TEST OF A NEW RF SEPARATOR STRUCTURE FOR CEBAF*

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Abstract

A prototype of the rf separator for CEBAF has been made and successfully beam tested. This structure is a new design which has a high transverse shunt impedance together with a small transverse dimension compared to more conventional structures. Five rf separators will be used at CEBAF to allow beam from any one of the five recirculation passes to be delivered to any of the three experimental halls. This paper presents the basic design of the structure, and theoretical, rf, and beam-test results.

Introduction

The electron beam at CEBAF recirculates five times through two superconducting linacs before reaching its final energy. In this scheme, it is desirable to break away some of the beam from the first, second, third, or fourth pass to have access to the beam at some fraction of the final energy. Four of the rf separators are used for this purpose. One separator is located after each pass to separate one out of every three bunches away from the main path into one of the experimental halls. The fifth rf separator has a somewhat different function. It is dedicated to the fifth and final recirculation pass to split the final-energy beam into three directions to be delivered to the three experimental halls. The CEBAF accelerating cavities operate at 1497 MHz, while all the rf separators operate at 499 MHz. Since the separators' frequency is one-third of the main frequency, they can kick the beam bunches in two or three different directions depending on the phase of the rf, as illustrated in Figure 1. Figure 1a corresponds to the first four separators, and 1b corresponds to the last separator's operating phase.

The rf separator structure is a new design [1] which combines high transverse shunt impedance with smaller transverse dimensions. With this design, 1.5 kW of rf power is enough to produce the required 0.1 mrad deflection in the case of Figure 1b at 4 GeV. To test our new design, a prototype was built and rf and beam tested. The beam test was done using the 45 MeV beam from the CEBAF injector. With a 45 MeV beam, one only needs on the order of 10 W of rf power to produce large enough separation to make the necessary measurements. The test was carried out with successful results. The following sections present the basics of the structure and the results of the tests.

Design Principles

The basic structure is shown in Figure 2. It is a cylindrical cavity with two rods placed along the z axis and connected to one end of the cavity. There are gaps between the rods and the cavity wall on the other end. The cavity is a 1/4 wavelength resonator. For deflecting the electrons, we are interested in the mode in which the rf current runs in opposite directions on the rods and the rods have opposite voltages. This creates an electromagnetic field which is locally very close to a TEM dipole mode (except the gap region). Here, the rods play an important role. They concentrate the field in the central region of the cavity, which leads to higher transverse shunt impedance ($R_\perp = \frac{V_\perp^2}{P}$), 200 to 500 MΩ/m. By concentrating the field in the center, the rods also make the outside cavity diameter less important–which means the cavity diameters can be made smaller, even as small as 15 cm for 500 MHz.

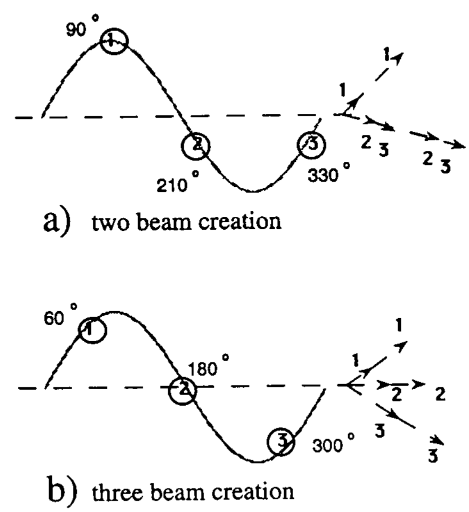

Fig. 1 Separation of the beam bunches through the RF separator field.

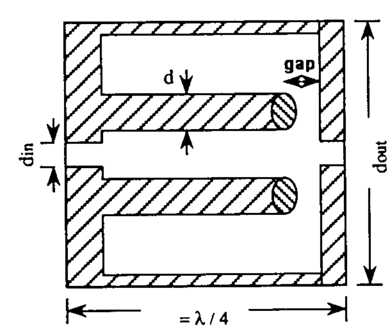

Fig. 2 The basic 1/4 wavelength structure.

The dipole mode described is not the lowest mode of the cavity. The lowest mode is the one in which both rods are at the same potential and the rf current runs in the same direction on both. The main potential is only across the gap, between the rods and the cavity wall. The

*Supported by D.O.E. contract #DE-AC05-84ER40150 magnetic field in this mode circles around both rods very much like the B-field pattern in a coaxial transmission line. There is no dipole field in this mode.

Now, one can couple together two of these basic structures by adding the structure to its mirror image (π mode) forming a 1/2 wavelength structure as shown in Figure 3. (In other words, put two 1/4 wavelength structures facing each other and remove the wall in between.) The 1/2 wavelength structure will have the same performances as the original basic cells. We used a 1/2 wavelength structure for our test. Figure 4 shows the electric and magnetic field patterns for the desired dipole mode. The B-field on the z axis is in the same direction through the length of the cavity while the E-field changes direction. Both electric and magnetic fields contribute to the total deflection (about 40% and 60% respectively). For maximum deflection, a beam bunch should enter the cavity when the E-field is maximum and B-field is minimum.

MAFIA is used to calculate the properties of this cavity. The frequency of the dipole mode increases with gap size and distance between the two rods, but it depends weakly on the outside diameter of the cavity. Table 1 lists the parameters of the test cavity. For the final rf separators, we intend to again couple two of these 1/2 wavelength cavities and make a 60 cm long structure. According to the MAFIA results, $R_\perp/Q$ of our structure is 47 kΩ/m, where $R_\perp = \frac{V_\perp^2}{P}$ and $V_\perp$ is the integrated deflection voltage. Therefore, assuming $Q = 5000$, $R_\perp = 240$ MΩ/m. The required rf power for a separation angle of 0.1 mrad at 4 GeV is:

$$P = \frac{{V_\perp}^2}{R_\perp \ell} = \frac{(4\text{GeV} \times 0.1\text{mrad}/\sin 60^\circ)^2}{(236\text{M}\Omega/\text{m})\ (0.60\text{m})} = 1.5\text{kW}$$

This is the rf power needed for the actual rf separators. For our test, however, we used the electron beam from the CEBAF injector at only 45 MeV. Consequently, 9.5 W of rf power can produce a separation angle of 0.5 mrad or 0.5 cm separation at 10 m away. This is a large enough separation to see on a view screen.

Table 1
RF Separator Test Cavity Parameters

Target frequency	499 MHz
Cavity length	30 cm
Cavity diameter (d_{out})	33 cm
Gap between facing rods	2 cm
Rod separation (center to center)	4 cm
Rod diameter (d)	2 cm

Test Cavity Construction and RF Test

A test cavity with the dimensions listed in Table 1 was constructed. The cavity is made up of one cylinder, two end caps, four rods, and two tuners. The four rods mount on the end caps, two on each end. Then, the end caps are

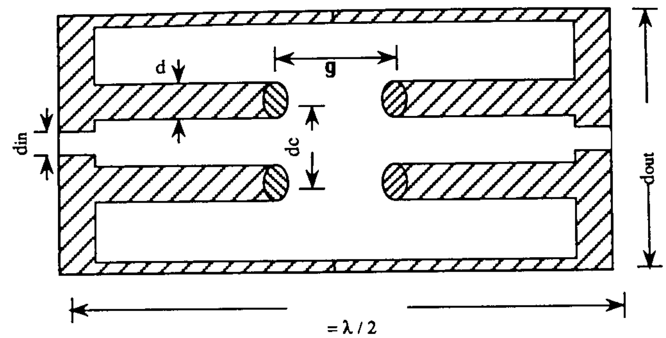

Fig. 3 The basic 1/2 wavelength structure.

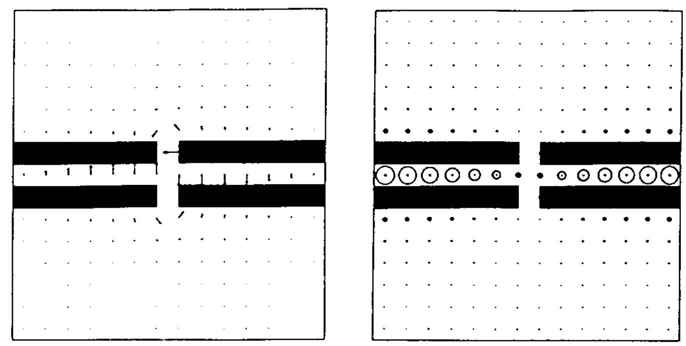

Fig. 4 E-field (left) and B-field in y-z plane.

bolted to the flanges on each end of the cylinder. These are O-ring flanges which have a raised step on an inner circle to provide the rf contact between the end caps and the cylinder. The rods are made of copper, but the cylinder and the two end caps are stainless steel plated with copper. Since one can not incorporate all the geometrical details into MAFIA to arrive at the exact resonant frequency, the rods were intentionally made slightly longer than needed. This resulted in a lower resonant frequency, about 489 MHz. Then, through several iterations the rods were cut shorter and the resonant frequency was raised to about 1 MHz above the 499 MHz target. The final tuning was done with capacitive tuners which come in at the center of the cavity and are capable of driving the frequency only down as much as 20 MHz with almost no degradation of the Q factor.

Figure 5 shows the frequency spectrum of the cavity (before tuning) from 320 to 580 MHz. The lowest mode in this figure at 337 MHz is the coaxial mode described before, where the currents on the rods run in the same direction and the potentials of the left rods are the same, but opposite to potentials of the right rods $\left(\begin{smallmatrix}+&-\\+&-\end{smallmatrix}\right)$. Therefore, there are no electric or magnetic dipole fields on the z axis in this mode. The second mode at 501 MHz is our desired mode. In this mode each rod is at opposite potential with respect to the rod paralleling or facing it $\left(\begin{smallmatrix}+&-\\-&+\end{smallmatrix}\right)$. The two other modes seen above the desired mode are new modes not present in the 1/4 wavelength cavity. One mode has all rods at the same potential $\left(\begin{smallmatrix}+&+\\+&+\end{smallmatrix}\right)$ and opposite to the inner surface of the cylinder. The other, labeled mode 4, is another dipole mode $\left(\begin{smallmatrix}+&+\\-&-\end{smallmatrix}\right)$. But the magnetic and electric dipole kicks act in opposite directions and the total effect is only the difference of the two kicks, which makes the

$R_\perp$ considerably lower. There are many other higher-order modes, but the important point here is that mode mixing is not a problem for this particular geometry. The desired mode is separated from its nearest neighboring mode by about 40 MHz.

The measured unloaded Q factor for the dipole mode (mode 2) is 5400. No sign of multipactoring was seen up to three times the rf power levels needed for this test.

Beam Test Results

As we mentioned before, the 45 MeV electron beam from the CEBAF injector was used for this test. The experimental setup was simple: a network analyzer produced the 499 MHz rf signal, which was synchronized to the 10 MHz main CEBAF rf reference signal. Next was a phase shifter and then a 50 dB amplifier. The output of the amplifier went to the separator cavity. A small pickup loop in the cavity takes a sample of the rf in the cavity and returns it to the network analyzer. At approximately 9 m downstream from the separator cavity, the beam can be seen on a view screen and by a harp (a wire scanner).

As soon as the rf was turned on to the cavity, the one beam spot on the screen was split into three spots (Fig. 6). Changing the rf phase changed the relative positions of the three spots. Since the beam is split in the y direction, the beam is focused in y and defocussed in x to give a sharper signal when scanned in the y direction. Figure 7 shows the harp traces of the beam for the two rf phases in Figure 1. The first signal on the harp trace is the x scan and the others to the right of it are the y scan. Using the amount of the beam separation vs. rf power, the measured $R_\perp/Q$ was determined to be 43.8 $\pm$ 2.4 kΩ/m.

We tried to measure the field uniformity by moving the beam within the cavity aperture and observing the change in the amount of the deflection; however, we did not see a significant change. In our next experiment we plan to perform a more accurate measurement of the field uniformity and its effect on the beam emittance. The uniformity of the field can be improved, if needed, by changing the rods' profiles.

No special cooling of the cavity was done for this test and the resonant frequency shifted less than 50 kHz only between rf on and rf off.

Conclusion

This has been a proof of principles experiment with successful results. We have established that this new design is viable for the CEBAF rf separator.

References

[1] C. Leemann and G. Yao, "A Highly Effective Deflecting Structure," 1990 Linear Accelerator Conference, Albuquerque, New Mexico.

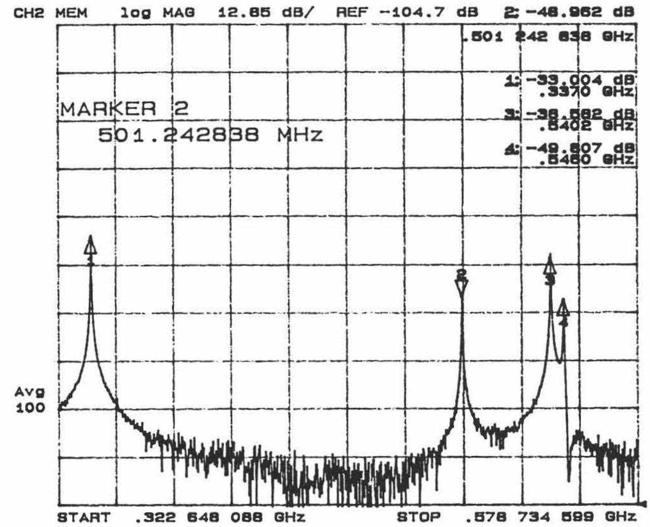

Fig. 5 Cavity modes from 320 MHz to 580 MHz.

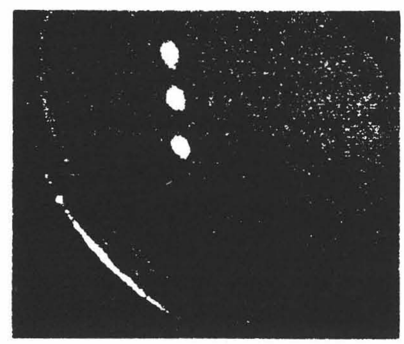

Fig. 6 The separated beam on the view screen.

a)

b)

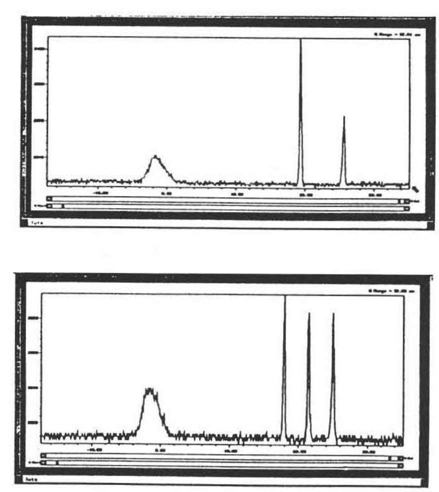

Fig. 7 Harp scan of the beam for a) two and b) three beam creation.