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Tuning of The 0.45 MeV PEFP RFQ Accelerator

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Abstract

The PEFP (Proton Engineering Frontier Project) RFQ Accelerator was constructed to accelerate 20-mA CW Proton beam from 50 keV to 450 keV. This 350-MHz RFQ is to form with one 98-cm cavity. It is essential that the field distribution meets the design requirement in order to minimize the beam losses. The results of experimental studies on RF characteristics of a four vane RFQ cavity was obtained. A mode separation and field distribution have been obtained with a loop coupler. The tuning procedure was performed by employing the bead-pulling technique. In this technique a metal bead was suspended on a nylon line and drawn through the four quadrants near the RFQ's outer wall. Sixteen Aluminum slug tuners distributed along the outer walls tuned the RFQ. By tuning the positions of 16 slug tuners, a uniform field distribution within errors a few percent both longitudinally and azimuthally were achieved in this RFQ.

1. Introduction

The high intensity (20-mA) of the continuous proton beam accelerated in 98-cm PEFP radio frequency quadrupole (RFQ) [1-3] from 50 keV up to 450 keV requires the achievement of a very accurate electromagnetic voltage law. It is tuned with the adjustment of several mechanical devices mainly deduced from the analysis of the field distribution measurements [4].

This experimental procedure must be especially efficient in the RFQ since it is accomplished through the 4 quadrants at many steps of its machining and assembly. All the tuners have been machined to length and installed. The RF drive port is plugged with temporary inserts that are flush with the interior wall of the RFQ. This paper describes the bead-pull system that has been extensively applied on our RFQ in order to validate the tuning procedure formalism that we have developed.

2. Measurement Principle and Set-Up

Applying the classical perturbation method, the measurement of the field profile consists in acquiring the resonance frequency as a small bead is displaced through the cavity. The frequency shift $\delta\omega$ is proportional to the combination of the squared amplitudes of the electric and magnetic fields at the location of the bead. In RFQs, high gradients of the accelerating electrical field E_{acc} that exist in the beam region make direct E_{acc} perturbation measurements too sensitive to positions errors. E_{acc} must be computed from indirect measurement of the field in the outer quadrant. A dielectric sphere is guided in contact with the vane tips so $\delta\omega \propto |E_{\perp}|^2$. And a metallic bead is guided close to the slug tuners side, the magnetic field H dominates and $\delta\omega \propto |H_{//}|^2$. The test bench must provide 2 main functions (bead displacement and RF measurement).

A complex pulleys system guides with a high mechanical accuracy the wire supporting the bead successively through the four quadrants at any of the several considered paths. Different size of beads have been tested. For H-field measurement, a aluminum cylindrical-shaped object (35mm-diameter and 4mm-thickness) is supported by a 0.55mm-diameter nylon wire. Figure 1 (a and b) shows the experimental set-up and tuner for RF field measurements.

3. Field Measurement Results

Measurements on or near the RFQ axis are impractical for several reasons. Axial measurements provide no information about the quadrupole and dipole admixture of the field distribution. Also, small spacing between vane tips makes the alignment of the bead path critical. Slight alignment errors produce larger effects than those we are attempting to measure. Finally, fluctuations caused by the vane-tip modulations dominate the measurements. Tolerances on the vane-tip machining guarantee the correct field pattern if the voltage distribution along the vanes is correct. Therefore, we infer the electric field distribution from a measurement of the magnetic field near the cavity outer wall. One RFQ-tuning goal is a pure quadrupolar field pattern. Differences among quadrants mix dipole field components with the predominantly quadrupole field, effectively shifting the quadrupole pattern off axis. Four measurements, one in which RFQ quadrant, quantify the dipole and quadrupole field admixture.

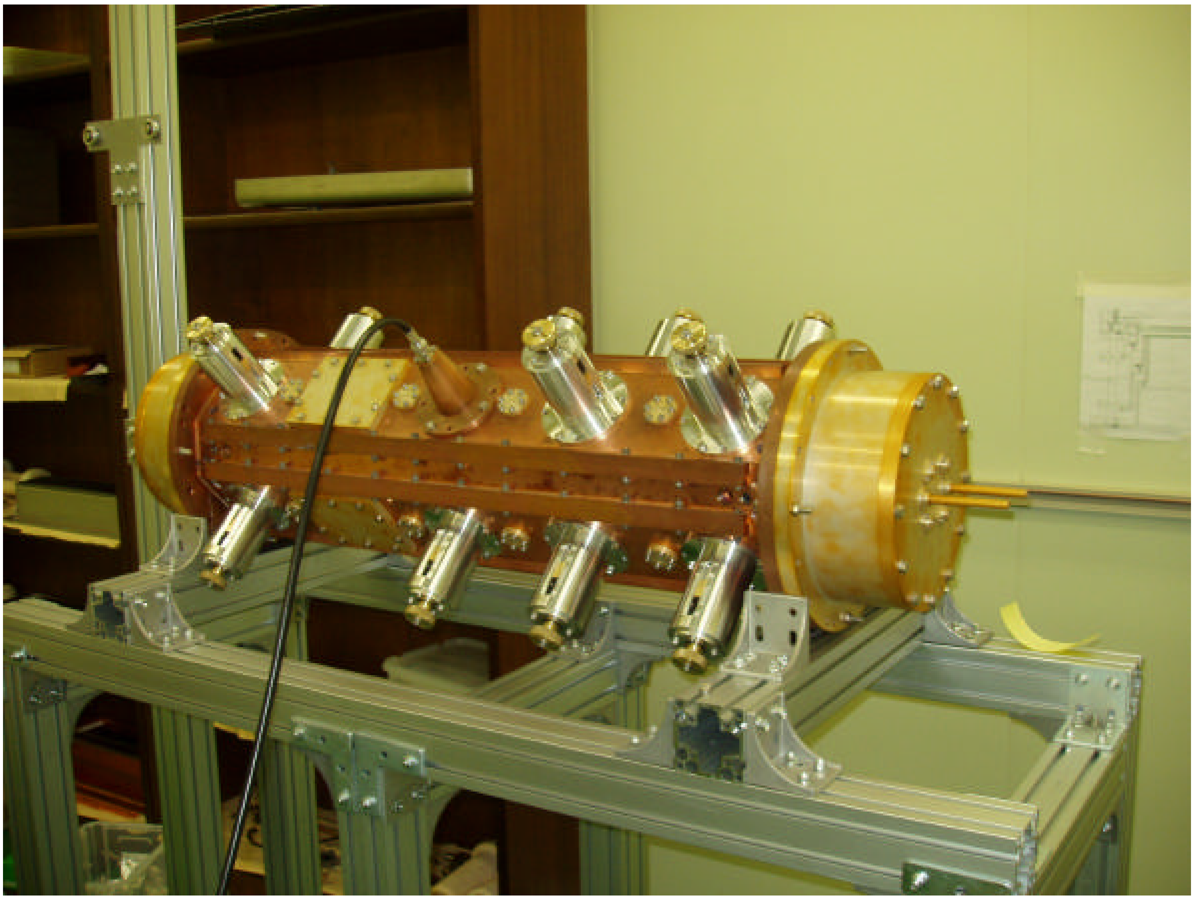

Figure 1 (a). Experimental set-up for the RF field measurement.

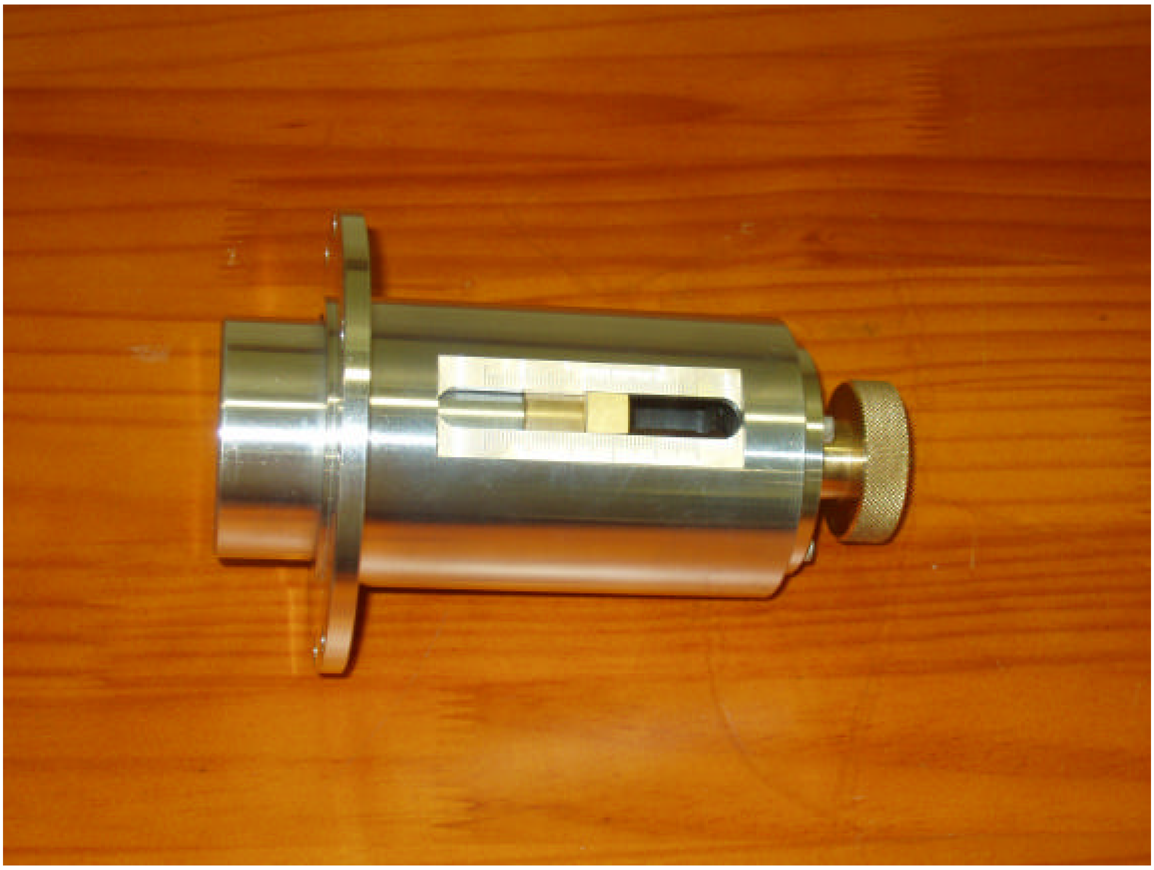

Figure 1 (b). Tuner for the RF field measurement.

An Agilent vector network analyzer (VNA) measures the S11 reflection coefficient through the cavity at the constant frequency f_0 of the unperturbed resonance mode. The magnetic field distributions in the four quadrants are obtained by measurement of frequency shifts with a aluminum rod inserted through a hole on the side wall. An RF power is fed to the cavity with a single coupling loop.

The magnetic field distributions in the four quadrants of the cavity before the tuning, with the tuner positions on the same plane of the wall, is shown in Figure 2. The resonance frequency is 350.3225 MHz. These distributions are presented in forms of the squares of the magnetic fields, since the resonant frequency shift measured by the bead perturbation method is proportional to the square of the field strength. The field has an asymmetry of ±25% azimuthally and tilts longitudinally. After the tuning, the azimuthal symmetry and longitudinal uniformity of the magnetic field distributions in the four quadrants are obtained, as shown in Figure 3. The field profile has bumps and these bumps in the fields are caused by the tuners. The longitudinal flatness and azimuthal distribution is uniform to within ±4 %.

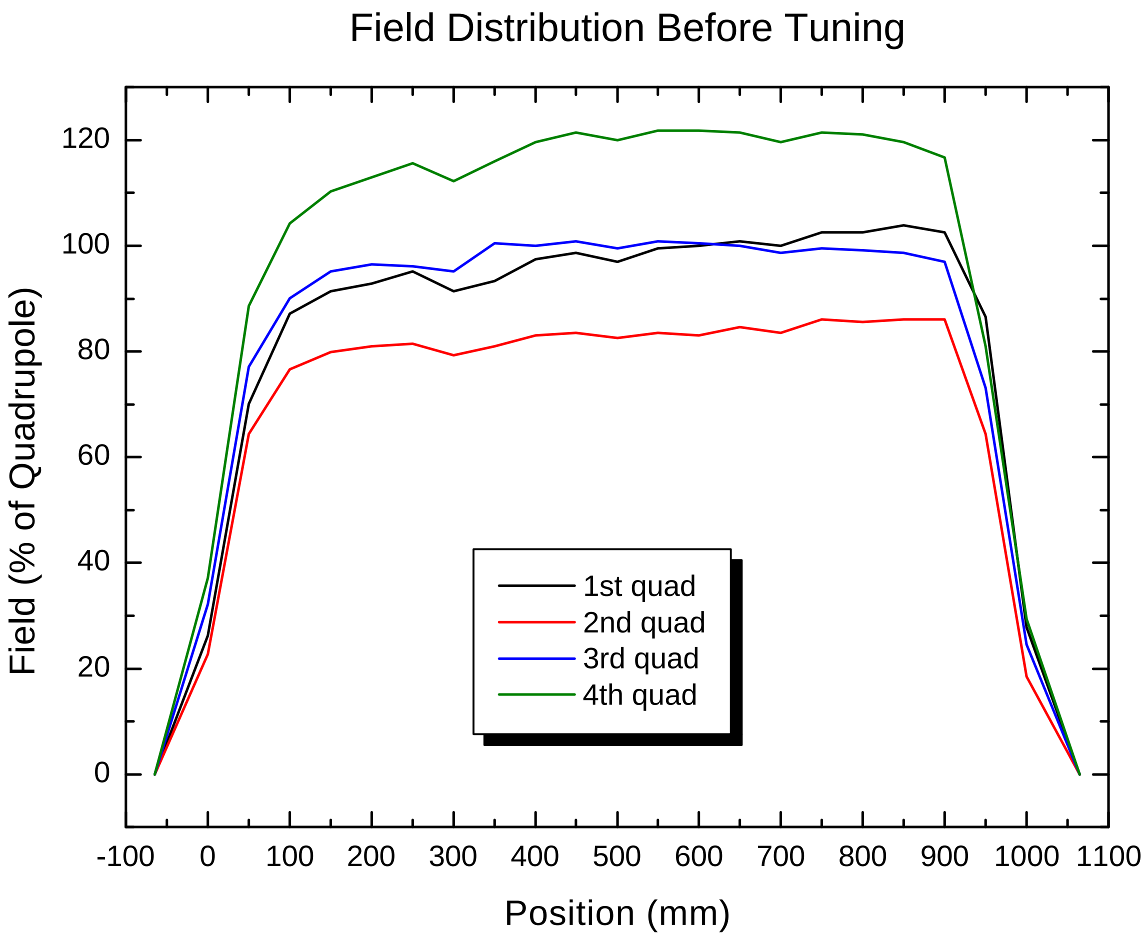

Figure 2. RFQ fields measured with the bead perturbation technique before tuning.

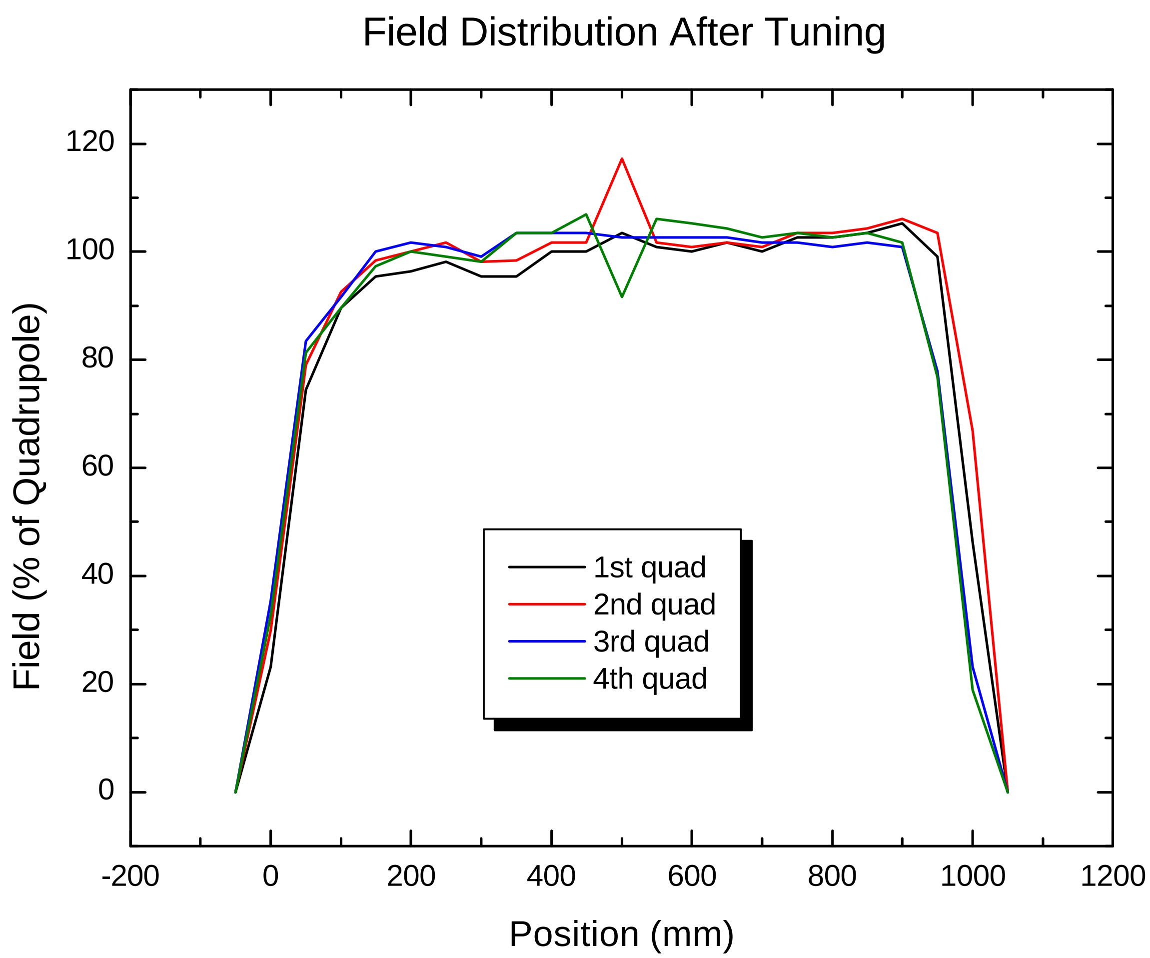

Figure 3. RFQ fields measured with the bead perturbation technique after tuning.

4. Conclusions

The reproducibility and the high sensitivity of the bead-pull bench have turned out to be very important for the development of our tuning formalism through tests in the 0.45 MeV RFQ. In particular the low signal to noise ratio of the raw data is a key point for a high precision tuning of the voltage profile.

The possibility of perturbing fields in four quadrants is useful to check the validity of a RFQ tuning procedure deduced from H-field towards E-field. Tuner adjustments achieve the correct frequency and establish the desired field profile.

Acknowledgment

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