RE-BUNCHING RF CAVITIES AND HYBRID QUADRUPOLES FOR THE RAL FRONT-END TEST STAND (FETS)*

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Abstract

The proposed FETS project at RAL will test a fast beam chopper in a 3.0 MeV H$^-$ Medium Energy Beam Transport (MEBT) line. Space restrictions in the MEBT line place constraints on component length and drive the requirement to identify compact component configurations. A description is given of candidate re-bunching RF cavities and hybrid quadrupole designs. The cavity options considered are the space efficient Drift Tube Linac type cavity (DTL) with integrated quadrupoles, and the high shunt impedance Coupled Cavity Linac type cavity (CCL) with external quadrupoles. The advantages and disadvantages of both structures are discussed and a comprehensive comparison between the two is made enabling the best cavity geometry choice. The compact hybrid quadrupole configurations considered are the 'tandem' combination of permanent magnet (PMQ) and electro-magnetic (EMQ) types, and the concentric combination of PMQ and laminar conductor (Lambertson) EMQ types.

INTRODUCTION

The international community has been showing a growing interest in high power proton accelerators (HPPAs), capable of producing beams in the MW range. Many applications have been identified including drivers for spallation neutron sources, production of radioactive beams for nuclear physics, hybrid reactors, transmutation of nuclear waste, and neutrino factories for particle physics [1]. For all these applications, high quality beams are essential. Significant technical development is necessary, especially at the front end of the accelerator where low energy (2.5 – 3 MeV) beam chopping at high duty cycle (1 – 10%) is required to minimise beam loss and the induced radioactivity at injection into downstream circular accelerators.

With the Spallation Neutron Source (SNS) in the USA and the Japan Proton Accelerator Research Complex (JPARC) due to deliver high-power beams in the near future, the RAL FETS project [2] demonstrates the UK commitment for development of HPPAs, preparing the way for a European next generation spallation source and a neutrino factory.

The MEBT chopper line is one of the key parts of FETS and it consists of a series of quadrupoles, RF cavities and a novel "fast-slow" beam chopper system [3]. In order to minimize emittance growth, halo formation and subsequent beam loss in the downstream linac, the MEBT optical design must be as short as possible, imposing the necessity of compact beam-line components. Two possible MEBT layouts are illustrated in Figure 1, showing the reduction in length using a

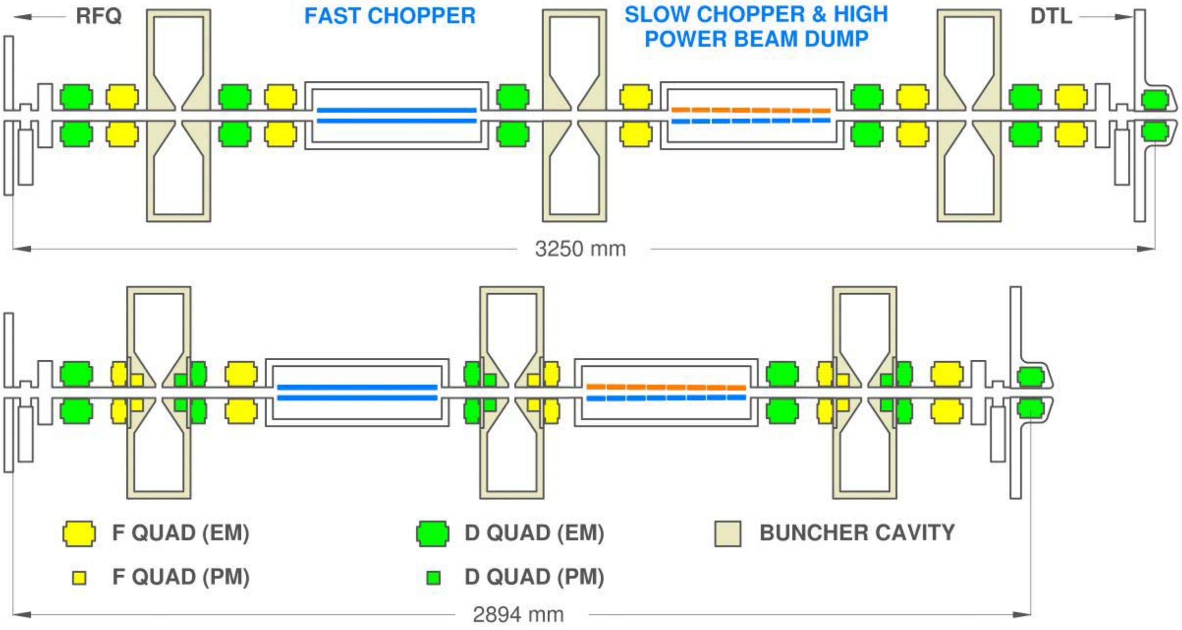

Figure 1: Two possible MEBT configurations showing a reduction in length using compact components.

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* Work supported by CCLRC/RAL/ASTeC and by the European Community-Research Infrastructure Activity under the FP6 "Structuring the European Research Area" programme (CARE, contract number RII3-CT-2003-506395)

compact combination of permanent magnet and electromagnetic quadrupoles.

RE-BUNCHING CAVITY DESIGNS

The re-bunching cavities maintain the longitudinal focusing as the beam proceeds through the chopper line. In designing the cavities, the following factors have to be considered:

- A high shunt impedance is desirable, to reduce power consumption, to simplify the cooling and thereby reduce the design complexity.
- Electrical discharge (sparking) must be avoided by limiting the peak surface electric field. A maximum accepted value of 1.4 for the Kilpatrick limit has been chosen.
- The cavities have to fit inside the mechanical limits imposed by the MEBT optical design, leading to a more compact structure.

Two design options are considered here: the DTL-type and the CCL-type cavity.

DTL-type Cavity

This structure, as shown in Figure 2a, is derived from the Drift Tube Linac design and is mainly optimised for space, allowing EMQs to be integrated inside the drift tube. From this point of view the DTL-type cavity is desirable, but on the other hand it is limited in terms of power efficiency. Figure 3 illustrates the effective shunt impedance obtained with Poisson Superfish [4], for different combinations of cavity lengths and gaps, and also the Kilpatrick factor variation with gap length for 160 kV effective cavity voltage. A region of high shunt impedance can be observed, allowing the optimal choice for cavity geometrical parameters.

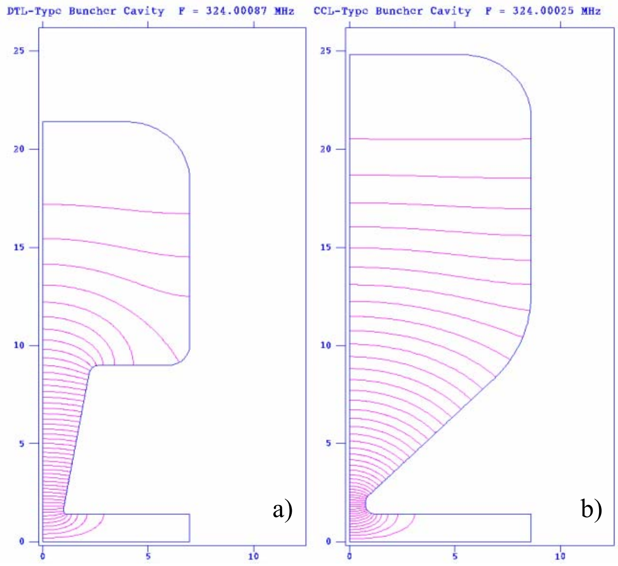

Figure 2: Superfish graph of a 324 MHz DTL-type cavity (a) and a CCL-type cavity (b).

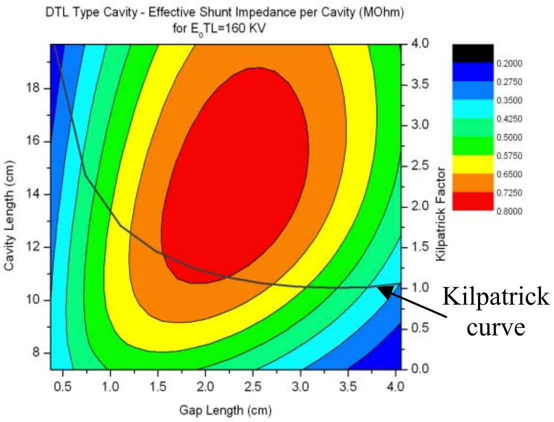

Figure 3: Effective shunt impedance (MΩ) as a function of gap and cavity length for a DTL-type cavity.

CCL-Type Cavity

The CCL-type buncher cavity, as shown in Figure 2b, is derived from a Coupled Cavity Linac cell. The structure is larger than the DTL-buncher, and due to its geometry, the nose cone cannot easily accommodate bulky EMQs. To overcome this limitation, a special combination of quadrupoles is proposed, that will be discussed in the next section. The main advantage of the CCL buncher cavity is its high shunt impedance, as shown in Figure 4, making the cavity about 3 times more efficient than the DTL buncher.

Table 1 presents a comparison of RF properties for the two cavity types. Considering the arguments given above regarding the CCL cavity's power efficiency and also the fact that they are easier to engineer, we can conclude that this cavity type is a good candidate for a buncher cavity for FETS.

Table 1: RF properties for the re-bunching cavities

Property	**DTL-Type Cavity**	**CCL-Type Cavity**	**Unit**
Energy	3	3	MeV
Frequency	324	324	MHz
E_0TL	160	160	kV
Cavity Length	140	172	mm
Bore Radius	14	14	mm
Gap Length	18	15	mm
Power Dissipation	19.2*	6.8*	kW
Q	17000	26800	-
r/Q	22.3	39.5	Ω
Max Power Density	15	5.1	W/cm^2
Kilpatrick	1.28	1.27	-

*values corrected by 15% from Superfish

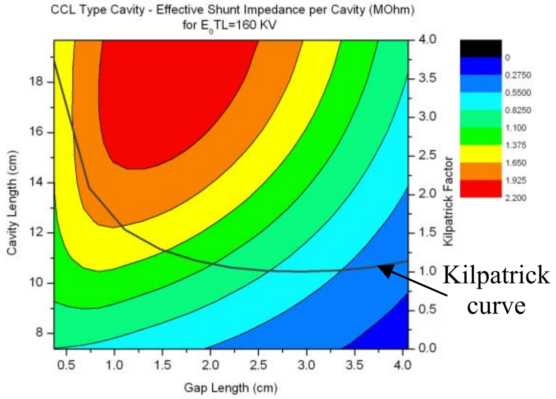

Figure 4: Effective shunt impedance (MΩ) for a CCL-type cavity.

HYBRID QUADRUPOLE DESIGNS

The type and design of quadrupole lens to be used in the MEBT line merits special attention. EMQs produce high magnetic fields, and can be adjusted by varying the current flow in the conductors. In this regard, they are preferable to PMQs whose field cannot be changed once they have been installed, except by complicated mechanical means. However, if space in the MEBT line is restricted, PMQs, being more compact than EMQs, may be more a suitable choice.

Two hybrid quadrupole options are under investigation at RAL, with the aim of combining adjustability and compactness into a single design. The 'tandem' combination of PMQ and EMQ is a solution proposed to overcome the limitation imposed by using a CCL-type buncher cavity whose geometry cannot accommodate a relatively bulky EMQ in the cavity's slender nose cone. However, as seen in Figure 1, a compact PMQ can be made to fit, and therefore makes efficient use of the 'wasted space' in the cavity nose cones. An EMQ is added next to it just outside the cavity's boundaries providing the necessary adjustability for the magnetic field. The MEBT line length is reduced by ~ 11 % when using this tandem quadrupole and the reduction in beam-line length is expected to produce a corresponding reduction in MEBT emittance growth.

The second hybrid option for the MEBT quadrupoles is the concentric combination of PMQ and laminar conductor EMQ types (Lambertson quadrupole). It has been shown that relatively small magnetic fields can be obtained by etching the coil's turns on a flexible printed-circuit board [5], [6]. The circuit board is rolled to form a cylinder that will provide a quadrupole field. By placing this structure inside the aperture of a PMQ, one can adjust the magnetic field by varying the current in the laminar conductors. The resulting structure, as shown in Figure 5, produces a very compact adjustable PMQ with multiple applications. A 2D model has been made using Pandira - Poisson Superfish [4] and a 3D model is in preparation, as well as a small experimental setup to measure the influence of external magnetic fields on the permanent magnet material, the quality of the resulting field, and the achievable degree of tuning. The printed circuit quadrupole model consists of 72 conductors with a well known cos(2θ) current distribution. For a maximum current density of 10 A/mm^2 in 4 equi-spaced conductors the change in field is limited to 0.45 T/m which is approximately 1% of the nominal FETS quadrupoles gradient and only 10% of the required adjustability range. Alternative solutions are taken into consideration like the use of multiple circuit-boards layers, or conductors with large cross section in a ceramic cylinder, that are able to conduct much more current.

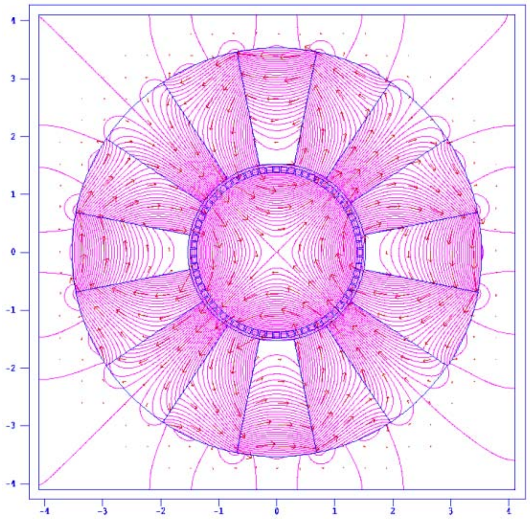

Figure 5: Pandira magnetic field plot of a PMQ with 16 wedges of material, and an integrated printed-circuit quadrupole.

SUMMARY

A comparison has been made between two re-bunching cavity types for FETS and compact hybrid quadrupole configurations have been proposed. The resulting combinations of cavities and quadrupoles offer more design options for the FETS MEBT line.

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