DETAILED STUDY OF THE RF PROPERTIES OF THE FETS RFQ COLD MODEL

S. Jolly, A .Kurup, D. Lee, P. Savage, Imperial College, London, UK
J. Pozimski, STFC/RAL, Chilton, Didcot, Oxon, UK/Imperial College, London, UK
A. Letchford, STFC/RAL, Chilton, Didcot, Oxon, UK
Y. Cheng, IHEP, Beijing, China

Abstract

A 324MHz four vane RFQ cold model has been built, as part of the development of a proton driver Front End Test Stand (FETS) at the Rutherford Appleton Laboratory (RAL) in the UK. Previous measurements to determine the electric field profile were made using the bead-pull perturbation method: these measurements have been refined and expanded. New measurements of the electric field profile, Q-value and resonant modes are presented. Measurements of the fundamental frequency and Q-value of the RFQ as a result of modifications to the profile of the end flange inserts are also given. Finally, an experiment is outlined to determine the beam transmission properties of the cold model based on beam transport simulations with the General Particle Tracer package (GPT).

INTRODUCTION

As part of the ongoing development of future high power proton accelerators (HPPA's) and to contribute to the UK design effort on the neutrino factory, the Front End Test Stand (FETS) is being constructed at the Rutherford Appleton Laboratory (RAL) in the UK. The aim of FETS is to demonstrate the production of a 60 mA, 2 ms, 50 pps chopped beam; a detailed description of the project and the current status is given in [1].

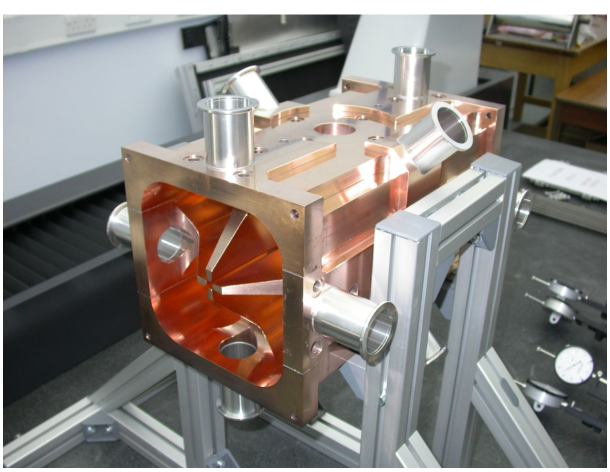


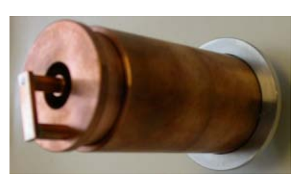
Figure 1: Brazed RFQ cold model and support stand.

To accelerate the beam up to the desired 3 MeV energy, FETS will utilise a 4-vane RadioFrequency Quadrupole (RFQ) channel, consisting of 4 resonantly coupled RFQ sections operating at 324 MHz. To allow RF measurements to be made, and to test the manufacturing process of the selected RFQ design, a copper cold model was designed and constructed. While electromagnetic modelling was carried out for both the 4-vane and 4-rod designs, the 4-vane model was selected for cold model testing due to the higher RF efficiency of this design and the ease of manufacture of any cooling channels. Details of the mechanical design of the FETS cold model are given in [2]. The fully brazed cold model is shown in Fig. 1.

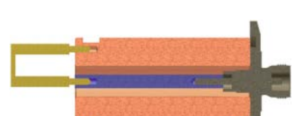
DESIGN MODIFICATIONS

Since the results presented in [3], two significant modifications have been made to the cold model: a new, dedicated RF input coupler and a series of end flange designs.

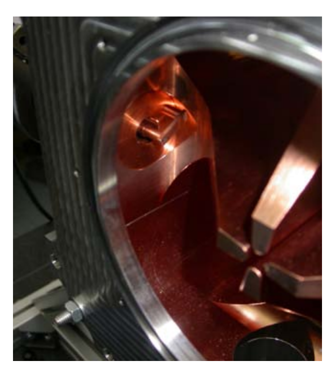
Input coupling was achieved for previous measurements with a simple wire loop. To improve repeatability of measurements a more robust input coupler was designed and built: this is shown in Fig. 2. The new coupler consists of an 80 mm long main cylindrical body, 40.75 mm in diameter, with a central 6.35 mm diameter coaxial core, coupled to the main body with a 5 mm diameter bridging loop. The dimensions were selected to maximise the occupation of the KF40 flange on the side of the RFQ, into which the coupler was inserted, one on either side; all components were machined from C101 grade oxygen free copper. The main body is mounted to a KF40 N-type connector and provides 50 Ω termination for the coaxial line.



(a) Input coupler.



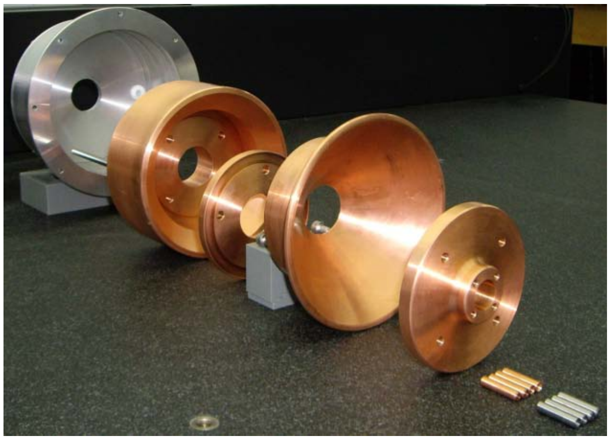
(b) Engineering cutaway.



(c) Coupler installed in RFQ.

Figure 2: New cold model RF input coupler.

The original RFQ cold model end flanges were made from 10mm thick stainless steel with a circular copper in-



(a) Left to right: end flange tube; hub; spacer (1 of 2); cone-shaped end flange; finger hub end flange; copper and iron fingers.

(b) Engineering cutaway drawing of finger (left) and cone (right) flanges.

Figure 3: New RFQ cold model end flanges.

sert with a central hole to allow for the bead pull experiment. The stainless steel plate sealed against the cold model using an O ring and the RF joint was maintained by the use of copper finger strips. In addition, 2 new end flange designs were employed in matching pairs at each end of the cold model: a cone-shaped flange insert and a flat insert with 4 removable fingers; these are shown in Fig. 3. Since the conventional tuning mechanisms can only increase the resonant frequency [3], the aim of both designs was to alter the capacitance and inductance of the RFQ, and hence decrease the resonant frequency [4].

The cone-shaped hub is a single copper piece with a maximum diameter of 141 mm, that introduces material into the cutaway sections of the RFQ vanes. The finger hub can be used with either copper or iron fingers, each 6 mm diameter and 25 mm long, or fingerless to allow it to be positioned very close to the vane tip. Both types of insert were mounted to a copper hub, with an optional pair of 7.5 mm thick copper spacers, that was itself mounted inside an aluminium hub that was fitted with guide pins running in PTFE bushes: this allowed the effect of the insert position with respect to the vane tips to be studied. RF contact between the inserts, the hub and the RFQ is provided by copper finger strips.

Table 1: Resonant frequency and Q-value for RFQ cold model bead-pull measurements.

	Frequency (MHz)	Q-value
CST Simulation [3]	319.7	9306
Brazed RFQ [3]	318.954 ± 0.1	5616 ± 50
Flat end plates	319.145 ± 0.1	7773 ± 30

RF MEASUREMENTS

Measurements of the electric field profile of the cold model were made using a refinement of the bead-pull perturbation method (details are given in [2] and [3]): a comparison between the new measurement and the CST simulation is shown in Fig. 4 (*cf.* Fig. 5 in [3]). The improvement in the field flatness and removal of the asymmetry in the field profile is attributed to an improvement in the electrical contact between the main body of the cold model and the end plates. In addition, both the resonant frequency and the Q-value have been improved to more closely match the simulation results: these are summarised in Table 1. Suppression of the dipole modes was also accomplished by electrically contacting opposing vane tips at the end of each vane with a wire loop.

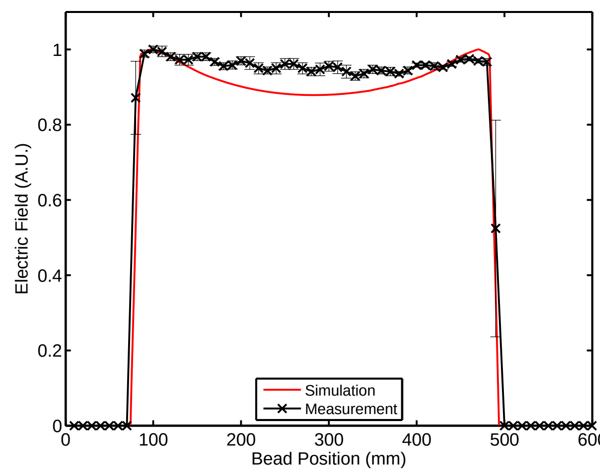


Figure 4: E-field profile for RFQ cold model simulation (red) and bead-pull measurement (black).

The effect of the different end flange designs on the RF properties of the cold model, as a function of the longitudinal position of the flange relative to the vane tips, has also been measured: results are shown in Fig. 5. The cone insert increases the resonant frequency of the structure at a rate of 60 kHz/mm as the cone approaches the vane tips, for a loss in Q of 40/mm. The quadrupole and dipole modes also separate at a rate of 90 kHz/mm. No major effect on the field-flatness has been observed. Difficulties coupling in the RF power whilst using the four-fingered insert have prevented results with this insert being obtained to date. However, measurements were made with the fingers removed from the insert (marked "fingerless" in Fig. 5). As with the cone insert, the field-flatness remains unchanged, but both the resonant frequency and Q-value decrease as the insert is

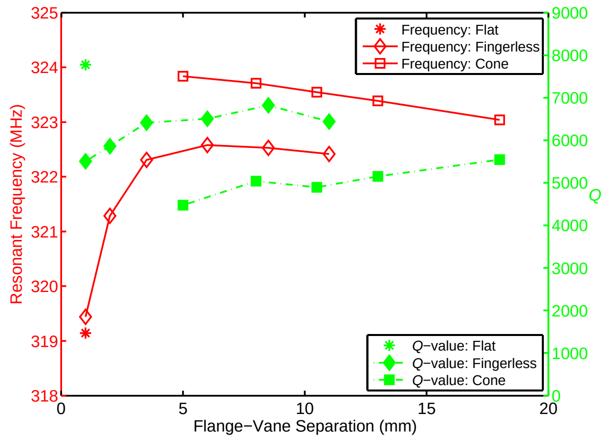


Figure 5: Variation in RFQ resonant frequency and Q-value as a function of the position of the 3 types of end flange.

brought closer to the end of the vanes. It is thought that the presence of the cone insert in the cut-away region of the RFQ vanes primarily decreases the inductance of the cavity, hence the increase in resonant frequency as the cone insert is introduced. The finger insert base, however, could be moved much closer to the vane tips, increasing the capacitance between the end plate and the end of the vanes, hence the shape of the initial part of the frequency curve in Fig. 5.

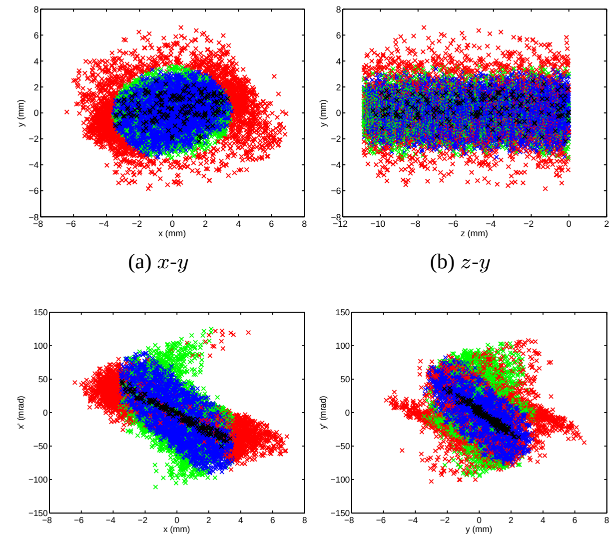
BEAM DYNAMICS SIMULATIONS

Simulations of the beam dynamics within the RFQ cold model have been carried out using the General Particle Tracer package (GPT). An E-field map was imported into GPT from the previous CST simulation [5], and further modified to match the RF conditions of the cold model setup. An RF input power of 43.9 kW is required for the real vane-to-vane voltage of 85 kV: the cold model power amplifier provides a maximum power output of 50 W, reducing the vane voltage by a factor of 29.6 to 2.87 kV.

The input beam was taken from recent measurements on the FETS ion source test rig [1], tracked through the FETS LEBT at a beam energy of 65 keV, then through the RFQ cold model field map as a single bunch, 10.9 mm in length (corresponding to 1 RF period), using 100% space charge. The results were compared to an identical simulation without RF power applied to the cold model. The results are summarised in Table 2. It is obvious from these simulations that, since the vane voltage of the cold model is much lower

Table 2: Beam properties for cold model simulation.

	Current	Beam size		ϵ (π mm mrad)	
	(mA)	x (mm)	y (mm)	$\epsilon_{x,rms}$	$\epsilon_{y,rms}$
Input	60	6.97	6.47	0.787	0.670
RFQ	0.94	3.43	3.26	0.106	0.113
Drift	0.58	3.24	3.20	0.040	0.024



(a) x-y (b) z-y

(c) x-x' (d) y-y'

Figure 6: RFQ cold model simulation input beam, colour-coded to show particles lost at the RFQ entrance (red), in the first 5 cm (green), in the rest of the RFQ (blue) and those that survive (black).

than the real FETS RFQ, particle losses are extremely high. These losses are shown even more clearly when plotted as a function of the input distributions, as shown in Fig. 6. The largest losses are seen at the RFQ entrance, since all particles greater than 3.6 mm from the beam axis are assumed to be lost on the RFQ vane tips. Additionally, no bunching is seen since the cold model has no vane modulations. However, even with such a low vane voltage, there is a measurable difference in transmitted current without any RF power (see Table 2). It is therefore predicted that, for an equivalent setup using the real FETS ion source and LEBT, with the cold model and power supply, a difference in transmitted current of ~ 0.5 mA will be observed.

CONCLUSIONS

Modifications to the cold model to improve the resonant frequency and Q-value have been carried out successfully: new measurements show better agreement to the predicted values. An experiment is planned to measure the beam transmission of the cold model with and without moderate RF power to compare to the simulation results.

REFERENCES

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[2] Y Cheng *et al.*, EPAC’06, MOPCH117, p. 318.

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