TUNING THE LEDA RFQ 6.7 MEV ACCELERATOR*

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Abstract

This paper presents the results of tuning the 8 meter long Radio Frequency Quadrupole (RFQ) [1] built for the Low Energy Demonstration Accelerator (LEDA)[2]. This 350-MHz RFQ is split into four 2-meter-long-RFQ's. Then they are joined with resonant coupling to form an 8-meter-long RFQ[3]. This improves both the longitudinal stability and the transverse stability of this long RFQ. The frequencies of the modes near the RFQ mode are measured. We show the effect on the RF fields of an error in the temperature of each one of the 2-meter-long RFQ's. Water-cooled copper slugs distributed along the outer walls tune the RFQ. The program RFQTUNE [4] is used to determine the length of the slug tuners. The tuners are machined to length when the final tuning is complete.

1 INTRODUCTION

The final tuning of the LEDA RFQ has been completed. All the tuners have been machined to length and installed. The RF drive ports are plugged with temporary inserts that are flush with the interior wall of the RFQ. Figure 1 shows the measured fields versus position along the RFQ. The RF magnetic fields near the outer wall are measured using the bead-perturbation technique. The vane gap voltage is inferred from the measured magnetic fields by comparison to SUPERFISH calculations of the RFQ cross section every 10 cm along the RFQ. In Figure 1 the measured fields are the lines with bumps. The smooth line through the measured quadrupole fields is the design field. The measured quadrupole field

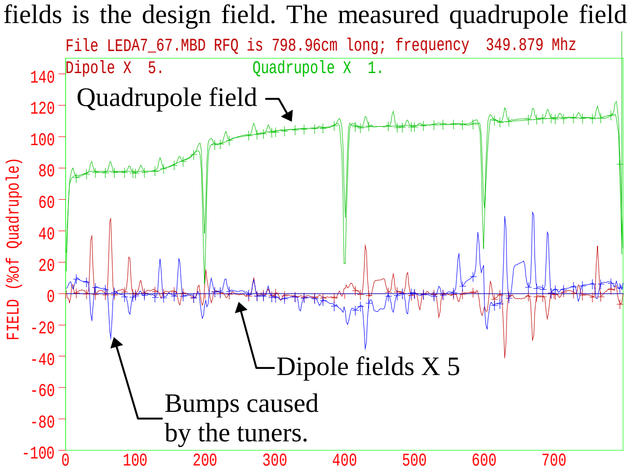

Figure 1. RFQ fields measured with the bead perturbation technique. The measured fields are within 1% of the design values. The dipole fields are multiplied by a factor of 5.

agrees so well with the design field that in this figure it is difficult to distinguish between the two lines except for the fact the design field has no bumps. These bumps in the fields are caused by the tuners. In Figure 1, the crosses (+) indicate locations between tuners where the measured field is valid. These bumps in the measured magnetic fields do not appear in the electric fields on axis. The large dips in the measured quadrupole fields are caused by the bead passing through holes in the coupling plates. The coupling plates join the four 2-meter-long RFQ's.

2 TUNING STEPS

The first step in the tuning of the LEDA RFQ occurred before the final brazing. Each 1-meter-long segment was checked for correct frequency and fields. The undercuts on one end of each segment have a large effect on the field tilt. Figure 2 shows the fields in section A1. The quadrupole fields are very nearly equal to the design fields, which means that the vane undercuts on the low-energy end are correct. The dipole fields of about 20% are correctable with the tuners. This measurement was performed with the tuners flush. The frequency is adjusted by machining the braze surfaces on the major vanes and moving the minor vanes in or out. Typically, the frequency of each 1-m segment was correct when the vane gaps were adjusted to the design dimensions.

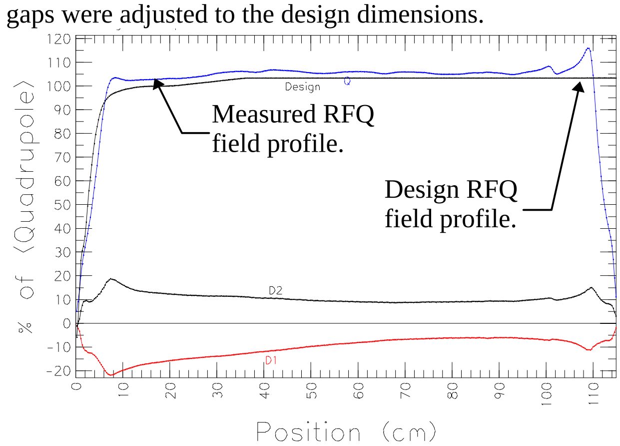

Figure 2. Perturbation measurement of the fields in section A1 before brazing. The measurement was performed with a short RFQ piece attached on the high energy end. This short piece has a vane undercut designed to properly terminate the RFQ with flat fields.

The next step in tuning occurred after the final section brazes. This step established the length of the dipole stabilizer rods. These rods, four of which are mounted on each of the end walls and on both sides of each coupling plate, adjust the frequency of the dipole modes. The

*Work supported by the US Department of Energy.

length of the rods are adjusted to approximately equalize the frequency difference between the quadrupole mode frequency and the nearest dipole mode above and below the quadrupole mode. Figure 3 shows the quadrupole modes in the frequency region near the operating mode that is free of dipole modes. This tuning scheme minimizes the dipole component in the quadrupole mode caused by asymmetric perturbations. The water cooled stabilizer rods are 1.27 cm in diameter and 15 cm long.

Step three in tuning adjusted the gap between the vane-tip ends at the segment joints. These gaps provide capacitive coupling between adjacent pairs of the four 2-meter-long RFQ's. The size of these gaps determines the capacitance between the vane-tip ends and thus the frequency of the coupling mode. The goal is to have the coupling mode frequency equal to the operating mode, which closes the stop band at the zero-phase-shift point in the dispersion curve shown in Figure 3. The fact that the dispersion curve is smooth through the operating mode shows that the frequency of the coupling mode is nearly equal to the RFQ operating mode. The operating mode has zero phase shift between the segments so the structure acts like one long RFQ. The resonant coupling provides longitudinal stability that is nearly as good as in a 2-meter-long RFQ.[5]

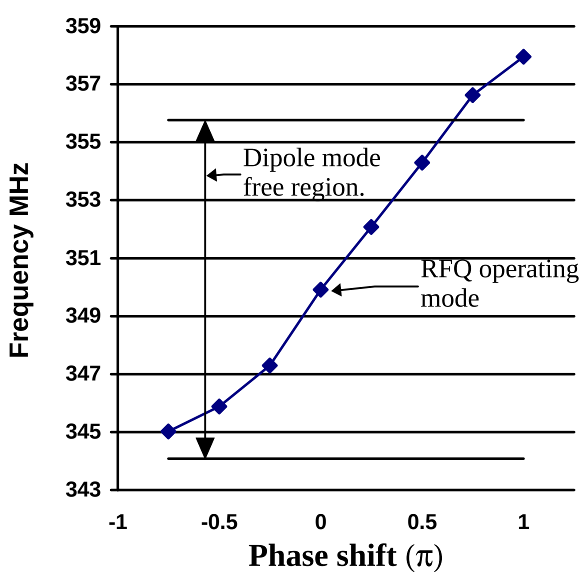

Figure 3. Quadrupole dispersion curve showing the RFQ operating mode and the frequency gap between the nearest dipole modes and the operating mode.

Step four in the tuning adjusted the RF field to the design values. This was done by moving the 128 movable tuners in accordance to the code RFQTUNE. A number of iterations were performed to adjust the field to within 1% of the design value. Figure 1 shows that the dipole component is less than 1% in over 90% of the RFQ. The D(2-4) dipole component is about 2% from 400 cm to 450 cm. When this tuning was completed the movable tuners were replace with water-cooled tuners machined to the final penetration of the movable tuners. Because the machined tuners raised the frequency slightly with respect to the movable tuners, this step was done in three stages. First 50% were replaced, then 25%, and finally the last 25%. After each stage the RFQ tuning was checked and the remaining tuners adjusted as necessary.

Step five in the tuning was to adjust the waveguide coupling irises. This RFQ is driven with three 1.2-MW klystrons. The RF power from each klystron is split 4 ways to reduce the power on the waveguide vacuum windows. The total coupling beta without beam with all three klystrons operating was chosen to be 2. The RFQ will be over coupled when all three klystrons are operating, but this RFQ is also expected to operate with only 2 of the 3 klystrons. With 2 klystrons operating, the total coupling beta without beam will be 1.33 and the RFQ will be under coupled with full beam current. A coupling beta of 1.58 would give the best match at full beam current.

A coupling beta of 2 with all twelve waveguides coupled to the RFQ requires each waveguide to be coupled with a beta of 0.167. To achieve this coupling a tapered ridge-loaded waveguide section reduces the size of the half-height WR2300 waveguide to 17.78 X 2.54 cm at the RFQ. The RF fields in this tapered section increase to the point where an iris only 9.144 cm long and 0.1575 cm wide is sufficient to achieve this coupling. The 12 RF waveguide ports were plugged with a copper piece flush with the interior walls during tuning. After the iris size was determined, the penetration of the tapered-waveguide test section was adjusted for minimum effect on the RF fields and frequency. This adjustment allows the final tuning to be completed with all the water-cooled tuners machined to length and installed before the waveguides are installed. Because the manufacturing of the tapered waveguides is taking longer than originally expected, we have completed the final tuning even though the fields may change a small amount after the waveguides are installed.

3 TUNING ERRORS

The RFQ cooling system controls the resonate frequency of the RFQ. The frequency is controlled by adjusting the temperature of the cooling water in the outer walls of the RFQ and maintaining 50° F water in the cooling passages near the vane tips. A +1° F change in temperature of the outer wall cooling water raises the resonant frequency of the RFQ by 17 kHz for constant temperature of the tip cooling water. Whereas if both the tip cooling and the wall cooling water raises by 1° F, the frequency of the RFQ will drop by 3.27 kHz. This dual temperature cooling system is required to keep the RFQ tuned to 350 MHz when dissipating 1.2 MW of RF power. The RFQ is tuned to 350 MHz at 70° F with low RF power. When it is operating, the average temperature will be ~84° F.

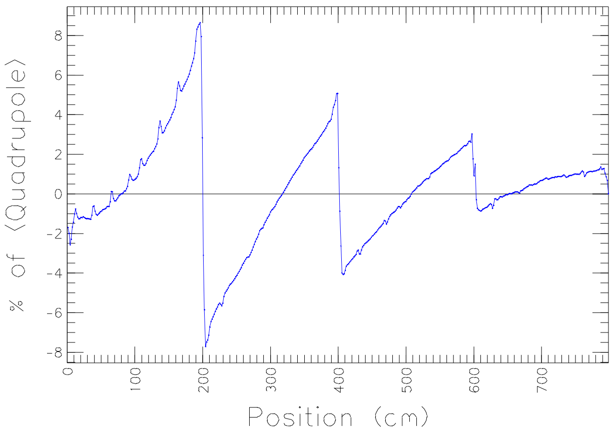

Figure 4. Change in quadrupole fields when segment “A” (0-200 cm) is tuned high in frequency by ~400 kHz. This corresponds to a cooling water temperature error of +23° F.

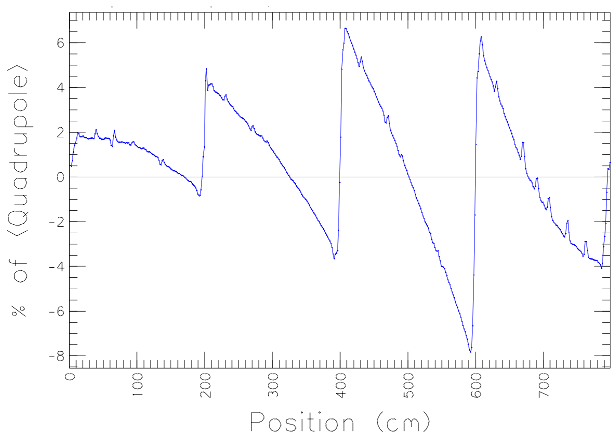

Figure 5. Change in quadrupole fields when segment “D” (600-800 cm) is tuned high in frequency by ~400 kHz. This corresponds to a cooling water temperature error of +23° F.

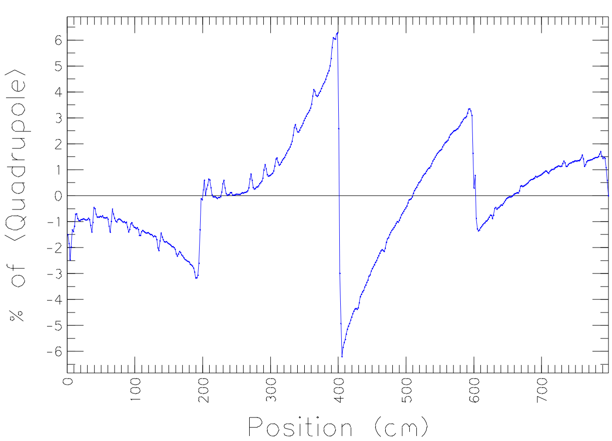

Figure 6. Change in quadrupole fields when segment “B” (200-400 cm) is tuned high in frequency by ~400 kHz. This corresponds to a cooling water temperature error of +23° F.

The cooling system has a separate cooling loop for each 2-meter section of the RFQ because each section dissipates a different amount of RF power. The cooling to the outer walls in each section have a cooling loop which mixes some of the cooling water heated by that section with the water from the outer cooling loop. This mixing ratio is adjusted manually with a remote control valve. An outer cooling loop mixes the water returning from all 4 inner loops with the 50° F supply water to control the resonate frequency of the RFQ. This outer loop is controlled by a PID feedback circuit.

The adjustment of the 4 manually controlled mixing valves will be performed by inspection of the field errors in the RFQ. RF pickup loops placed in 64 of the 128 tuners will measure the RF field distribution. Inspection of the errors in the field distribution will allow adjustment of the mixing valves. Figures 4, 5, and 6 show the changes in the quadrupole field for a temperature error in the outer wall cooling water in sections A, D, and B. The changes in the quadrupole field for section C looks like the mirror image of B. This type of perturbation does not effect the dipole component in the operating quadrupole mode.

Thus a cooling water temperature error of +23° F results in a maximum field error of only 8%. Therefore, it should be easy to set the manually controlled mixing valves to minimize the field errors by setting the mixing valves to obtain the predicted temperatures. The predicted temperatures of the 4 loops are 71, 65, 63, and 61° F respectively.

ACKNOWLEDGMENTS

Many people have been involved in the design and manufacturing of this RFQ. They include: D. Schrage, P. Roybal, A. Naranjo, D. Baca, W. Clark, F. Martinez, H. Haagenstad, J. Mitchell, D. Montoya, A. Rendon, F. Krawczyk, T. Davis, D. Casillas,A. Gonzales, G. Gonzales, S. Hidalgo, E. Kettering, G. Leeches, B. Ormond, R. Reinert, O. Smith, and J. Tafoya.

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