PRODUCTION OF THE FETS RFQ

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Abstract

The Front End Test Stand (FETS) project at RAL will use a 324 MHz 4-vane Radio Frequency Quadrupole (RFQ) to accelerate H- ions from 65keV to 3 MeV. This paper will report on the current status of the production of the FETS RFQ and will detail the manufacturing strategy used to produce the major and minor vanes. In addition the inspection results will be shown and the experiences from the assembly and alignment operations will be shared. Finally, the design of the bead-pull apparatus, end flanges, tuners and pick-ups required to measure the frequency and field-flatness of the assembled RFQ will be discussed.

INTRODUCTION

The RFQ for the Front End Test Stand project [1] is being manufactured. Since early in 2012, sixteen blocks of copper with a combined weight of 4 tonnes have been machined into 8 major vanes and 8 minor vanes. The vanes, when assembled along with hundreds of ancillary components, will form a 4m long, 4-vane RFQ. At NAB Precision Tooling Ltd [2], the bulk machining of the vanes is approaching completion. All machining operation types have been conducted and have been proven to work. RFQ section 1 is complete apart from end face machining, see Fig. 1.

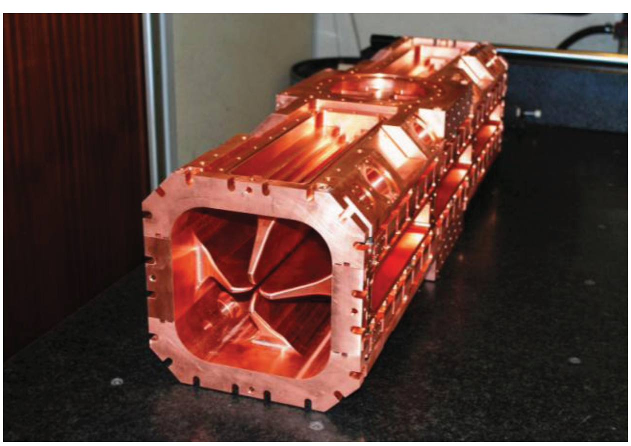

Figure 1: RFQ Section 1 assembled.

RFQ sections 2, 3 and 4 will be completed following verification of the inspection results. All external features including vacuum and tuning ports plus pockets for cooling have been machined in all sixteen RFQ pieces. The RFQ ancillary components for RFQ section 1 have been manufactured in the High Energy Physics workshop [3] at Imperial College, London. These components include the end flange assemblies, section-to-section flanges, tuner assemblies, RF pick-ups, vacuum port flanges, vacuum port cooling manifolds, as well as a lifting frame, alignment pieces and bead-pull measurement items. Additionally, a dedicated vane assembly jig has been manufactured. The cooling baffles are the final items to be manufactured. When each of these component types has been proven on section 1, the components will be produced for sections 2, 3 and 4.

MANUFACTURING STRATEGY

The manufacturing strategy was to gradually iterate towards the final major and minor vane geometry via a set of roughing operations [4]. All joints on the FETS RFQ will be bolted rather than using the more traditional joining technique of vacuum brazing and therefore there are no high temperature operations required during manufacture. The performance of the RFQ accelerator benefits from having a good interior surface finish, a high quality factor and good vacuum performance. These features are best achieved by preserving the hardness of the Copper. Furthermore, the stiffness of the vanes will remain high which improves assembly and handling plus the strength of tapped holes is increased. For these reasons annealing was not desirable and therefore induced machining stresses had to be minimised. A delicate machining approach over an extended period of time along with the natural thermal cycles caused by machining and changes in ambient temperature has effectively provided a low temperature stress relief. This has resulted in a very stable end product that shows little internal stress.

INSPECTION RESULTS

The first inspection has been completed and further work is underway to present the data in a concise format. Early indications are that the machining accuracy is very high with little or no measurable distortion. Surface finish is below that expected in the regions of the large radii that shape the quadrupole fields. This is due to the cutter linear speed approaching zero as the cutter radius approaches zero. Extensive machining tests were performed to minimise the effect but without great success. The FETS team are confident that the surface can be manually polished to create the design surface roughness of 1,6 microns Ra without pushing the RFQ out of its tuneable range of 500 kHz. The option remains to finish machine the interiors of sections 2, 3 and 4 using coolant which will greatly improve the surface finish

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though this will compromise the cleanliness of the bulk copper and will increase the commissioning time.

ASSEMBLY & ALIGNMENT

The first assembly of RFQ section 1 has been performed at NAB Ltd. Weighing 20kg each minor vane can be manually lifted into place. However, each major vane weighs 80kg and has the added complication that the top vane must be rotated through 180 degrees prior to fitting. This necessitated the manufacture of handling frame that can lift a major vane uniformly, allow rotation about its centre of gravity, and that will leave the major vane interfaces unobstructed so that it can be lowered into position onto the two minor vanes. Figure 2 shows the lifting frame being locked following the successful rotation of a major vane.

Figure 2: RFQ section 1 in the lifting frame.

RFQ ANCILLIARIES

Field-flatness measurement components

The existing bead-pull apparatus was extended to allow field flatness measurements [5] to be made on axis over approximately 1.3m. This length covers one RFQ section plus the end flanges. In order to compensate for the lack of vane cutbacks and to restore the frequency of an individual RFQ section to 324MHz, special end flange assemblies have been produced, see Fig. 3.

Figure 3: One bead-pull test end flange assembly.

The end flange was designed based upon simulations made using COMSOL software [6] and has been equipped with an adjustable central protrusion to allow for fine frequency tuning. Furthermore, the end flange assembly acts as the guide for the bead-pull line, ensuring it remains constrained to the beam axis. Alternatively, the guide can be replaced with a blank to achieve a vacuum seal if required.

End flanges

The RFQ input and output end flange assemblies have been manufactured. Both assemblies are identical. Figure 4 shows one end flange assembly prior to the vacuum brazing operation that closes the water cooling channel. The main flange completes the vacuum seal with the body of the RFQ. A removable water-cooled insert in the main flange enables internal fingers to be replaced. This will enable the FETS team to optimise the fields in the end regions without compromising the main vacuum seal. The insert also houses a toroid, enabling the RFQ input and output beam current to measured. The toroid closure plate contains a DN40KF flange for connection to a VAT Series 012 mini gate valve [7].

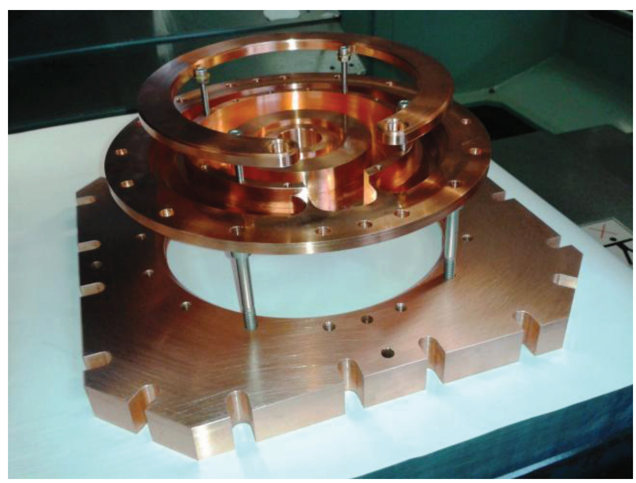

Figure 4: Exploded assembly showing the RFQ end flange components prior to vacuum brazing.

Tuners

The tuner design was reviewed after five tuner assemblies from a batch of sixteen were misaligned either prior to, or during the vacuum brazing process. The improved tuner assembly design does not require disassembly to introduce the braze paste and therefore the risk of misalignment is eliminated. The tuner design will be proven following field-flatness measurements and then the remaining forty-eight tuners will be manufactured and brazed by Tecvac Ltd [8].

Pick-ups

RF pick-ups have been designed to use a DN16CF flange. Each 1m long RFQ section has a total of eight ports that could be fitted with a pick-up. The unused ports will be fitted with blanking plugs. The pick-up assemblies use a rotatable flange and a bellows that allows the loop

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area protruding inside the RFQ to be optimised. Four pick-ups have been manufactured and are ready to be tested.

RF Coupler

The 500kW of peak power will be delivered to the RFQ will be shared between two couplers. The design uses tapered inner and outer conductors to reduce the size from a standard EIA 6/1-8" coaxial cable down to a DN40CF flange – the common port size on the RFQ. Figure 5 shows a side section view of the coupler design.

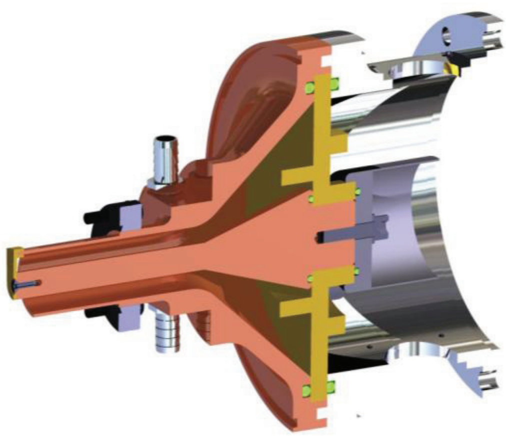

Figure 5: Section view of the RFQ Coupler.

The coupler has been designed to fit into any one of the sixty-four DN40CF 'tuner' ports in the RFQ. One design goal was to minimise the length of the coupler which reduces the indirectly pumped gas volume and reduces the assembly cost, machining time and coupler weight. The RF / vacuum window will be made from cross linked polystyrene Q200.5. This material has been chosen for its RF , mechanical and vacuum properties, plus availability, machinability and cost. The window has been shaped to maintain 50 ohms impedance and to increase the electrical path, reducing the possibility of breakdowns. Simulations show a power dissipation of 40W in the coupling loop leading to a 60^0C temperature rise. The 50 ohm geometry and small port size dictate an inner conductor diameter of 14,7mm and an outer conductor diameter of 34,0 mm which does not allow sufficient wall thickness for direct water cooling. Instead, a water cooled collar will be clamped around the outer conductor plus provision will be made on the air side of the coupler for forced air cooling if required.

NEXT STEPS

After completing the alignment and inspection of RFQ section 1 the final machining operation can be made – machining the end faces. The four assembled vanes will be machined as one unit to create a coplanar face which will ensure the best surface for obtaining a good vacuum seal. In addition to coplanarity, the faces must be perpendicular to the beam axis, parallel to each other and to the correct length and position relative to the vane modulations. An end face datum strip will be created using a SIP Hydroptic AF8 jig boring machine before being transferred to the Soraluce SP6000 for machining of the end faces, including the finger strip and vacuum sealing grooves. At this stage, the RFQ section will be fitted with dowel blocks that define the positions of the major and minor vanes. The RFQ will be delivered to the Rutherford Laboratories as an assembly both to protect the vulnerable vane tips and to benefit from the increased stiffness of the assembly. At RAL, the RFQ section will be inspected, then dismantled, fitted with the 3D rubber vacuum seal and finger strip and then reassembled to the dowelled alignment. Next the ancillary items previously discussed will be fitted. Finally, the RFQ will be bead-pull tested and vacuum tested. If required, the RFQ section can now be low power tested. When all tests are complete, RFQ section 1 will be positioned onto the FETS rail system and aligned to the beam axis. In parallel to these operations RFQ sections 2, 3 and 4 will be completed and delivered to RAL. After each section is tested and aligned to the beam axis it can be coupled to its upstream partner and sealed and vacuum tested as an assembly. This process will continue until the RFQ is complete.

A clean tent has been erected inside the experimental hall at RAL, complete with optical table and lifting apparatus. This will be the controlled environment within which the RFQ will be tested.

The design, installation and testing of the RF delivery system [9] is progressing in the experimental hall at RAL. This comprises of a circulator, waveguide and coaxial cable network. In parallel, a concrete radiation shield is being designed in collaboration with NELCO Worldwide [10]. The target date for completion of the RF system including partial shielding is the year end, coinciding with the completion of the RFQ.

ACKNOWLEDGEMENTS

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REFERENCES

[1] A. Letchford et al., "Status of the RAL Front End Test Stand", IPAC'13, THPWO086
[2] N.A.B. Precision Tooling Ltd, http://www.nabprecisiontooling.com
[3] High Energy Physics group, Imperial College London, http://www3.imperial.ac.uk/highenergyphysics
[4] P. Savage et al., "The Manufacture and Assembly of the FETS RFQ", IPAC'1 2, THPPP053
[5] S. Lawrie et al.,"Simulations to flatten the field of the FETS RFQ", IPAC'11, MOPC061
[6] COMSOL Ltd, www.uk.comsol.com/
[7] VAT Vacuum Products Ltd, http://www.vatvalve.com
[8] Tecvac Ltd, http://www.wallworkht.co.uk/
[9] S. Alsari et al., "FETS RF System Design and Circulator Testing", IPAC'13, WEPFI067
[10]NELCO Worldwide, http://www.nelcoworldwide.com