PXIE RFQ BEAD PULL MEASUREMENTS*

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Abstract

The Project X Injector Experiment (PXIE) radio frequency quadrupole (RFQ) is being built for Fermilab by Berkley laboratory (LBNL). This RFQ will be placed after the low energy beam transport (LEBT) and before the medium energy beam transport (MEBT). The RFQ will operate at 162.5 MHz in CW regime; its function is to accelerate and focus particles coming from the LEBT at 30 keV, and to deliver a beam at 2.1 MeV to the MEBT. In order to make sure that the RFQ meets the specifications of field flatness and frequency the field in the vanes should be measured using bead pull technique and tuned according to specifications. FNAL created a new single wire bead pull set up for the RFQ of PXIE. The measurements are used to find the electrical centre of the structure, then the amplitude of the electromagnetic field in all the sectors of the RFQ; and the tuning will be based on these measurements. This paper describes the bead pull experimental set up, the software developed for this particular application and the measurements taken.

INTRODUCTION

PXIE is a CW injector experiment of the new multi MW linac to be built at Fermilab [1]. The project is composed of a H^- ion source, a low energy beam transport (LEBT) section, a radio frequency quadrupole (RFQ), medium energy beam transport (MEBT) and two cryomodules of superconducting cavities for a final beam energy of 30 MeV. All the components will operate in CW regime having 100% duty cycle. The main RFQ parameters are reported in Table 1.

Table 1: Main RFQ Parameters

Input energy [keV]	30.00
Output energy[MeV]	2.10
Frequency [MHz]	162.50
Vane-vane voltage [kV]	60.00
Vane Length [cm]	444.60
RF Power [kW]	100.00
Beam Power [kW]	10.50
Duty factor	100%

The RFQ is being built at LBNL and is the product of collaboration between FNAL and LBNL [2] [3]. It consists of four modules that will be attached together to form the whole structure. Figure 1 shows the full RFQ 3D model. Once the RFQ is constructed, the electric centre, field profile on axis, and quadrant symmetry can be measured with a bead pull technique.

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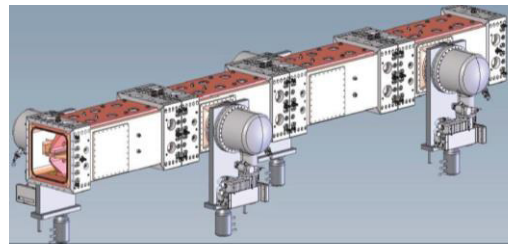
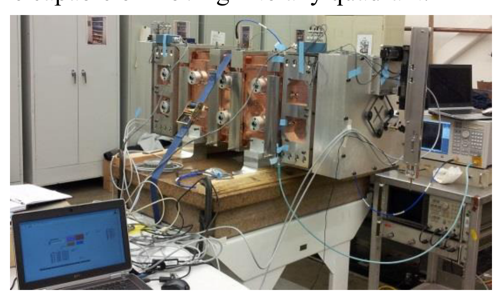


Figure 1: PXIE RFQ 3D model.

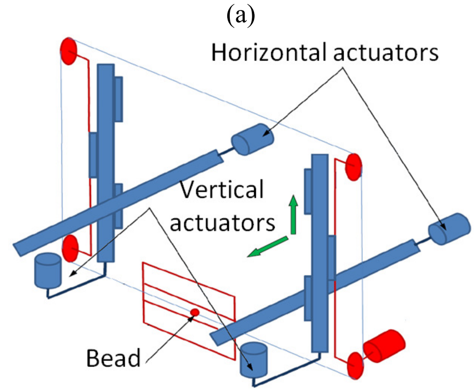
This paper reports the results of the bead pull measurements taken on the dry fit of a single RFQ module before brazing. The main focus is to verify RF simulations and machining tolerances. Once RFQ construction is complete, in early 2015, tuning and final measurements will be taken using this bead-pull setup.

MEASUREMENT SET UP

A common measurement set up for RFQ bead pull uses 4 lines, a separate line for each quadrant. The set up used for the measurements of PXIE RFQ module consists of one line capable of moving into any quadrant.



(a)



(b)

Figure 2: (a) measurement set up on module 2 at LBNL, (b) schematic of the bead pull system for PXIE RFQ.

The measurement apparatus and its schematic are presented in Figure 2; the main advantages of using such a sophisticated set up are:

- Reduction of number of lines necessary.

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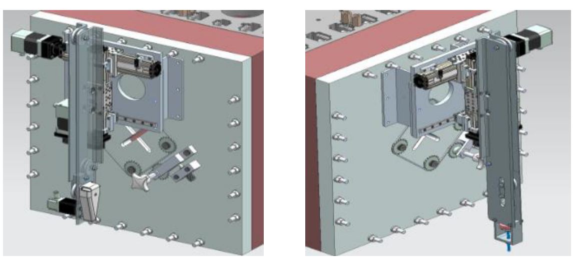
- Possibility to run string scan to measure the electric axis of the structure.
- Possibility of taking measurements near and on RFQ axis, if the diameter of the bead is small enough.

This system can be converted into a horizontal bead pull set up for virtually any kind of cavity.

Mechanical Set Up

Two support plates, both with independent horizontal and vertical positioning systems, are attached to the module matchers. [4] The bead line is supported by two beams having pulleys to allow the push and pull motion. Each axis of transverse positioning is moved by a stepper motor connected to an actuator with an anti-backlash screw. The bead line is moved by another stepper motor (on the entrance plate) and the tension on the line is monitored by a load cell (at the other end) to allow sag correction of the data. Fig. 3 shows a 3D model of the two support plates mounted on the module.



(a) (b)

Figure 3: (a) bead line drive motor plate, (b) load cell support plate.

Labview® Control

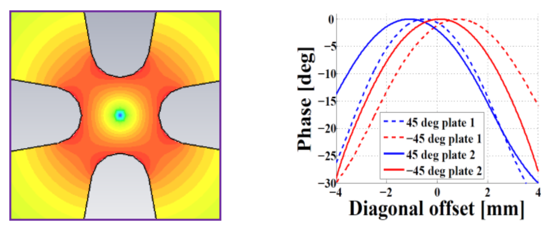
The whole system is controlled by a Labview® program which communicates with all the motors and the load cell; in addition it provides real time data acquisition from the network analyser (NWA). The motors and the load cell communicate with the computer via USB/RS485 serial interface, while the NWA is controlled via GPIB protocol. Having different buses allows parallel communication with all the instruments. In addition the program allows data processing, and includes a correction for sag error of the bead along the phishing line.

MEASUREMENT RESULTS

The common measurement procedure for RFQs consists of measuring each quadrant and comparing field flatness along the length of the structure. Processing this data [5], it is possible to assess how much each tuner should penetrate in to the cavity volume to get a flat field profile. Since the mechanical set up allows the motion of the bead line along the two diagonals, a string scan to get the electric axis of the RFQ was performed. This procedure allowed aligning the bead with the electric axis of the cavity, rather than relying on mechanical alignment of the two end plates. Also, bead pull measurements of the accelerating field were taken using a sphere small enough to fit between the modulated tips.

Electric Axis Measurement

Before taking any measurements the bead was positioned to the visual centre of each end plate. In order to measure the field amplitude symmetry for each quadrant, it is preferable to refer all the diagonal offsets with respect to the electric centre. The baseline measurement consists of two diagonal scans, at 45 degrees and at -45 degrees, keeping the metallic bead outside the structure. The phase shift due to the interference of the phishing line with the field was recorded from the NWA while the movement was in progress. The line scanned the two diagonals from -5 mm to 5 mm radial offset. Then, the scans were repeated at each end with the bead inserted inside the structure, just beyond the end plates. The smallest field perturbation should occur when the bead is at the electrical centre. Fig. 4(a) shows the electric field in a section of the RFQ from CST. Subtracting the baseline data from the measurement data taken with the bead inserted, one can isolate the effect of the bead on the field at the ends of the structure. This allows referencing the electric centre of each end to the geometrical centre of the end plates. The phase vs diagonal offset, relative to geometrical centre, for the bead at the two ends of the RFQ, is plotted in Figure 4(b).



(a) (b)

Figure 4: (a) transverse section electric field distribution, (b) phase vs diagonal offset string scan data.

The electric centre location is identified by the maximum of each curve; the values reported in table 2 have been used to correct the position of the bead pull line on the two end plates. After the correction a new measurement was taken and the corrected centre, ideally supposed to be zero, was found to be less than 0.2 mm. Fig. 5 shows the centre measurements after aligning the bead line on the electric axis.

Table 2: Electric Centre Coordinate Relative to End Plates

	Plate 1	Plate 2
1st diagonal (45 deg)	-0.52 mm	-1.1 mm
2nd diagonal (-45 deg)	0.84 mm	0.1 mm

Table 3: Electric Centre Coordinate Relative to End Plates, After Correction.

	Plate 1	Plate 2
1st diagonal (45 deg)	0.13 mm	-0.07 mm
2nd diagonal (-45 deg)	0.16 mm	-0.03 mm

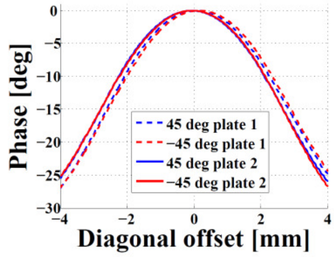


Figure 5: electric axis measurements after correction.

Quadrant Measurements

Quadrant measurements of field flatness give information about the frequency along the whole RFQ length. Quadrant bead pull data has been taken first relying on visual alignment with the end plates, Fig. 6 shows the field amplitudes for quadrants 1 to 4. The overall field flatness was 93%, and the specification calls for 98% field flatness after tuning. Once the electric axis had been found, the quadrant bead pull was run again to get more accurate data, since some asymmetry in the fields was due to the misalignment. Fig. 7 presents the results of the new measurements; the field amplitude shown is much lower than the one in Fig. 6 since the bead diameter went from 9.5 to 4 mm.

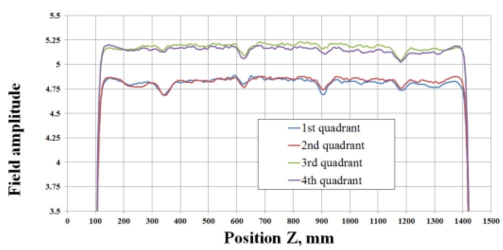


Figure 6: quadrant bead pull, R= 30 mm, bead diameter= 9.5 mm, visually aligned on the end plates.

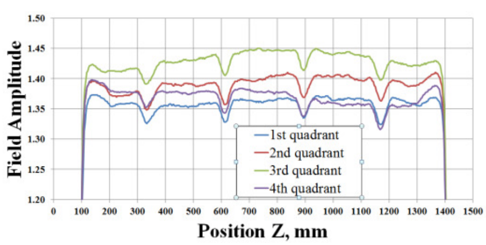


Figure 7: quadrant bead pull data, R= 30 mm, bead diameter= 4 mm, aligned on electric axis.

The overall field flatness went up to 94.6%, taking out the third quadrant the value would make it 97%. This is an indication that the 3rd quadrant of the RFQ is slightly higher in frequency and it will require more attention during the tuning process. The lower bumps on the field amplitude measured correspond with the pi rods locations, where the field is perturbed by the presence of the metallic cylinders.

Accelerating Field Measurements

The electric field on axis was measured with a bead having diameter 4 mm, capable of fitting between vane tips. Fig. 8(a) shows the field on axis measured in module 2 of PXIE RFQ, the amplitude modulation decreases and the period increases (to match the particle speed) along the axis. The simulated Ez field is shown in figure 8(b) for graphic comparison.

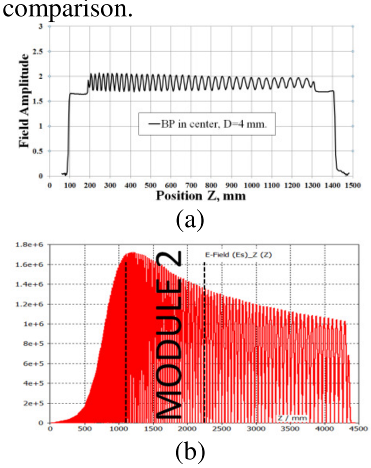


Figure 8: RFQ Ez field on axis measured with bead pull (a) and simulated (b).

Fig. 9(b) shows four quadrants' field distribution measured off axis at a diagonal offset of 1 mm. The tip modulation amplitude increases with Z, so the data is affected by the reduced distance between the bead and vane tip. This measurement was possible since the aperture allows displacing a 4mm bead of 1 mm within the tips without direct contact.

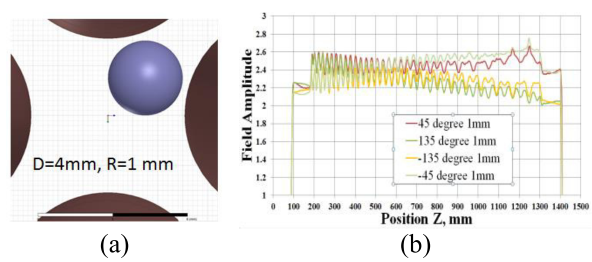


Figure 9: (a) bead 1 mm off axis inside the tips aperture of the RFQ, (b) electric field measured off axis.

CONCLUSIONS

The module 2 of PXIE RFQ was measured with bead pull technique at LBNL, results showed that the untuned cavity has field flatness of almost 95% and that the different quadrants appear to be symmetric. The electric centre and the field on axis have been measured as well.

REFERENCES

[1] S. Nagaitsev, et al., "Functional Requirements Specification PXIE", Project X docdb #980.
[2] G. Romanov et al., THPPP064, Proceedings of IPAC2012, New Orleans, Louisiana, USA.
[3] S. P. Virostek et al., WEPMA21, Proceedings of NAPAC13, Pasadena, California, USA.
[4] S. Virostek, "RFQ Subcomponents", PXIE RFQ Fabrication Readiness Review, Berkeley, California, USA.
[5] J. Staples, "Tuning the PXIE RFQ", PXIE RFQ Fabrication Readiness Review, Berkeley, California, USA.