BEAD-PULL TEST BENCH FOR STUDYING ACCELERATING STRUCTURES AT RHUL

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Abstract

A bead-pull test stand has been constructed at Royal Holloway, University of London (RHUL) with the ability to provide electric field profile measurements along five degrees of freedom using the perturbation method. In this paper, we present example measurements using the test bench which include a field flatness profile of a 324MHz four vane Radio Frequency Quadrupole (RFQ) model designed as part of the Front End Test Stand (FETS) development at Rutherford Appleton Laboratory (RAL). Mechanical and operational details of the apparatus will also be described, as well as future plans for the development and usage of this facility.

INTRODUCTION

RF cavities can support various electromagnetic oscillations (so-called "modes"). For simple geometries, such as rectangular or cylindrical cavities, the shape of these modes in each of the appropriate degrees of freedom may be calculated analytically. Their excitation by a beam of charged particles may also be calculated by integrating the electric field along the path of the beam.

For more complicated cavity structures, where an analytical calculation of these modes is not normally feasible, a computer simulation, or direct measurement is required.

In order to measure such modes, a bead-pull facility has been constructed at RHUL with the ability to scan across five degrees of freedom in order to fully characterise the field profiles of RF cavities.

BEAD-PULL PERTURBATION TECHNIQUE

The standard bead-pull perturbation technique for measuring the electric fields versus position involves moving a small bead through the cavity.

A simplified schematic of the RHUL setup is shown in Figure 1. Five stepper motors are used to control the motion of the bead. Two pairs of motors are used to move the bead in the transverse direction. The thread is mounted on three pulleys and a rotary stepper motor attached to the transverse motors. The five motors means the setup can scan along five degrees of freedom, three degrees for x, y, z spatial movement and 2 degrees for x',y' angular movement.

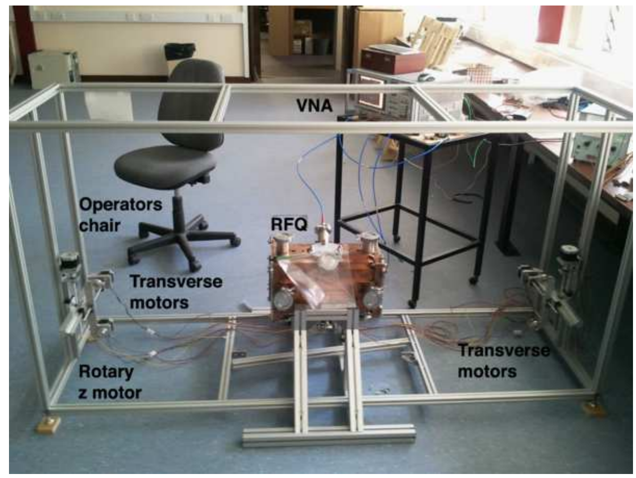

Figure 1: Existing bead-pull setup.

A synchronous movement of the transverse motors results in an offset along x or y while an asynchronous movement results in a angle variant in x' or y'.

A vector network analyser (VNA) is connected to a cavity port and the phase of the reflection coefficient is measured at the frequency of the unperturbed resonance [1].

$$\frac{\Delta\omega}{\omega_0} = \frac{\int_{\Delta V}(\mu_0 H^2 - \epsilon_0 E^2)dV}{\int_V(\mu_0 H^2 + \epsilon_0 E^2)dV} \tag{1}$$

A phase shift measurement was chosen rather than resonant frequency shift as the phase is significantly easier to detect.

$$\phi = \arctan\left[2Q\frac{\Delta\omega}{\omega_0}\right] \tag{2}$$

The system is operated by a program written in LabVIEW (version 8.5) which controls the motors and the VNA via an ethernet connect. The software has been setup to perform a scan in the longitudinal direction at any desired offset or angle. There is also the capability to perform a circle which is illustrated in Figure 2. The bead is moved along the transverse plane in a circular trajectory making it easy to determine the number of poles of a mode and therefore, it type.

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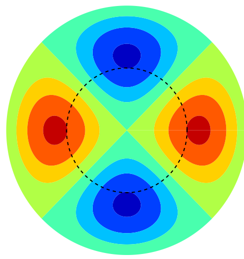

Figure 2: Quadrupole mode, black dotted line represents the motion of the bead for a circle scan.

PRELIMINARY RESULTS OF RFQ

Some preliminary scans have been performed on a radio frequency quadrupole (RFQ) which was designed as part of the Front End Test Stand (FETS) development at Rutherford Appleton Laboratory (RAL).

Initial scans were performed on a resonant mode at 319 MHz, given this was the frequency of the quadrupole mode found in [2]. Figure 3 shows a scan along the longitudinal direction of the cavity. The longitudinal scan exhibits an asymmetry which was observed in previous studies [3]. However, the effect is enhanced due to the scan being performed off-centre. Figure 4 represents a circle scan which appears to show this mode is dipole-like given that two poles can be seen.

A mode which was observed with a frequency of 328 MHz, however, shows feature of a quadrupole mode, Figure 5, with four poles clearly visible. Figure 6 shows a longitudinal scan performed once opposite poles were of similar magnitude indicating the bead is close to the centre. A flat and z-symmetric profile was measured for this mode.

The discrepancy between the these scans and previous studies in assuming the mode at 319 MHz is the quadrupole mode could be caused by a number of reasons.

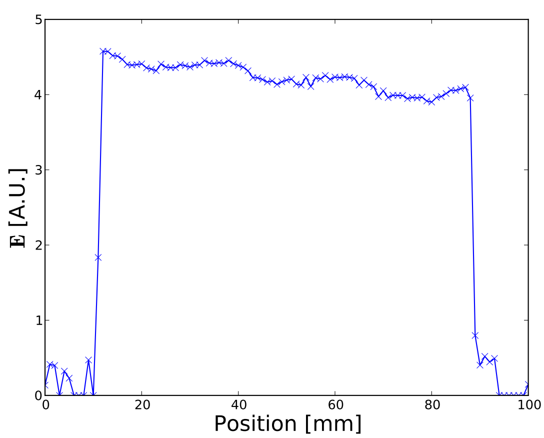

Figure 3: Longitudinal scan for a mode at 319MHz.

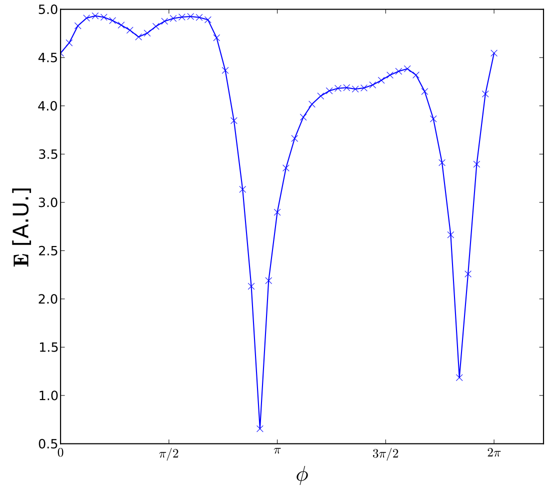

Figure 4: Circle scan for a mode at 319MHz.

The RFQ has been transported a number of times, and could have sustained damage leading to a change in resonant frequency. However, no obvious damage was observed that could cause a shift as large as 9 MHz. It is also possible that the mode at 328 MHz could be the second polarisation, and lower frequency polarisation could exist but was not observed due to the orientation of the loop coupler used.

Another possibility is that the previous studies lacked the ability to identify the mode type with no transverse scan possible.

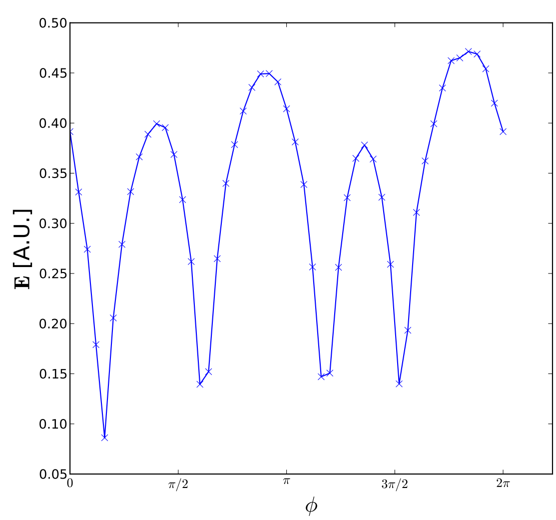

Figure 5: Circle scan for a mode at 328MHz.

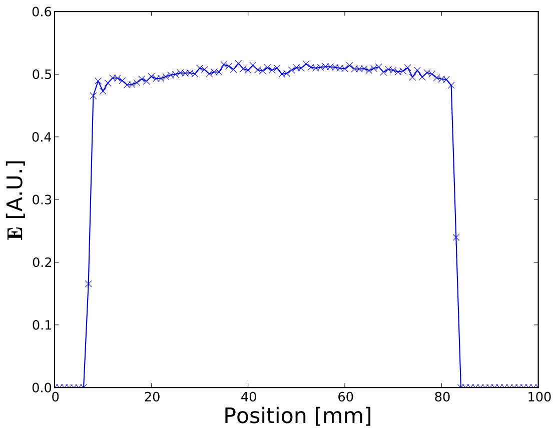

Figure 6: Longitudinal scan for a mode at 328MHz.

UPGRADES

The bead-pull system is currently in the process of being upgraded in order to address a number of problems that arose with the original design.

The current setup is susceptible to vibrational resonances which affect the stability of the bead and accuracy of the results. Initially, a delay was used in the software to allow the bead to become stable. The upgraded system will be constructed using two aluminium columns mounted on an optical table. One column will have mechanisms for X-Y and Z movement, the other column just X-Y movement. Constraining the system to just two structures makes it more portable and, with the addition of suitable mounting brackets, much less susceptible to vibrational resonances.

The test bench is required to be as generic as possible from the point of view of the cavity designs that can be accommodated. The current setup uses a thread mounted in a loop, which requires the top thread to always fit around the cavity. This means unique hardware has to be constructed for mounting different cavities. In the upgraded system the thread will be fastened directly to a nut on a threaded rod driven by a stepper motor, with the thread kept taught by a mass on the opposite column. This removes the problem of the thread slipping on a rotary motor eliminating read-back errors. The introduction of extra pulleys in a ‘block & tackle’ form will allow bead movement in the z direction to be greatly extended.

The bead position in the current system is calculated using the stepper motors’ step size and number of steps done. This is unsatisfactory since motors are liable to miss steps or slip particularly when under load. The initial idea was to use LVDTs to read back position for each motor; however the upgrades will use movers with built-in encoders simplying read-back and integration into the current software framework.

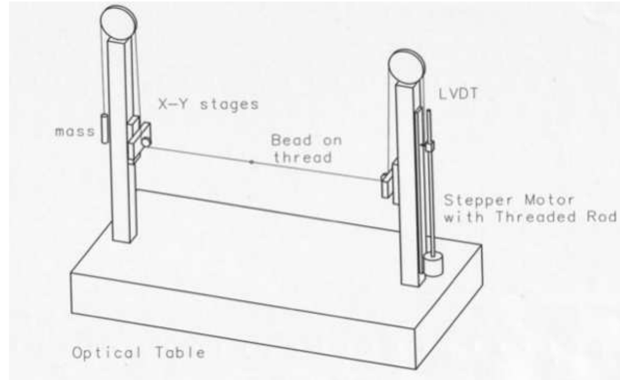

Figure 7: Proposed upgrade.

FUTURE WORK

With the inclusion of read back in the upgraded system, an automated centre finding algorithm can be included in the control software. The current planned algorithm would perform a circle scan identifying the poles of a mode. A linear scan between two opposite poles in the transverse direction can then be performed with the centre determined from the minimum of that scan. In the case of a monopole mode where there exists no opposite poles, a linear transverse scan be performed with the centre adjudged to be the maximum.

It is planned to continue to investigate the RFQ once the upgrades have been completed. Of importance is to investigate the reason for the discrepancies between previous results and those shown in this paper. A series of studies will also be performed in order to optimise the system to provide the greatest possible accuracy. These studies would include optimising the bead and thread used, as well as modelling the effect of the thread on the resonant frequency, and accounting for any effects that may arise from the thread ‘drooping’. The final aim is that the system will accommodate any RF cavity that is transported to the RF lab at RHUL.

REFERENCES

[1] D. Pozar, “Microwave Engineering”, 2004.

[2] S. Jolly, et al, “Detailed Study Of The RF Properties Of The FETS RFQ Cold Model”, THPP024, EPAC08.

[3] Y. Cheng, et al, “RFQ cold model RF measurements and waveguide-to-coaxial line transition design for the Front-End Test Stand at RAL”, TUPAS002, PAC07.