

THE MECHANICAL ENGINEERING DESIGN OF THE FETS RFQ

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Abstract

This paper will present the mechanical engineering design for a 324 MHz 4-vane RFQ, which has been developed for the Front End Test Stand (FETS) project based at the Rutherford Appleton Laboratory (RAL) in the UK. The design criteria will be discussed along with particular design features of the RFQ including the tuners, vacuum ports, main body cooling pocket design and the support/alignment structure. Different techniques for creating the RF and vacuum seal between major and minor vanes are also discussed.

INTRODUCTION

The RAL Front End Test Stand [1] is an experimental H⁻ ion accelerator front end. It consists of a 60mA H⁻ ion source [2], a laser diagnostics vessel [3] and a three solenoid magnetic Low Energy Beam Transport (LEBT) [4], which is currently being commissioned. Subsequently a 324MHz Radio Frequency Quadrupole (RFQ) and a Medium Energy Beam Transport (MEBT) [5] including a fast-slow chopping system [6] will be built.

The H⁻ ion beam is produced by the ion source and given its initial acceleration of 65keV. The beam then travels through the laser diagnostics vessel and on into the LEBT. Here the magnetic solenoids focus the beam and modify the emittance ready to enter the RFQ. During the first 1.5m length of the RFQ the ion beam is gently bunched before being accelerated to 3MeV. The ion beam is then transported through the MEBT.

The FETS RFQ is a four metre long vane type structure made from grade C10100 Oxygen Free Copper (OFC). It has four longitudinal sections of approximately equal length. Each section is identical apart from the amplitudes and cell lengths of the vane tip modulations which control the particle dynamics [7]. Each section is made from two identical major vanes and two identical minor vanes. The major and minor vanes must be joined together to form a vacuum seal and RF barrier. Each one metre section has several features including tuners, a vacuum port and cooling pockets. These features including the vane joining method and the lifting/support system will be described.

TUNER DESIGN

Each one metre RFQ section will have the capacity for sixteen plug tuners. One tuner will be moveable and will be positioned using feedback from a control circuit [8]. A linear shift mechanism ZLTM50W from Kurt Lesker [9] uses a stepper motor and an edge welded bellows flanged assembly to move the tuner. During assembly a bead pull test will determine the flatness of the electromagnetic field. The remaining 15 static plug tuners will be

machined to lengths determined by the results of the field flatness test. Both static and dynamic tuner plugs share a common design and therefore their positions are interchangeable. Each tuner consists of a hollow copper plug that is vacuum brazed to a modified DN40CF 304 s/steel blank flange. They mount to the RFQ via a modified DN40CF bored flange that remains in place on the RFQ. This minimises the mounting loads experienced by the relatively soft copper. The tuners have been designed to be water cooled if required, see Fig 1.

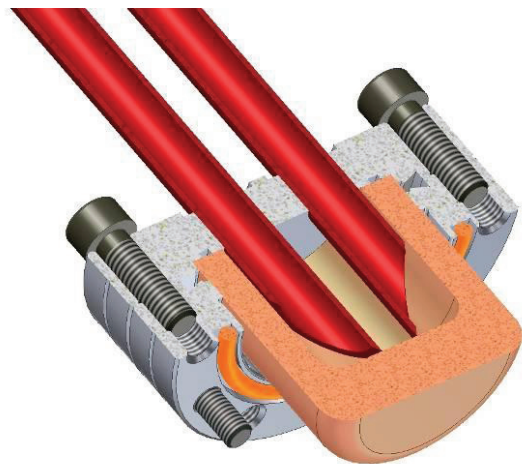


Figure 1: Section view of a static tuner.

VACUUM PORT DESIGN

The internal volume of the RFQ will be subject to a vacuum pressure of approximately 10^{-6} mbar. Without sufficient vacuum pressure the internal gas could become ionised by the high voltage potential which will provide a conductive path leading to an RF breakdown. One Oerlikon Leybold [10] TURBOVAC MAG W 830 pump (760 l/s for N₂) will be mounted vertically at the centre of each one metre RFQ section. To maximise pumping speed the pump is mounted directly to the RFQ via a DN160CF flange, the largest flange that will fit the RFQ width. The pumping holes are transverse slots, which will be manually radiused internally to reduce hotspots caused by concentrations of RF power. The webs between the pumping slots are cooled via holes that run the full width. The cooling holes are fed via a manifold that bolts to the RFQ sides and is sealed using rubber O rings, see Fig 2. Further CAD modelling and thermal FE modelling is planned to optimise the vacuum port opening size versus the space remaining for cooling channels. Additionally a calculation will be made to ensure that the vacuum pump standard debris mesh will prevent RF from travelling inside the pump.

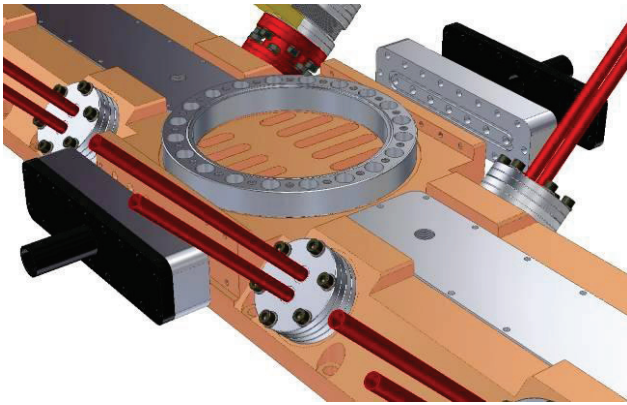


Figure 2: Vacuum port with cooling manifold

COOLING POCKET DESIGN

RFQs must be cooled to counteract the heating due to the power input. If not cooled the temperature rise causes the copper to expand which degrades the beam dynamics. Figure 3 shows the cooling pockets that will be machined into the copper from the outer surface [11]. The pockets extend towards the vane tips. These pockets are then closed using a bolted lid that seals using an ‘O’ ring. Baffles bolted to the underside of the lid direct the flow of cooling water.

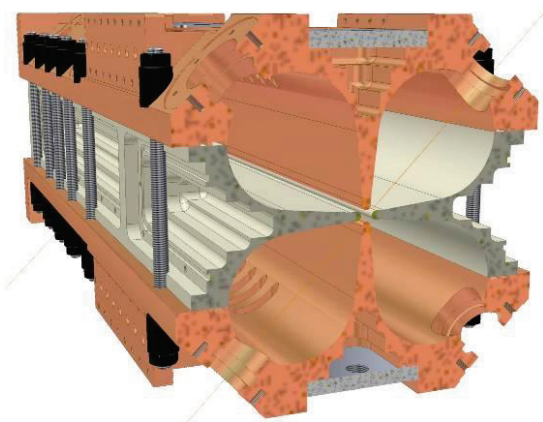


Figure 3: Transverse section showing cooling pockets

A squirt nozzle design is being investigated that mounts to the baffles and directs water flow to the vane cutback hot spot. There are several advantages of this design over the more traditional gun drilled cooling holes. These include:

- The cooling pocket can be accessed, for instance to clean the cooling channel or to change the baffle geometry and hence change the flow pattern.
- The vacuum port cooling channels can span the uninterrupted transverse profile, simplifying their design.
- Long gun drilled holes in copper drift from their axis necessitating an extra alignment step before machining.
- The use of baffles allows for a more concentrated flow of fluid towards the areas of heat concentration.
- The pockets can be manufactured using the same CNC milling machine as for the rest of the structure.

- Sealing gun drilled cooling holes often requires brazed blanking plugs that are on the vacuum side. The cooling pocket design avoids any vacuum to water interfaces.

HANDLING / ALIGNMENT / SUPPORT

The RFQ needs to be mounted to the FETS rail system, with each section aligned to the beam axis and to each other.

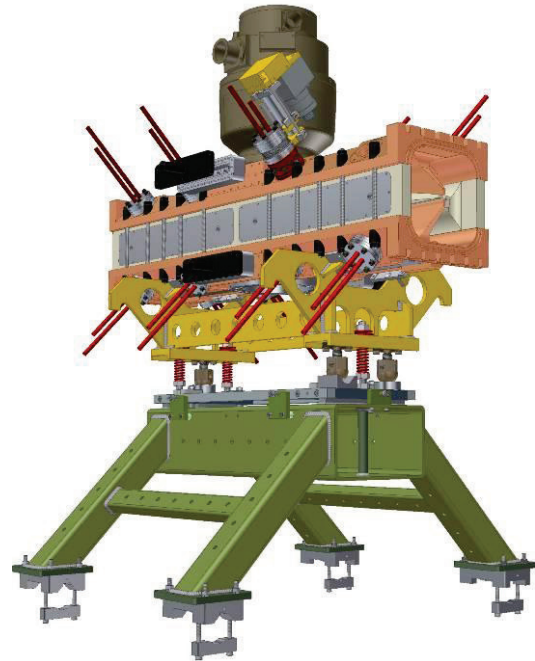


Figure 4: One metre RFQ section on support frame.

Figure 4 shows how each RFQ section rests in a welded steel cradle on four pads. The pads can be changed to suit minor design changes to the RFQ. The cradle has screw-jacks mounted to the underside that sit in guides. These provide height and rotational adjustment. The guides are mounted to an assembly that can be moved in the horizontal plane. Together they allow for a fully kinematic position adjustment. The kinematic mount sits on a welded steel framework that fits onto the main FETS rail system.



Figure 5: Complete RFQ support system installed at RAL

Figure 5 shows the mounting frames, kinematics and support cradles for the full length RFQ installed at RAL.

THE RF AND VACUUM JOINT BETWEEN VANE SECTIONS

RFQ structures need to be vacuum tight with few RF leak paths and have a high quality factor (Q). There are several alternative methods for joining together the RFQ major and minor vanes and each method has advantages and disadvantages. FETS is a research front end and as such the beam parameters may not always be optimal. For this reason the goal is to join the RFQ vanes in a non-permanent manner. This will enable the RFQ to be dismantled and re-polished in the event of an RF breakdown. In order to characterise the joining methods four scale models are being manufactured in Bilbao, see Fig 6.

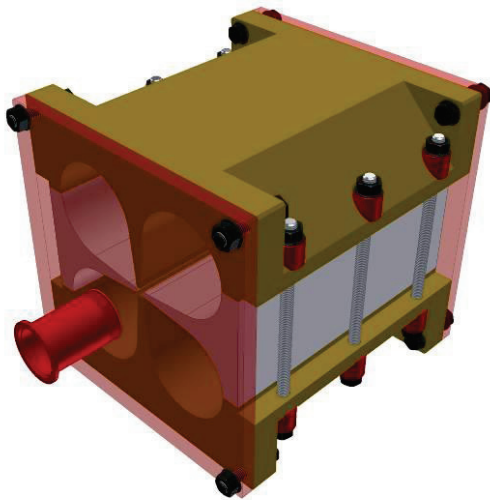


Figure 6: A 250mm long joint test model.

The four models will be used to test vacuum brazing, electron beam welding, laser welding and bolting. The vacuum braze model is included as a benchmark. RFQs are typically vacuum brazed because the process produces a clean continuous zero thickness high strength joint - resulting in high Q value. Electron beam welding would produce a structure that, as with vacuum brazing could not be dismantled. However, unlike vacuum brazing the heat affected zone is small (less than 2mm) and therefore deformations due to high temperature stress relief are minimised. Laser beam welding would be done from the inside of the RFQ. This is the challenge; the laser welding head needs to pass along the inside of the cavity. The resulting weld is shallow in depth and would need additional bolting to provide mechanical strength. However, it is envisaged that the shallow weld could be machined away in order to dismantle the RFQ. For the final method of bolting three types of RF and vacuum seal will be tested. These are using indium wire, using separate 'O' ring and contact finger strip and using Garlock HELICOFLEX [12]. The ultimate goal is to

design bolted joint that, if required can be additionally laser welded. When the joint test models are complete they will be transported to TWI [13] for joining.

PROGRESS SUMMARY

- The latest full length electromagnetic simulations have shown that the resonant frequency is too high at 338MHz. To bring the frequency back to 324MHz the internal profile will be enlarged.
- A combined electromagnetic, thermal and structural simulation has been produced showing that the cooling pocket concept with squirt nozzles can direct sufficient cooling to the RFQ hot spots. CFD calculations to verify the squirt nozzle flow dynamics is underway. Structural deformations will be fed back in to the electromagnetic model, effectively defining the structural tolerance.
- Tuning plugs have been manufactured and tested and are due to be vacuum tested. The automatic tuning mechanism has been sourced. The tuning feedback system has been developed.
- A vane to vane joint study is underway, the results from which will enable us to choose the most suitable joining method.
- Calculations to balance the vacuum pumping speed with sufficient vacuum port cooling are underway.
- Modelling to optimise the number of RF couplers is underway which will determine the coupler diameter. Once determined we will begin the engineering design.
- Provision to add Pi mode stabilizing rods if required will be added to the design.
- RFQ section supports and lifting cradles including kinematic mounts have been designed, manufactured and installed.
- Refinements to the RFQ particle dynamics will continue up until engineering drawings need to be produced for manufacture.

The FETS team are on schedule to start manufacture of one RFQ section by the year end. Upon successful manufacture, vacuum testing and RF testing we will proceed to manufacture sections two, three and four.

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