A COAXIAL LINE AZIMUTHAL FIELD STABILIZER FOR RADIO FREQUENCY QUADRUPOLES*

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Abstract

Azimuthal stabilization studies have been performed on a 1.75-m-long low-power model of a Radio Frequency Quadrupole (RFQ). The model was modified to accept seven resonant coaxial azimuthal stabilizers spaced at $\lambda/2$ intervals longitudinally and alternating in orientation between two orthogonal planes (Figure 1). The stabilizers are resonant versions of similar stabilizers proposed some years ago [1]. Measurements have shown that these stabilizers are easy to tune even in a very crudely constructed RFQ. They are fairly insensitive to asymmetries and tuning and can be used to adjust the dipole component of an RFQ.

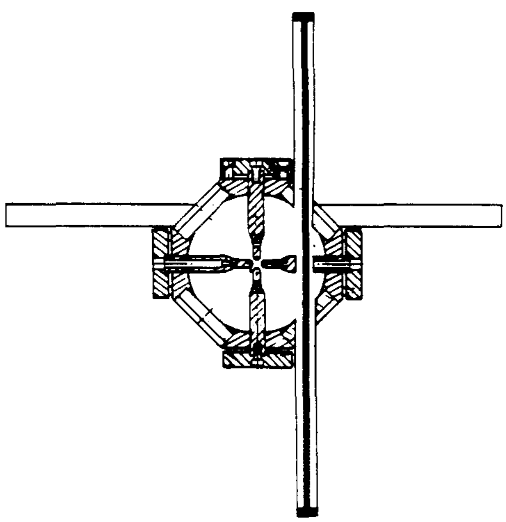

Fig. 1 RFQ model w/stabilizers.

Stabilizer Design & Principle of Operation.

As shown in Figure 1, the stabilizers consist of 41.6-Ω coaxial resonators (CRs) with shorted ends, inserted through a hole in a RFQ vane and walls. Their center conductors have a diameter of 0.64 cm. The CRs are nominally λ long at the RFQ operating frequency with provision for tuning by approximately ± 20 MHz by movement of their shorted ends. They are arranged so that their electric field nodes are located at the vane center line. The areas enclosed in adjacent quadrants by the resonator center conductor, the RFQ wall, and the vane should be approximately equal. For the orientation shown in Figure 1, if no vertical dipole exists in the RFQ, the RFQ's magnetic field fluxes through the adjacent enclosed areas are equal. Voltages induced in the CR by these equal fluxes will cancel, leaving the CR unexcited. If, however, a vertical dipole is present, the fields in adjacent quadrants will be unequal. The CR will then be excited in such a way that the fields will become equal (zero dipole), acting just like the off-axis cavity in a side-coupled linac operating in π mode. Changing the position of the CR's electric field node by offsetting both shorted ends in the same direction has the same effect as changing the relative sizes of the enclosed areas. The CR then makes the fields unequal to make the fluxes equal. This offset can then be used either to introduce a dipole component into the RFQ or to correct for unequal enclosed areas caused by mechanical asymmetries.

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Stabilizer Tuning

Because of the length and crude construction of the RFQ model, it was impossible to tune its end resonators to obtain a uniform quadrupole field without first installing the stabilizers. In fact, the admixture of dipole and quadrupole modes was such that the lowest quadrupole mode could not be identified from field measurements. Instead, the quadrupole was shorted at its ends and the quadrupole cut-off frequency (approximately 612 MHz) was estimated from the measured quadrupole mode dispersion diagram. The CRs were then tuned, in place, to 612 MHz while the RFQ was shorted in all quadrants at $\lambda/2$ longitudinal intervals by conducting rods inserted radially to contact the vane tips. Care was taken to assure that the CR's electric field nodes were approximately at the RFQ vane center line. Then, with the RFQ unshorted, the lowest quadrupole mode (which now had very little dipole admixture) was tuned for longitudinal field uniformity by using the RFQ end tuners. Then the CRs were re-tuned to give the smallest dipole admixture with the quadrupole mode. The final frequencies were the following:

- RFQ quadrupole frequency = 610.2 MHz, and
- CR frequency (RFQ-shorted) = 611.0 MHz.

Finer adjustment of the CRs can be made by perturbing the RFQ to introduce a dipole mode and by tuning the CRs for minimum dipole component. This is a tedious procedure that was found unnecessary with these stabilizers.

Experimental Results

The CR and quadrant numbering convention is shown schematically in Figure 2. All even-numbered CRs (2,4,6) were oriented to lie in the vertical plane and penetrated quadrants 3 and 4. All odd numbered CRs were in the horizontal plane and penetrated quadrants 1 and 2. Thus the even-numbered CRs could affect only the vertical dipole D_v and the odd CRs only the horizontal dipole D_h, which are here defined in terms of the quadrant fields F_i as:

$$D_h = \frac{F_3 + F_4 - F_1 - F_2}{4} \tag{1}$$

$$D_v = \frac{F_1 + F_4 - F_3 - F_2}{4} \quad . \tag{2}$$

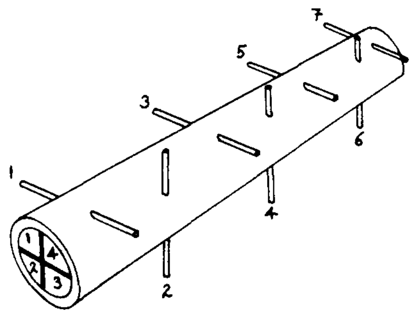

Fig. 2. Numbering convention.

The quadrupole component is defined as

$$Q = \frac{F_1 + F_2 + F_3 + F_4}{4} \quad . \tag{3}$$

Fields were measured by using the conducting bead-pull technique in the magnetic fields of the RFQ quadrants. A computer was then used to extract the dipole and quadrupole field components.

Figure 3 shows the measured quadrupole and horizontal and vertical dipole components in the as-tuned RFQ. Notice that the dipoles are less than 5% of the quadrupole component everywhere except at the ends of the RFQ where there was no stabilization and the end tuners introduced large asymmetries. The large amplitude spikes are an artifact of the measurement that occurs when the perturbing bead enters the enhanced magnetic field area near the CR center conductors. The size and polarity of these spikes is actually a measure of the stabilizers' excitation, stored energy, and therefore of their power dissipation. The on-axis fields do not exhibit these spikes. Notice that the quadrupole does not show the "clothesline" shape of a vane coupling-ring-stabilized RFQ.

To show the sensitivity of the dipole fields to offsets of the CR electric field nodes, the even CRs were moved upward by 2.5 cm while they remained tuned to 611 MHz. Only the vertical dipole field component was affected appreciably, as expected. Figure 4 shows the difference between the dipoles measured before and after the CR offset. The vertical dipole has increased by approximately 10% while the horizontal dipole has changed by only approximately 2.5%. This result indicates some mixing between horizontal and vertical dipoles caused by mechanical asymmetries.

Field stability of the RFQ with CRs relative to a partially stabilized RFQ was measured in the following manner:

1. CR 4 was detuned and the fields measured.
2. A 50-kHz perturbation was introduced into quadrant 1 at the CR 4 longitudinal position and the fields measured.
3. CR 4 was retuned to the proper frequency for stabilization and the fields measured.
4. With CR 4 properly tuned the same 50-kHz perturbation was applied to quadrant 1 and the fields again measured.
5. Differences between the dipole components of cases (1) and (2) and also between dipoles of cases (3) and (4) above were calculated.

Figure 5 shows the differences between cases (1) and (2) above with the longitudinal position of the perturbation indicated by the arrow. The horizontal dipole is not affected by

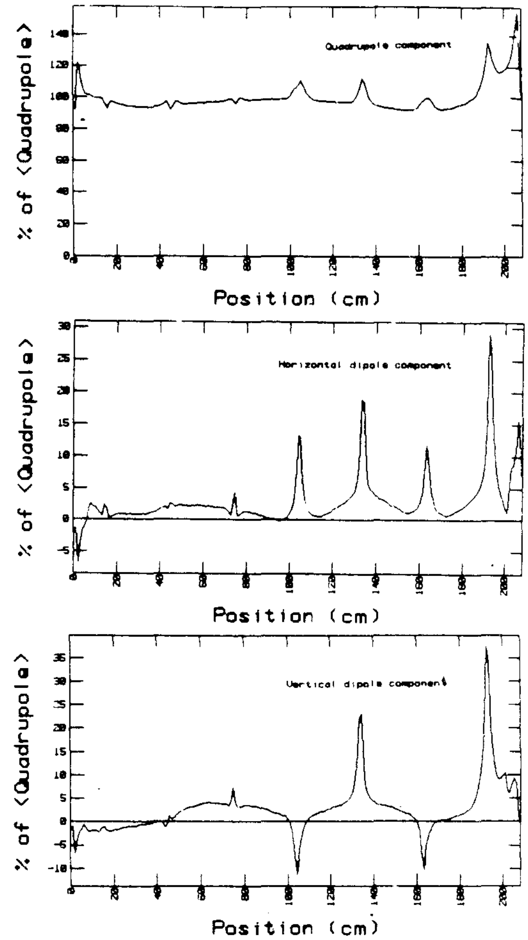

Fig. 3. As-tuned RFQ field components.

the perturbation because there are horizontal stabilizers at $\lambda/2$ on either side of it. The vertical dipole is changed drastically because the nearest vertical stabilizers are at λ distance on either side of the perturbation and CR 4 is detuned.

The differences between cases (3) and (4) above are shown in Figure 6. Neither the horizontal nor the vertical dipoles are affected by the perturbation when all stabilizers are correctly tuned.

Stored energies and power dissipation in the stabilizers for a given frequency perturbation were not measured. This measurement should be performed before any CW application is contemplated.

Conclusion & Comments

Coaxial resonant stabilizers appear to be promising candidates for stabilizing RFQs azimuthally. Their simple construction, ease of tuning, and tolerance to offsets makes them well suited even for cryogenic RFQ applications. However, because they are quite long, they protrude considerably from the RFQ, making the structure difficult to handle without damaging the CRs. If adjustment of the RFQ dipoles is desired without offsetting the CRs, they can be modified as shown in Figure 7. Here an axial rotation of the

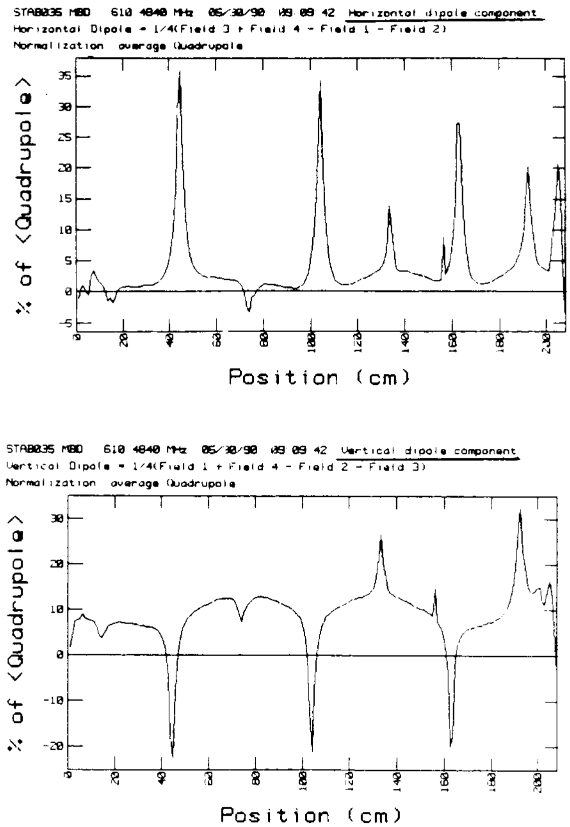

Fig. 4. CR's 2, 4, 6 offset 2.5 cm upward.

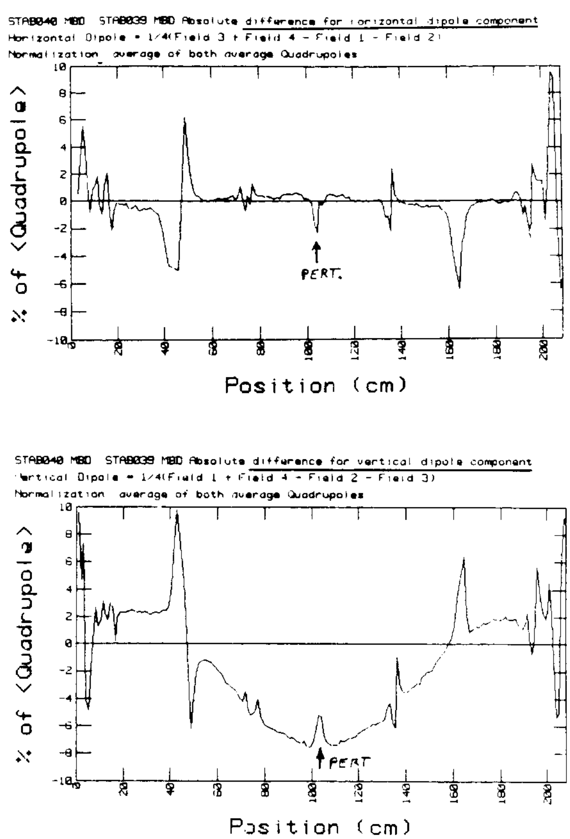

Fig. 5. 50 kHz perturbation in quadrant 1, CR 4 detuned.

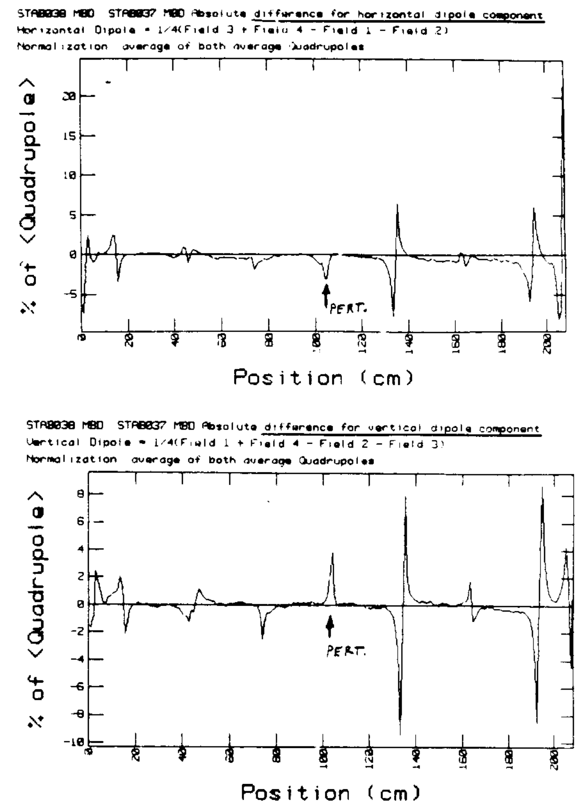

Fig. 6. 50 kHz perturbation in quadrant 1, CR 4 tuned.

CR will change the relative areas enclosed by the CR and the RFQ walls in adjacent quadrants, thus making the stabilizer behave just as if its electric field node had been displaced.

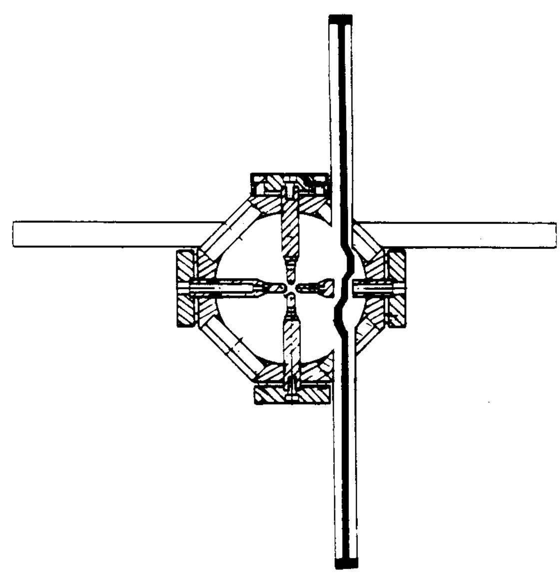

Fig. 7. Modified stabilizer.

Reference

1. A. Schempp, "Field Stabilization of RFQ Structures," 1984 Linac Conference, Lufthansa-Schulungszentrum, Seeheim, F.R.G., May 7-11, 1984, p. 338.