BEAD PULL MEASUREMENTS OF THE FETS RFQ AT RAL*

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Abstract

A Radio Frequency Quadrupole (RFQ) is a part of the Front End Test Stand (FETS) at the Rutherford Appleton Laboratory (RAL), Didcot, UK. The aim of the FETS project is to produce a 60 mA H-beam at 3 MeV. The RFQ is a four-vane type with 4 modules, each of 1 m length, and is designed to accelerate the beam from 65 keV to 3 MeV at 324 MHz.

A bead pull system has been designed to measure the field along the RFQ. This will be used in conjunction with 64 tuners to produce a uniform field. In order to optimise the tuning procedure, a model of the RFQ has been created in COMSOL Multiphysics. This study shows the results from the bead pull measurements and the tuning studies.

INTRODUCTION

FETS is a project for the High Power Proton Accelerators (HPPAs) applications [1]. It also could be considered as an injector for a prototype of Fixed-Field Alternating Gradient accelerator (FFAG). The goal is to perform a fast beam chopping by producing a 60 mA H-minus, 2 ms, 50 pps beam. The FETS is currently being constructed at the STFC Rutherford Appleton Laboratory in the UK.

The 324 MHz RFQ has been designed to accelerate the beam from 65 keV to 3 MeV. It is a four-vane structure consisting of 2 minor and 2 major vanes per section. A total length is 4.2 m with four sections, approximately one-metre each. Sixty-four tuners will be applied to correct the field to make it uniform. This will be done using bead pull measurements [2, 3].

This paper shows the results of the changes in a pulley system to cover the complete FETS RFQ. The tuner effects and the results of varying radius distance from the centre of the RFQ will be provided. Only return loss (S_{11}) with section 2 have been made because of the delay of the remaining modules and time limitations.

BEAD PULL MEASUREMENTS

Due to the imperfect manufacturing of the RFQ, the tuning system is necessary to produce a flat field. In order to correct the field by using the tuners, the field can be observed by the bead pull measurement. It is done by using a perturbation technique.

$$\frac{\Delta\omega_0}{\omega_0} = \frac{\int_{\Delta V}(\mu_0 H^2 - \epsilon_0 E^2)dV}{\int_V(\mu_0 H^2 + \epsilon_0 E^2)dV} = \frac{\Delta U_m - \Delta U_e}{U} \quad (1)$$

The local field can be calculated by the change in local frequency when the small object was introduced into the cavity leading to a change in the cavity stored energy (ΔU) as shown in Eq. (1), the Staler perturbation theorem [4, 5].

Bead Pull Measurement Set Up

The bead pull setup has been set to test a pillbox cavity and the RFQ cold model [2, 5]. At RAL, the bead pull layout was first designed to measure only one section of the RFQ. Then, it was reconstructed to cover all four modules.

The bead pull consists of three main parts: a Vector Network Analyser (VNA), LabVIEW software, and pulley system (a silver-coated bead, cotton thread, load and motors) (see Fig. 1). LabVIEW programme is written to control the pulley system, including collecting the measurement data from the VNA such as the frequency and S-parameters. The resonant frequency can be found by scanning the S-parameters through a range of frequencies. Controlling the bead position, five stepper motors have been used; one for longitudinal direction (z) and the others to control in transverse section (x and x' for horizontal and y and y' for vertical axes). This means there are five degrees of freedom.
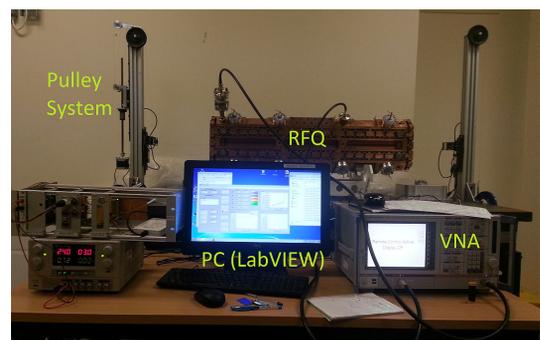
Figure 1: Bead pull set up for one-section of the RFQ.

The bead pull measurement was created for tests and for studying the tuner effect in one section of the RFQ.

It was then extended to cover the four-module RFQ. The new measurements (see Fig.2) with the new system were taken in the beamline. The layout needed to be reconstructed because of the limitation of the site space. However, only section 2 of the RFQ has been tested so far.

MEASUREMENTS AND RESULTS

This section demonstrates the results from the bead pull measurements. The data before and after the move will be shown, including the tuner effects of one section of the RFQ and the results of the shift in radius.
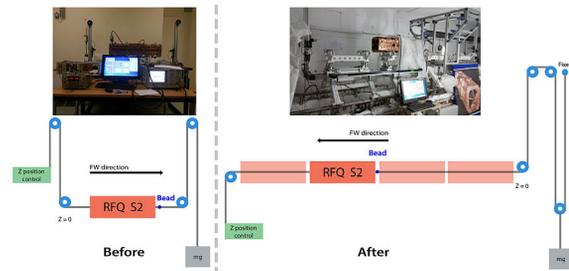
Figure 2: The change of bead pull measurement layouts from one-section to four-section of the RFQ.

Different Pulley Layout

The measurements before and after changing the bead pull construction have been measured in both forward and reverse directions. The results of data taken from quadrant 2 are shown in Fig. 3.
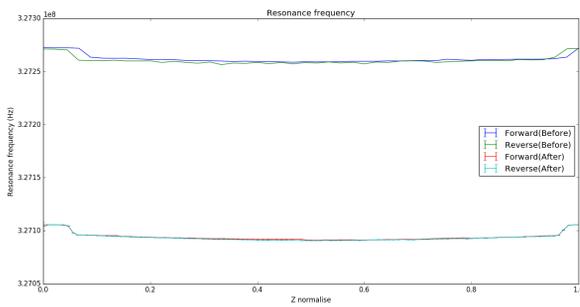
Figure 3: Resonant frequency against z position of quadrant 2 in different bead pull layout (forward and reverse).

The uneven lines similar to the one on the graph occurred in every result and seem to be caused by the pulley systems. However, the lines of the new measurement are smoother than the previous data.

The frequencies before and after differ by around 160-170 kHz. This might be due to several different factors, such as temperature, environment, different experimental area and bead position (errors from the bead pull axis which was manually adjusted).

The measurements have also been made in all four quadrants (Q1-Q4) with both forward and reverse directions both before and after the move (see Fig. 4 and Fig. 5). The trend of the frequency of each plot seems to be in a good agreement in both measurements. The data of Q1, Q4 and Q2, Q3 are close, respectively.

Tuner Effects

The tuners have been inserted from the RFQ wall to correct the uniformity of the fields along the RFQ. The idea behind this is that, a local frequency shift is produced to compensate the errors from manufacture and assembly. The 'zero' position of the tuners is partially inserted so they can move both in and out. The move of the tuner affects the volume of the cavity. For instance, the frequency increases when the volume is decreased.
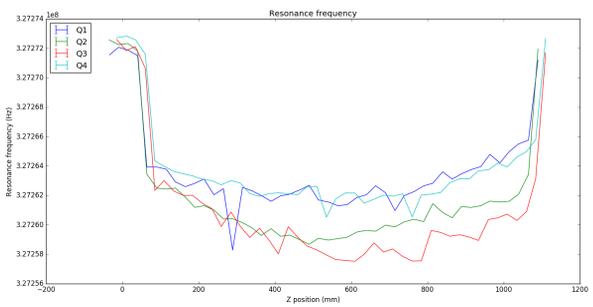
Figure 4: Frequency against z position of one-section bead pull measurement set in each quadrant (forward).
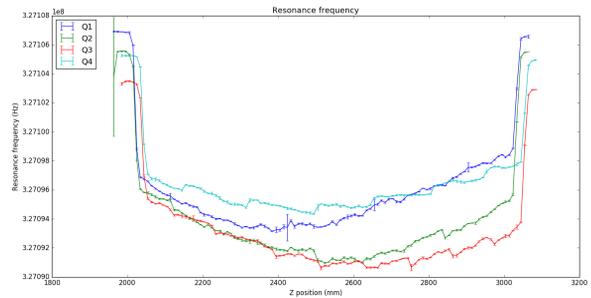
Figure 5: Frequency against z position of four-section bead pull measurement set in each quadrant (forward).

Before the length of the bead pull layout was extended to cover 4 modules, the tuner effects were studied. A third static tuner (T3) of quadrant 4 (Q4) was adjusted manually to measure the frequency (see Fig. 6). The length of the tuners from the RFQ surface was increased from 5, 10, 15 and 19 mm, respectively.

Figure 6: Slug tuner of the RFQ: 1 turn = 1 mm.

As shown in Table 1, it is clear that the frequency increases when the internal volume of the RFQ is reduced by the tuners. As expected, tuners affect the overall frequency. But there are only small changes in each tuner position as seen in Fig. Fig. 7: the ratio of frequency change ($\Delta f / f_{0mm}$) where f_{0mm} is the frequency of the tuner in zero position. This is because the measurement was done only on one section and without end-plates.

Radius Variation

After the bead pull layout has been moved to the actual site, the data was taken in the short range of z (100 mm) from the middle of the RFQ.

Table 1: LEngth of Tuner and the Average Frequency (Forward Direction)

Length of Tuner (mm)	Average Frequency (MHz)
0	327.58
5	327.62
10	327.68
15	327.75
18	327.81
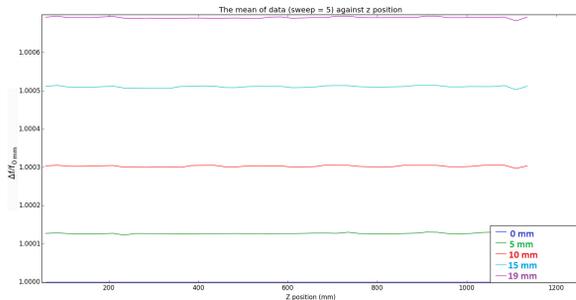
Figure 7: Results ($\Delta f / f_{0mm}$) of inserting the tuner 3 into the centre of the RFQ: 5, 10, 15 and 19 mm (forward direction).

The transverse radial offset of the bead was considered. With a one-mm step, the data was measured at various offsets from the beam axis in each z position as seen in Fig. 8. The data vary when the bead is adjacent to the centre of the RFQ. This is due to the effect of the vane modulations. Even though, we need to make the measurement in the strong filed which is between the vane tips, the region which is not affected by the modulation will be chosen. The measurements are also very sensitive to a small change in position.
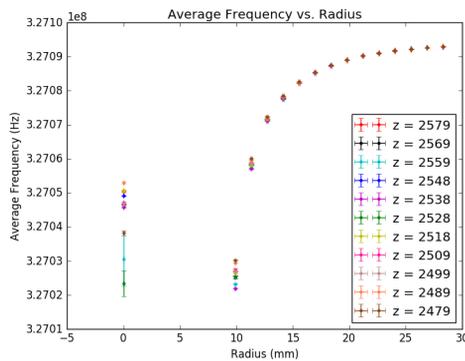
Figure 8: Radius against frequency in different z position when the bead is at 45° of the fourth quadrant.

Angular Variation

This study also considers an angular effect between the bead and the vanes. The data were taken when the bead was set to be 11 mm away the centre of the RFQ.

Figure 9 shows the results of sweeping the angle from 34° to 56° in 1° steps for each z position. The data show some variation. This is might be because the pulley axis
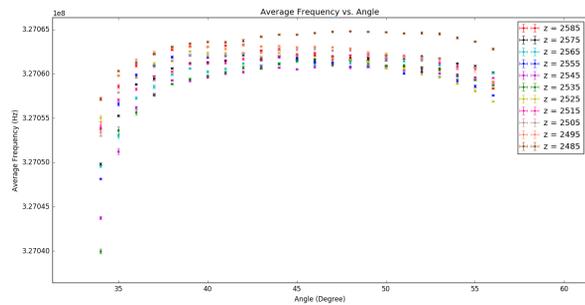
Figure 9: Angle against frequency in different z position when the bead is 11 mm away from the beam axis.

which was adjusted manually did not match the RFQ axis. Moreover, the hole of the bead is bigger than the thickness of the string. This means the bead hangs on the string. The actual position of the bead comparing to what it should be is changed as the function of the angle.

This is still not understood and is being studied using COMSOL Multiphysics [6]. After understanding the effect of the radius and angular variations, we will able to calculate the x-y offset between the RFQ centre and the bead pull axes.

CONCLUSION

The change of bead pull layout shows a similar trend before and after reconstruction. The length of the tuner from the RFQ surface affected the overall frequency, as expected. When the bead was close to the centre, the frequencies in each z position showed more variation.

The next step will be to make a bead pull measurement covering all four sections of the RFQ. In addition, a model created in COMSOL will be used to study the RFQ results and to provide the tuning average of the RFQ.

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