EMMA RF CAVITY DESIGN AND PROTOTYPE TESTING AT DARESBURY

C.D.Beard [#], N.Bliss, P.A.Corlett, D.M.Dykes, P.Goudket, C.Hill, P.A.McIntosh, A.J.Moss,
J.F.Orrett, J.H.P.Rogers, A.Wheelhouse, STFC Daresbury Laboratory, Warrington, WA4 4AD, UK
A.Bogle, T.Grimm, A.Kolka, Niowave Inc, Lansing MI, USA
E.Wooldridge, EDFA-JET, Culham Science Centre, Abingdon, UK

Abstract

EMMA (Electron Machine of Many Applications) is a prototype non-scaling FFAG (Fixed Field Alternating Gradient). It will contain 19 RF cavities operating at 1.3 GHz with a baseline accelerating voltage of 120 kVper cavity. A prototype copper cavity and an aluminium model have been manufactured by Niowave, Inc. to verify the RF calculations and manufacturing techniques. From experience with the aluminium model the cavity tuner was modified to provide a much larger tuning range, whilst maintaining as high Qo as possible. Low power tests of the prototype cavity have achieved a Qo of 20,500, measurements to characterise the cavity have demonstrated a shunt impedance of 2.1 MΩs. These were superior to the specification required for the accelerator. In this paper, the cavity design and cavity test results are discussed.

INTRODUCTION

EMMA [1] is a proof of principle non-scaling FFAG facility currently under development at Daresbury Laboratories. The accelerator consists of 19 normal conducting RF cavities placed in alternate cells around the 42-cell storage ring using 21 straights. Two cavities were omitted to allow space for beam injection and extraction. The cavities have to provide sufficient acceleration for a net gain of 2.3 MeV per turn with the potential to accelerate up to 3.4 MV per turn, equivalent to a peak voltage of 180 kV per cavity.

To study the operational performance of the accelerator, a large tuning range was desirable, as well as the ability to upgrade the acceleration per turn in order to study the rate of acceleration. EMMA uses ALiCE (Accelerators and Lasers in Combined Experiments) [2] as the injector and will be located inside the same accelerator hall. The space availability is very constrained restricting the size of the ring.

Due to the compact nature of EMMA, certain geometrical constraints restricted the cavity design. The beam has a large divergence, and as a result the beam pipe aperture had to be a minimum of 40 mm in diameter. Also the longitudinal space including cavity flanges was 110mm. Both dimensional have a large effect on the shunt impedance, and therefore careful assessment of the geometry was carried out to optimise the efficiency.

RF DESIGN

For the cavity a number of constraints and requirements influenced the design of the final cavity. The cavity design was constrained to a 40 mm diameter beam pipe and had to be less than 110mm flange to flange. Each cavity had to be adjustable in operating frequency from 1296 MHz to 1301.5 MHz. Optimisation of the cavity shape lead to an improved shunt impedance on the ELBE Buncher cavity [3] by almost three times. The final cavity geometry including manufacturing technique is shown in Figure 1 below.

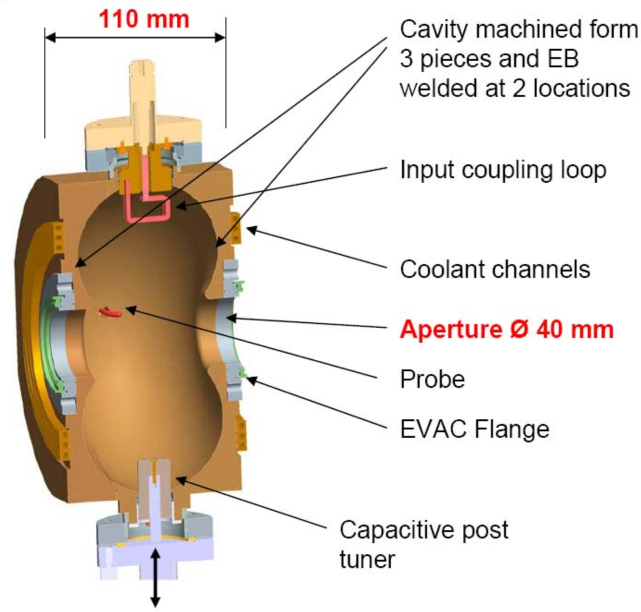

Figure 1: Cross-section of the final RF cavity design

The cavity adopts a torus shape in order to maintain the highest efficiency possible. The beam pipe aperture and short beam tube length from using EVAC flanges has meant that the cavity was able to be electron beam welded, avoiding the use of brazing materials that could potentially introduce losses into the structure.

Cooling channels have been applied to both sides of the cavity to maintain symmetric cooling, although with the low average powers RF heating should not be an issue.

To further improve the Q of the cavity, the prototype cavity was chemically etched. Measurement of the Qo before and after etching showed an increase of Qo of over 7%, thereby reducing the total RF power required.

Parameter	Value	
Frequency (GHz)	1.3	
Shunt impedance (MΩ)	2.05	
Q_0	20500	
R/Q	100	
Tuning Range (MHz)	-4.0 to +1.6	
Accelerating Voltage (kV)	120	180
Power to generate voltage (kW)	3.6	8.1
Power including overhead	4.7	10.5

TUNER

In order to allow tuning of the cavity, a plunger-tuner is placed on the cavity equator to be able to adjust the inductance on the cavity surface and hence change the resonant frequency. The original tuner design provided a tuning range just within the cavity parameters of -4MHz to + 2 MHz. Upon manufacture of the aluminium prototype at Niowave Inc., the mechanical tolerances meant that the design goal could not be achieved. A redesign of the tuner was performed to increase the tuning range such that the mechanical tolerances of the cavity could be reduced whilst still meeting the full tuning specification.

The tuner design can be seen in Figure 2 below. This shows the maximum and minimum designed penetration, with a full extension into the cavity of 20 mm.

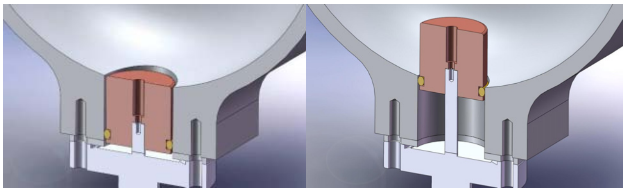

Figure 2: Modified larger Tuner

The increase in tuner diameter provided a much larger tuning range without reducing the Qo significantly. The full tuning range as a function of penetration into the cavity is shown in Figure 3. By considerably increasing the tuning range to 1300 MHz ± 7 MHz, meant that the tolerances on the cavity shape could be reduced, consequently reducing the cost for the production cavities.

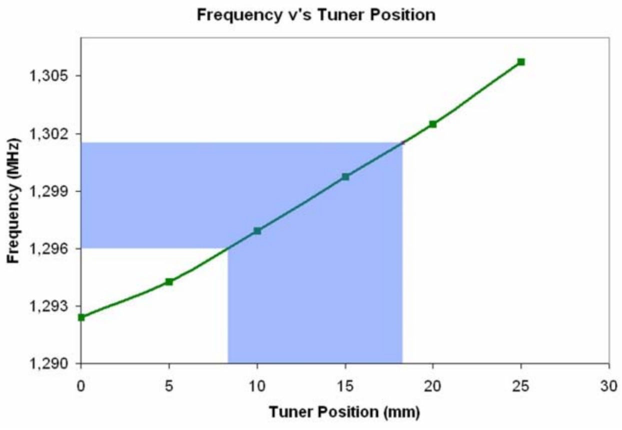

Figure 3: Tuning range

FUNDAMNETAL POWER COUPLER

A coupler design was required to ensure optimum coupling to the RF cavity over the RF bandwidth desired for the cavity, in order to minimise reflections and avoid breakdown. An inductance loop was adopted that couples to the cavity magnetic field since this design is also more rigid and easier to adjust than an electric probe penetrating into the cavity.

An RF feedthrough is required as part of the coupler design to provide a necessary vacuum seal, since the cavity is held at ultra high vacuum levels. The feedthrough needs to be able to withstand over 10 kW peak power at 1.3 GHz. An appropriate feedthrough design has been demonstrated on the PEP-II longitudinal feedback kicker cavities at SLAC[4]. Such feedthroughs have since been procured from Times Microwave, ready for high power validation.

Figure 4: EMMA High Power Coupler

R/Q MEASUREMENT

In order to measure the shunt impedance of the cavity, a bead pull characterisation of the aluminium model has been performed. Since R/Q is purely dependant on cavity geometry, this information can then be used to predict the performance of the final copper, welded and etched prototype cavity.

As a bead of known size is drawn through the centre of the RF cavity, the bead displaces the RF frequency which is measured as a function of distance along the beam axis. Equation 1 is then used to convert the change in frequency into a real time R/Q measurement for the structure. For increased accuracy the rate of change of phase was used.

Equation 1 R/Q calculation of the monopole mode.

$$\frac{R}{Q} = \frac{1}{2\pi r^3 \omega \varepsilon}\left[\int_0^L \pm\sqrt{\frac{\Delta f}{f}}.dl\right]^2$$

The measurement was taken with two different bead sizes in order to confirm the value with the simulations. The phase change as a function of distance through the cavity is displayed for two bead sizes on figure 5 below this value is then calibrating for the size of the bead. An integration of the phase change yields an R/Q value of 100 for the cavity.

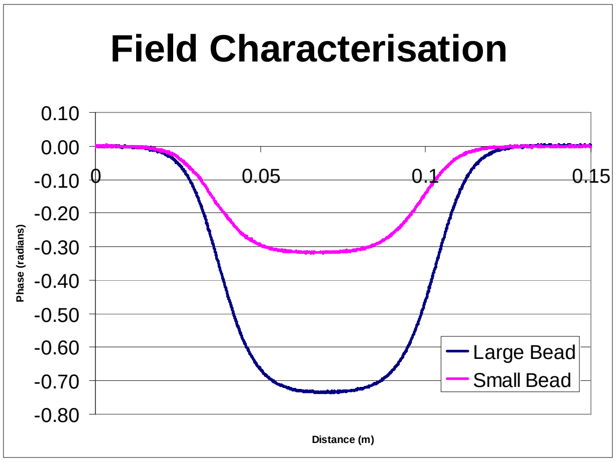

Figure 5: Bead pull measurement for the EMMA aluminium cavity

The cavity was evaluated using two different size metal beads, calibrating for the size of the bead and the expected frequency shift, the results predicted an R/Q of 100 Ω. This showed only a 7% drop from the calculated values using Microwave Studio.

COPPER PROTOTYPE TEST RESULTS

Once the frequency shift was measured, the linear actuator was run through its full range of motion on the prototype, yielding a tuning range of 8 MHz over a distance of 12 mm, compared to the specification value of 5.6 MHz. The tuning range is centred on the mid-frequency of the desired tuning range, 1298.75 MHz. The loaded Q of the cavity was measured simultaneously during the final tuning range checks, which showed a variation of 10,250 – 9,800 MHz from 1296 – 1301.5 MHz. Practical measurement also showed a much less than expected drop in Q_0 over the full range. These results are displayed in Figure 6.

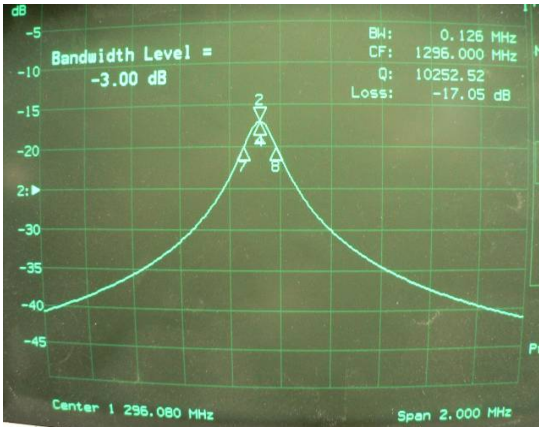

Figure 6: Cavity measurements

The finished prototype cavity is photographed in Figure 7. This shows the stepper motor used to remotely adjust the RF frequency by driving the tuner post.

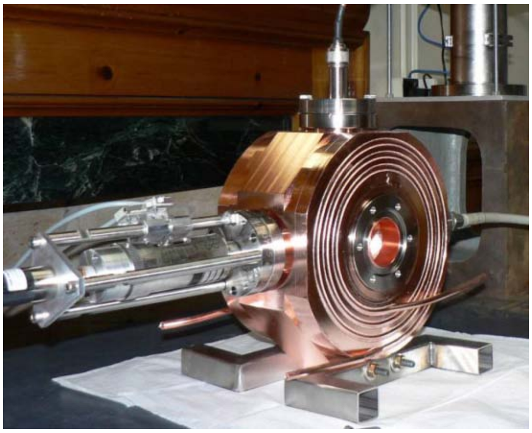

Figure 7: RF Cavity Prototype

CONCLUDING REMARKS

The EMMA cavity has now been characterised for frequency, tuning range, Q and R/Q. Final RF tests to be performed on the RF cavity will be the RF testing to verify the performance at higher powers and to ensure the cooling channels are adequate for operation.

The success of the chemical etching has been essential to minimise the RF power for the system. Since there are a large number of cavities are on the accelerator the overall gain is vast.

REFERENCES

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[4] P.A.McIntosh et al “An over-damped cavity longitudinal kicker for the PEP-II LER” proceedings of PAC 2003. pages 3141-3143