DESIGN OPTIMISATION OF THE RE-BUNCHING CAVITIES FOR THE FRONT END TEST STAND AT RAL

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Abstract

The Medium Energy Beam Transport (MEBT) line for the Front End Test Stand (FETS) at Rutherford Appleton Laboratory (RAL) will transport a 60 mA, 2 ms, 50 pps H^- beam at 3 MeV. Its main components include a number of quadrupoles, re-bunching cavities and a fast-slow chopping system with dedicated beam dumps, as well as a diagnostics beam line. In this paper we present the design approach for the MEBT re-bunching cavities. A description is given for the proposed geometry and the main design choices are examined. In addition, the latest RF simulations results performed with 2D and 3D electromagnetic codes are presented including optimisation details and manufacturing plans.

INTRODUCTION

The development of high power proton accelerators (HPPAs) has increased significantly especially in the last decade. Facilities like SNS are already delivering beams in the MW range and J-PARC is currently working on the construction of a 400 MeV linac upgrade to ramp up its power to a similar level.

The Front End Test Stand (FETS) project at Rutherford Appleton Laboratory is the main HPPA R&D project in the UK [1]. It represents the national commitment to the development of a next generation high power, high intensity proton accelerator and at the same time prepares the way for a future upgrade for the ISIS spallation source and for the development of a proton machine as the driver for a proposed neutrino factory.

When completed, FETS will consist of an H^- Ion Source, a Low Energy Beam Transport Line (LEBT), an RFQ and a Medium Energy Beam Transport line (MEBT). The ion source will generate a 65 keV, 60 mA, 2 ms, 50 pps H^- beam which will be focused and matched into an RFQ by a three-solenoid LEBT. The 4 m long, 324 MHz RFQ will bunch and accelerate the beam up to 3 MeV. The RFQ will be followed by the MEBT line which houses two choppers with dedicated beam dumps and it will transport the beam through a comprehensive set of diagnostics and into a dedicated target area, or matches the beam to the next accelerating structure. A schematic layout of FETS can be seen in Fig. 1.

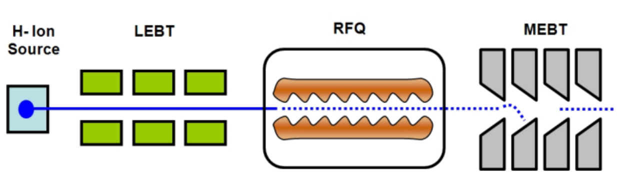

Figure 1: Schematic layout of the Front End Test Stand.

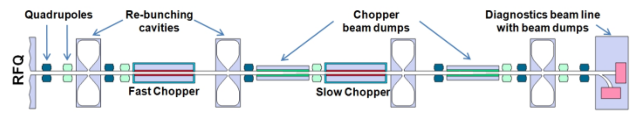

Figure 2: Schematic drawing of the FETS MEBT line showing the main components.

CAVITY DESIGN CONSIDERATIONS

One of the key components of FETS is the MEBT line [2]. The most advanced MEBT scheme consists of 11 quadrupoles, 4 re-bunching cavities a fast-slow beam chopping system consisting of two electrostatic choppers with dedicated beam dumps and a diagnostics beam line (Fig. 2).

As the beam proceeds through the chopper line, the re-bunching cavities maintain the longitudinal focusing and match the beam from the RFQ into the MEBT and from the MEBT to the any subsequent accelerating structure.

The main cavity requirements have been specified by the MEBT beam dynamics design: a resonant frequency of 324 MHz, a minimum aperture of 30 mm and an effective voltage of 160 kV.

In addition, in designing the cavities, we have taken the following guidelines into consideration:

- A high shunt impedance is desirable to reduce power consumption and simplify cooling.
- Electrical discharge (sparking) must be avoided by limiting the peak surface electric field. A maximum accepted value of 1.5 for the Kilpatrick limit has been chosen.
- Mechanical design: the cavities have to fit inside the physical limits imposed by the MEBT optical design.
- Manufacturing: consider the available cooling options, tolerances and generally ease of manufacture.

ELECTROMAGNETIC MODELLING

Different possible cavity types have been evaluated and a decision has been made to adopt a single gap pillbox type cavity with nose cones [3].

In order to meet the design specifications, various optimisations of the geometry have been performed, using Poisson Superfish [4], a well established 2D EM code. 3D simulations have also been carried out in order to confirm the chosen configuration, using Ansoft HFSS [5] and CST Microwave Studio [6]. A cavity cross section as modelled by Superfish can be seen in Fig. 3 which shows the outline of the right half of the cavity.

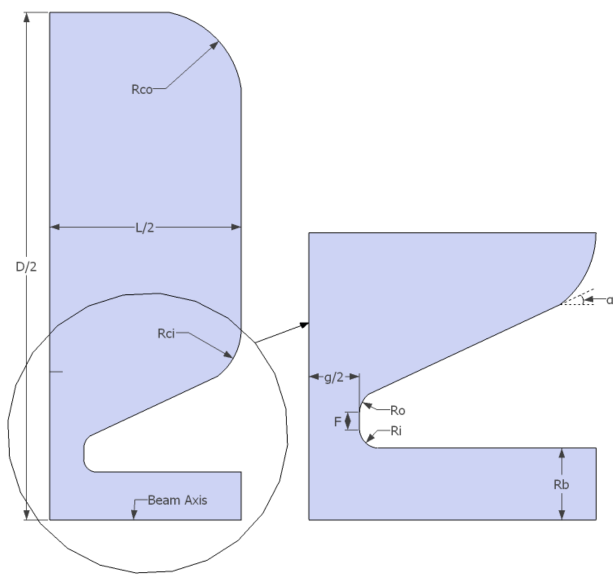

Figure 3: Cavity cross-section as modelled by Superfish. Main parameters: Rco - Outer corner radius, Rci - Inner corner radius, L - Cavity length, D – Diameter, Rb - Bore radius, F - Flat length, Ri - Inner corner radius, Ro - Outer corner radius, α - Cone angle, g: Gap length.

Optimization Procedure

To ease and facilitate the optimal choice of parameters in this multidimensional simulation space, a script was developed using Visual Basic. The script allows multiple simulations to be performed automatically choosing the starting, final and step values for each variable.

Each parameter was thus simulated and its effects independently studied. Figure 4 shows the relationship between the cavity length and the effective shunt impedance per unit length for a given geometry as calculated by Superfish. As it can be seen, the shunt impedance increases with length, therefore an elongated cavity is desirable within certain limits. However, due to space restrictions in the MEBT line, this parameter had to be limited to ~ 15 cm.

For the given value of 15 cm, a full set of values for each of the six variable parameters (gap, inner and outer corner radius, inner and outer nose radius, flat length and cone angle) and all their combinations were tested, with the aim of covering the full range of possible cases. For each simulation run, the resonant frequency of 324 MHz was achieved by adjusting the cavity diameter. An example of possible combinations of parameter values can be seen in Table 1.

Table 1: Example of Possible Parameter Combinations Tested with Superfish

Gap (cm)	Cone Angle (º)	Inner Corner Radius (cm)	Outer Corner Radius (cm)	Flat (cm)	Outer & Inner Nose Cone (cm)
1.1	0	2	6.2	0	0.3
1.2	5	3	7.2	0.1	0.4
1.3	10	4	8.2	0.2	0.5
1.4	15	5	9.2		
1.5	20	6			
1.6	25	7			
1.7	30	8			
1.8	35				
1.9					
2.0					
2.1					

The gap length is an important parameter and its choice merits special attention. As already mentioned, the nose cones concentrate a high electric field in the gap region. This makes the mechanical design and construction of the nose cones particularly challenging as tight tolerances are required in order to avoid the distortion of the field lines in the gap region and the resulting resonant frequency change. Decreasing the gap length has the effect of increasing the transit time factor and consequently the effective shunt impedance. However, a small gap increases the peak surface electric field, which can result in electric breakdown. Also if the gap becomes too small, the voltage gain in the cavity is significantly reduced. Figure 5 shows the Kilpatrick factor and shunt impedance variation with gap length. As it can be seen, setting an upper limit for the Kilpatrick factor of ~1.5 puts a lower limit on the gap length of ~1.6 cm.

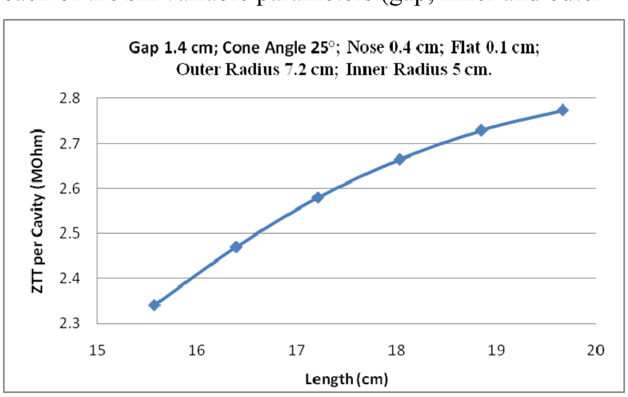

Figure 4: Effective shunt impedance per cavity as a function of cavity length.

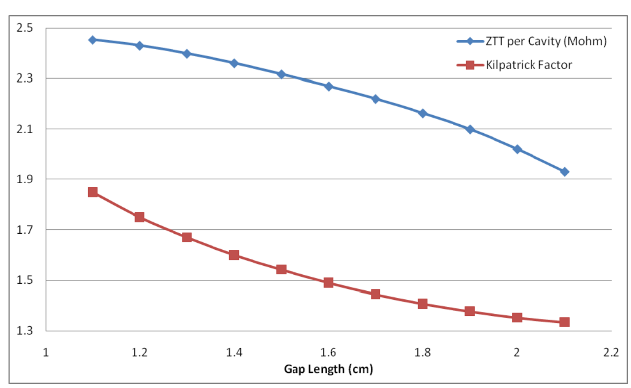

Figure 5: Kilpatrick factor end effective shunt impedance variation with gap length.

After the full set of simulations was finished, we have observed that the highest shunt impedance values always correspond to a cone angle of 0º. However this particular configuration reduces the nose cone dimension to ~1 cm in the radial direction. This can result in a much more fragile mechanical structure as well as making cooling of the nose tip region much more difficult. As a result the nose cone was increased to 25º leading to a reduction in shunt impedance of about 10%. A summary of the RF and geometrical properties of the cavity is given in Table 2.

Table 2: Cavity RF and Geometrical Properties

Parameter	Value
Frequency (MHz)	324
Effective Voltage (kV)	160
Q	27815
ZTT (MOhm/m)	15.158
ZTT per Cavity (MOhm)	2.27
Kilpatrick / Peak Electric Field (MV/m)	1.49 / 26.54
Power dissipation (kW)	10.99
r/Q (ohm)	40.87
Maximum Power Density (W/cm^2)	5.69
Cavity Diameter (cm)	60.60
Bore Radius (cm)	1.5
Cavity Length (cm)	15
Gap Length (cm)	1.6
Inner Radius (cm)	2
Outer Radius (cm)	7.2
Flat Length (cm)	0.1
Nose Cone (cm)	0.3
Cone Angle (º)	25

Code Comparison

3D software has been used for problems that lack cylindrical symmetry and can't be simulated with 2D codes, like the effect of tuners, pumping holes, etc. HFSS and MWS models showing the electric field in the cavity can be seen in Fig. 6. Much effort has also been put into confirming the Superfish calculations discussed above. Table 3 shows the main RF parameters of a cavity simulated with three codes already mentioned, while Fig. 7 shows the electric field on axis. The initial results are encouraging and show an acceptable degree of agreement. We believe that the small discrepancies are cause by differences in the mesh density as well as the different methods used by the codes for field normalisation.

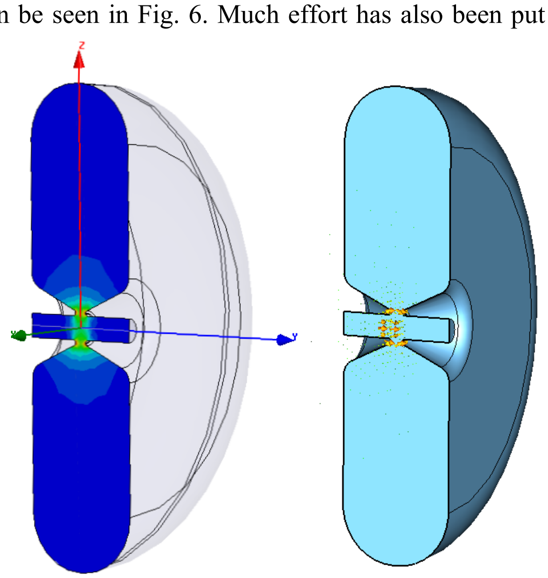

Figure 6: 3D models of the chosen cavity geometry from HFSS (left) and Microwave Studio (Right).

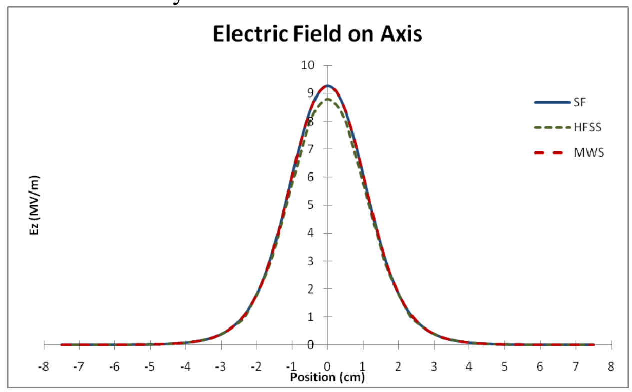

Figure 7: Electric Field on Axis as calculated by Superfish, HFSS and Microwave Studio.

Table 3: Cavity RF Parameters from SF, HFSS and MWS

Parameter	SF	HFSS	MWS
Frequency (MHz)	324.0	323.961	324.103
Q	27815	27812	28150
Shunt Impedance (MOhm)	6.04275	5.9874	5.984
Power Dissipation (kW)	11.26	10.32	11.13
Stored Energy (J)	0.154	0.141	0.154*
Axial Voltage (kV)	260.85	248.62	258.06
Effective Voltage (kV)	160.0	152.5	158.3
Peak Electric Field (MV/m)	26.546	26.546*	29.334
E0 (MV/m)	1.74*	1.66	1.72

* normalisation parameter

CONCLUSIONS AND FUTURE WORK

The work on the re-bunching cavities for the FETS MEBT line has been progressing well. However, before making a decision on a full scale prototype, the accuracy of our EM simulations will have to be checked against real measurements. To do this we plan to build a cold model which could also be a useful mechanical design and machining exercise as well as an indication of the tuning requirements and available manufacturing options.

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