were able to calculate the frequency sensitivity coefficients. The resonance frequency of the π-mode is calculated before and after applying the pressure load. Deformation is calculated using the solid mechanics module then the mesh is deformed with the resultant displacement values to acquire the frequency change.

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The mechanical design of the cavity's helium vessel underwent several iterations [4]-[6] in order to minimize the df/dP coefficient. The first generation of the HV design adopted a blade tuner with a 441 mm diameter bellows [4]. Later on a modified design was presented in [5]-[6] with an end tuner that can afford smaller diameter bellows.

Figure 1 depicts that cavity geometry with the blade and end tuner locations indicated. Also the stiffening ring size is an important factor that changes the stiffness of the cavity and thus affects the frequency sensitivity coefficients. Fig. 2(a) demonstrates how the df/dP coefficient and the stiffness changes versus the radius of the stiffening rings. It is clear that by increasing the stiffening ring radius, the cavities becomes stiffer reducing the frequency sensitivity coefficient df/dP.

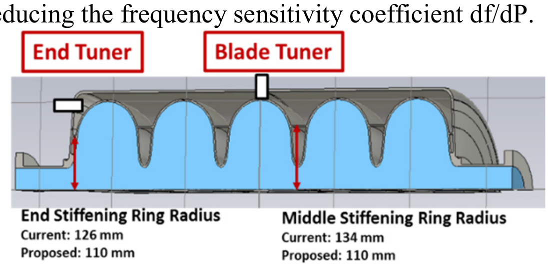

Figure 1: Geometry of the 650 MHz β=0.9 5-cell cavity.

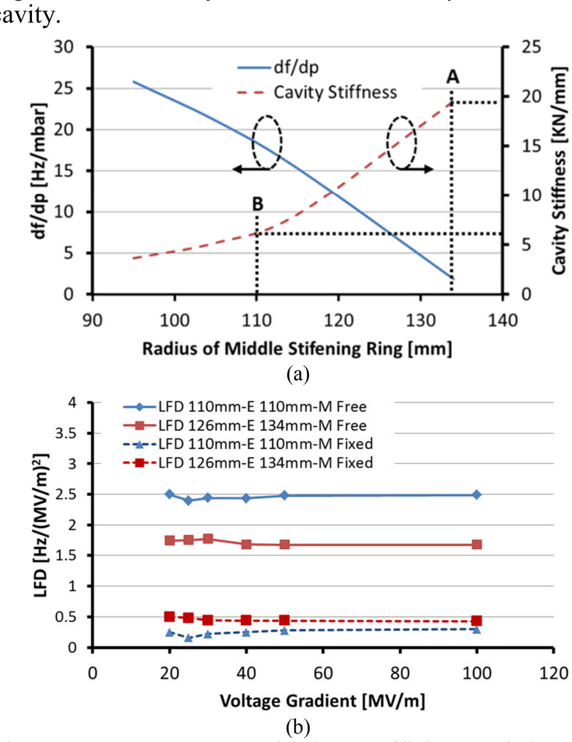

Figure 2: Frequency sensitivity coefficients of the 650 MHz β=0.9 5-cell cavity. (a) df/dP and cavity stiffness versus stiffening ring radius. (b) Lorentz Force Detuning (LFD).

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The initial goal was to minimize df/dP as much as possible. Therefore we decided to build the prototype cavity with a middle stiffening ring radius of 134 mm (marked by A in Fig. 2(a)) that resulted in df/dP < 5 Hz/mbar. But in this case the cavity is quite stiff ~18 kN/mm, which will make the RF tuning for field flatness and frequency adjustments quite challenging. Thus, we decided to relatively sacrifice df/dP for the sake of making the cavity less stiff in order to also avoid complicating the tuner design. At a ring radius of 110 mm (marked by B), the df/dP would be 18 Hz/mbar with a cavity stiffness of 7 kN/mm.

Figure 2(b) demonstrates the LFD coefficient for both cases (A) and (B) of stiffening ring sizes in case of free and fixed boundary conditions. The coefficient won't exceed 0.5 Hz/(MV/m)^2 for the fixed boundary condition.

On the other hand, Fig. 3 shows df/dP versus the bellow radius to demonstrate the benefits of having smaller bellow radius using the end tuner, which significantly helps to reduce df/dP. Therefore end tuner is favoured over blade tuner for this cavity.

RF MEASURMENTS

Four prototype cavities, namely; B9A-AES-007, B9A-AES-008, B9A-AES-009, and B9A-AES-008 were received from AES. Picture of the prototype cavities is shown in Fig. 4.

Figure 5(a) shows the measured main pass-band spectrum of the four prototype cavities. Cavities are designed to have a room temperature resonance frequency of 649.093 MHz for the π-mode. After cool-down to 2K, the π-mode resonance frequency would shift by about 900 kHz ending up very close to 650 MHz. The resonance frequencies of the π-mode for the four cavities at room temperature are in the range of 649.078 MHz to 649.141 MHz, which are in good agreement with the designed value and are in the acceptable tuning range.

Figure 5(b) shows the field flatness of the π-mode for the four prototype cavities. Field flatness of the cavities ranges from 53% to 75%. Prototype cavities are planned to be tuned after chemistry and 800ºC baking by mechanically squeezing/stretching the cells. A mechanical fixture was developed for this purpose.

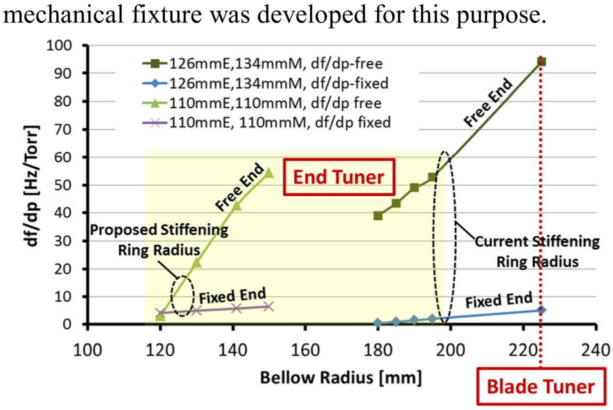
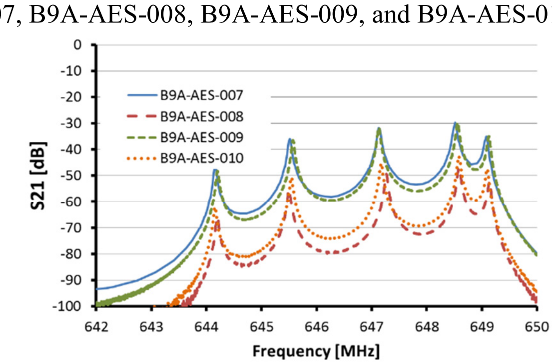


Figure 3: Frequency sensitivity to pressure versus bellow radius depicting the blade tuner versus end tuner cases.

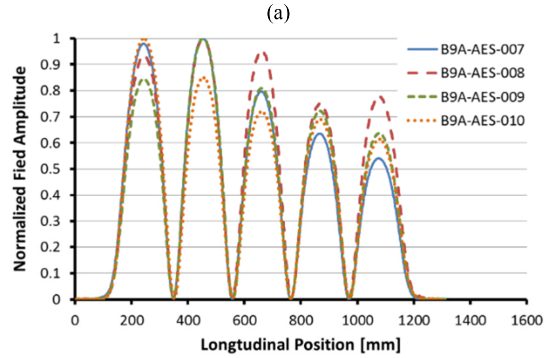
Stiffness of the cavity is an important parameter in this case as the more stiff the cavity the more difficult will be the tuning. Table 1 summarizes the important measured RF parameters of the four prototype cavities from pi-mode resonance frequency to quality factor, and field flatness.

On the other hand, it was interesting to check the 5th monopole pass-band modes as it was indicated in [7] that these resonances might get trapped and could cause beam instabilities as well as early thermal quenching of superconducting cavity. Tables 2 lists the simulated resonance frequencies of the 5th monopole pass-band modes. All five modes are in the narrow range of 1983.061 MHz to 1983.127 MHz, spanning just a 66 kHz. It was difficult to excite and measure all of these five modes, however we were able to see some of them. Figure 6 presents the measured normalized phase shift due to bead perturbation of the on axis fields for the 5th pass-band modes in B9A-AES-009 and B9A-AES010.

Figure 4: Picture of the prototype cavities; B9A-AES-007, B9A-AES-008, B9A-AES-009, and B9A-AES-010.



(a)



(b)

Figure 5: Measured (a) frequency spectrum and (b) field flatness of the prototype cavities.

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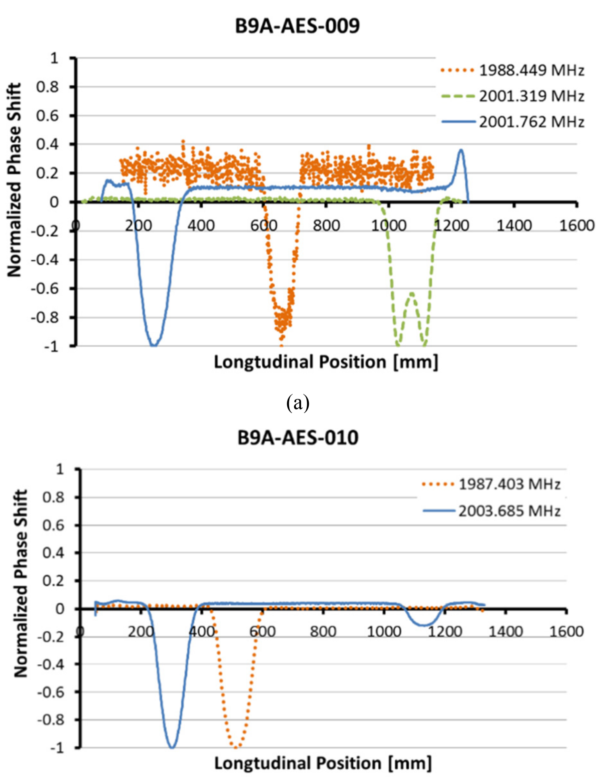
Table 1: Summary of the Frequency, Q and Field Flatness of the Prototype Cavities

Cavity#	F [MHz]	Q	FF [%]
B9A-AES-007	649.078	10184	53.2
B9A-AES-008	649.141	12768	75.0
B9A-AES-009	649.127	12700	62.5
B9A-AES-010	649.096	12691	61.5

A 5.5 mm metallic bead was used in the measurements and the phase shift due to the bead perturbation was measured. The negative phase shift is because of the electric field on-axis component of the TM monopole modes. It was used to discriminate the monopole modes (the one of interest here) from TE dipole modes, which will have positive phase shift due to their magnetic on-axis components. Phase shift was normalized to absolute maximum of 1, as shown in Fig. 6. In some cases there were some mixed magnetic disturbance observed but still the major contribution indicates that this is a monopole mode. Figure 6(a) shows the measured phase shift for three modes observed at 1988.449 MHz, 2001.319 MHz, and 2001.762 MHz for the B9A-AES-009 cavity. The modes are trapped in the 1st, 3rd, and 5th cell, respectively. Similarly, Fig. 6(b) depicts the modes trapped in the 1st and 2nd cells of B9A-AES-010 at 1987.403 MHz, and 2003.685 MHz, respectively.



(b)

Figure 6: Measured normalized phase shift of the 5th pass-band modes in (a) B9A-AES-009 and (b) B9A-AES-010.

Table 2: Simulated Resonance Frequencies of the 5th Pass-band Modes

Mode #	Frequency [MHz]
1	1983.061
2	1983.075
3	1983.090
4	1983.106
5	1983.127

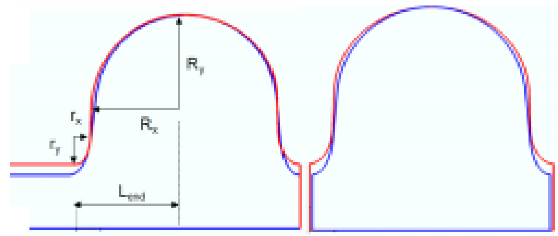


Figure 7: Old β=0.9 (blue) and new β=0.92 (red) cell shapes.

These measurements agrees well with the simulation results presented in [7] that the β=0.9 cavity design contains trapped modes in the 5th monopole passband. Therefore, there was a decision to adopt the β=0.92 design in [7], where the irises between the cells were opened to avoid the trapped modes problem. Figure 7 depicts both the β=0.9 design (in blue) and the new β=0.92 (in red) design.

CONCLUSION

Four prototypes of 650 MHz β=0.9 5-cell cavity are under preparation for testing at Fermilab. RF measurements confirmed our expectations for trapped modes at the 5th monopole passband. Stiffness of the cavity will be loosen in future prototypes to avoid complications in the tuner design. Also, end-tuner with smaller bellow size will be adopted to reduce frequency sensitivity to pressure fluctuations.

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