A TWO STAGE FAST BEAM CHOPPER FOR NEXT GENERATION HIGH POWER PROTON DRIVERS

Michael A. Clarke-Gayther, STFC RAL, Didcot, United Kingdom

Abstract

The Front End Test Stand (FETS) project at RAL will test a two stage fast beam chopper, designed to address the requirements of high power proton drivers for next generation spallation sources, neutrino factories, and radioactive waste transmutation plants. A description is given of the status of development of the proposed two stage beam chopper. The results of a recent study on the dimensional optimisation of the proposed slow-wave structures, together with an updated beam line configuration for the chopper components, will be presented.

INTRODUCTION

Proton drivers for the next generation of spallation neutron sources, neutrino factories, and waste transmutation plants, will produce beam powers of up to 10MW, typically an order of magnitude increase with respect to current designs [1]. The ability to achieve routine operation with beam loss at or below the 1W per metre level required to enable an efficient regime of 'hands on' maintenance will be key and extremely challenging. During critical accelerator tuning procedures, and crucially for the ring based schemes at injection and extraction, beam loss and the consequent activation of components can be minimised by a programmed population of the beams' longitudinal phase space, produced by 'chopping' the beam at low energy in the Linac. The 'chopper' is required to produce precisely defined gaps in the Linac beam, and this is typically achieved by deflecting the 'chopped' beam onto a downstream beam dump with a rapidly switched transverse electric field [2]. Chopping at low beam energy minimises the required deflecting field magnitude, and also the power dissipation, and neutron activation, of the chopper beam dump. A beam chopper is typically implemented downstream of the ion source, in the Low Energy Beam Transport Line (LEBT), downstream of the Radio Frequency Quadrupole (RFQ), in the Medium Energy Beam Transport Line (MEBT), or in both locations, as shown in Figure 1. The choice of location is determined by a number of factors. Layout (A) in Figure 1 (LEBT chopper) may be optimal for a high intensity H^+ ion source followed by a very short uncompensated space charge LEBT, consisting of short electrostatic lenses in a medium to high vacuum. In this case, the challenging design issues will be the implementation of a high duty cycle, DC coupled electric field chopper, within the space restriction imposed by the compact LEBT, and the fast transition time, high quality chopper waveform required to ensure that high energy beam loss resulting from off axis beam in the RFQ during the chopper transition time, is minimised [3]. Layout (B) in Figure 1 (LEBT and MEBT chopper) is an alternative option for a high intensity H^+ ion source with a compact LEBT as outlined above. In this case the specification for the slower transition time LEBT chopper is less demanding, but the resulting off axis beam exiting the RFQ during the LEBT chopper transition time must be intercepted by a more complex fast transition time MEBT chopper. However, the MEBT chopper operates at low duty cycle and power dissipation in the MEBT beam dump is minimised. Layout (C) in Figure 1 (MEBT chopper) may be optimal for a high intensity H^- ion source followed by a space charge compensated LEBT consisting of magnetic solenoid lenses operating in a low to medium vacuum. In this case the relatively long time (~10 to ~200µs) taken for LEBT space charge neutralisation to reach equilibrium [4, 5] precludes the use of a LEBT chopper, and restricts implementation to the MEBT location where the design poses some unique challenges. The MEBT beam is bunched at the RFQ RF frequency and the chopping field must therefore rise and fall within, and be synchronous with, bunch intervals that are typically just a few nanoseconds in duration. Chopper field, duty cycle, and power dissipation on the chopper beam dump are all high, and neutron activation of the components and dump will occur if the MEBT beam energy is above the neutron production threshold.

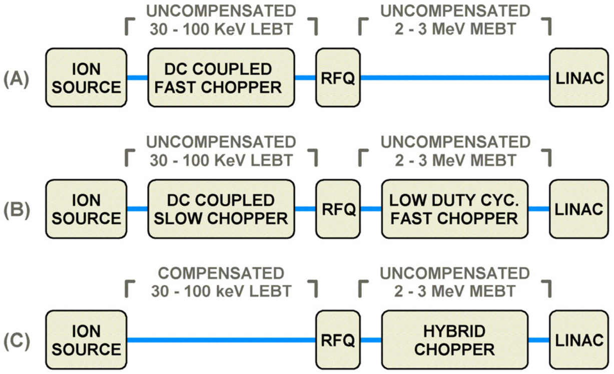

Figure 1: Chopper location block schematic

FETS PROJECT

The UK based FETS project, a collaboration involving RAL, Imperial College London, the University of Warwick, and the University of the Basque Country, will test a fast beam chopper in a high duty factor MEBT line [6]. The key components, as shown in Figure 2 are: an upgraded ISIS 'Penning' ion source, a three solenoid Low Energy Beam Transport line, a high duty factor 324 MHz RFQ, a novel two stage beam chopper, and a suite of

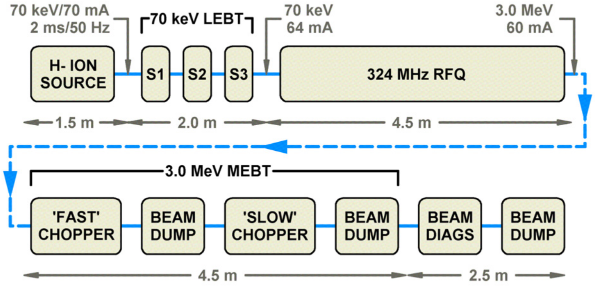

Figure 2: FETS beam line block schematic

beam diagnostic instruments. The specification, as shown in Table 1, calls for significant technical development in attempting to address the generic, and specific requirements for a next generation proton driver and a 0.16 to 0.5 MW upgrade for ISIS [7], respectively.

Table 1: FETS parameters

Parameters		Parameters	
Ion species	H^-	RFQ input energy	70 keV
RFQ output energy	3.0 MeV	MEBT beam current	60 mA
Beam pulse duration	0.2 - 2 ms	RF frequency	324 MHz
Beam pulse repetition frequency			50 Hz
MEBT chopper field transition time (10-90 %)			2 ns
Chopped beam duration			0.25-100 μs
Chopper pulse repetition frequency			1.3 MHz

TWO STAGE CHOPPING

A schematic of the proposed two stage beam chopper is shown in Figure 3. This configuration addresses the conflicting chopping field requirements of fast transition time (~ 2 ns) and long duration (~ 0.1 ms), with a tandem combination of 'fast' transition time short duration, and slow transition time long duration fields. The upstream field is generated by a pair of AC coupled 'fast' transition time (~ 2 ns) pulse generators that output high voltage, dual polarity pulses into a 'slow-wave' transmission line electrode structure, where partial chopping of beam bunches is avoided by ensuring that the deflecting E-field propagates at the beam velocity. The 'fast' chopper deflects just four bunches at the beginning and end of each chopped beam interval, creating two ~ 15 ns gaps in the bunch train. These gaps ensure that partial chopping of beam bunches is avoided in the downstream 'slow' chopper, whose field is generated by eight DC coupled, 'slow' transition time (~ 12 ns) pulse generators that output high voltage pulses to discrete, close-coupled, electrodes. The 'slow' chopper generates a long duration E-field that deflects the remaining bunches in each chopping interval onto a downstream beam 'dump' [8, 9].

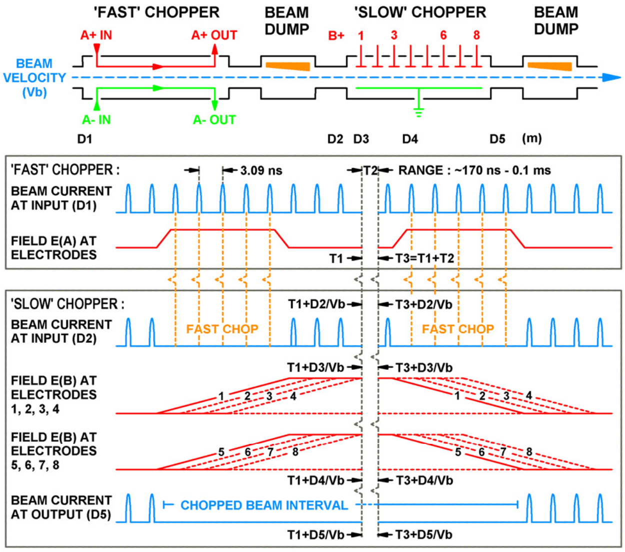

Figure 3: Two stage chopper timing schematic

SLOW-WAVE ELECTRODES

The RAL helical and planar slow-wave electrode designs and measurements of the transmission line properties of the helical and planar test assemblies have been previously described [10]. Manufacture of the test assemblies has helped to verify the predictive accuracy of the CST MWS design code [11], and the selection of suitable machine-able ceramics and alloys of copper and aluminium. The subsequent planar and helical 'short length' prototype structures, will build on the experience gained from the test assemblies, and should facilitate the choice of a candidate design for the full scale structure, as outlined in the development plan, shown in Figure 4.

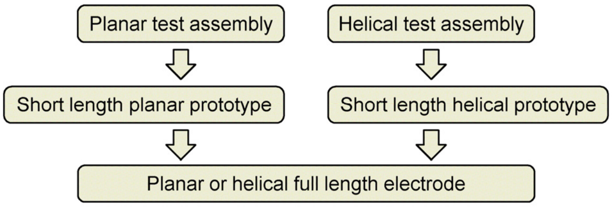

Figure 4: Development plan

Dimensional optimisation

Recent studies, prompted by a requirement to address some detailed design issues highlighted by the manufacture of the test assemblies, have focussed on a dimensional optimisation of the electrode structures. The purpose of this optimisation process was to select a dimension for strip-line width that not only maximised

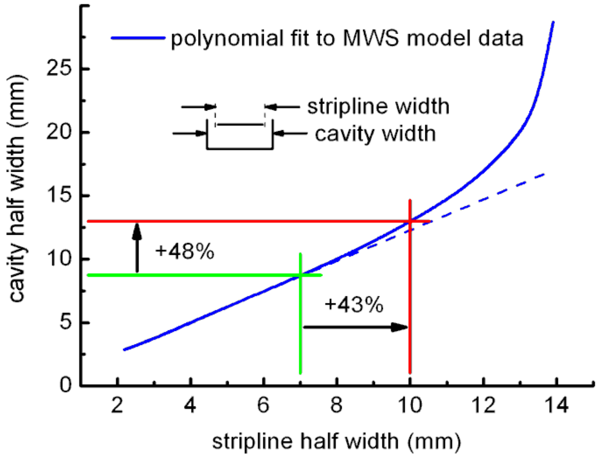

Figure 5: 50 Ohm strip-line parameters

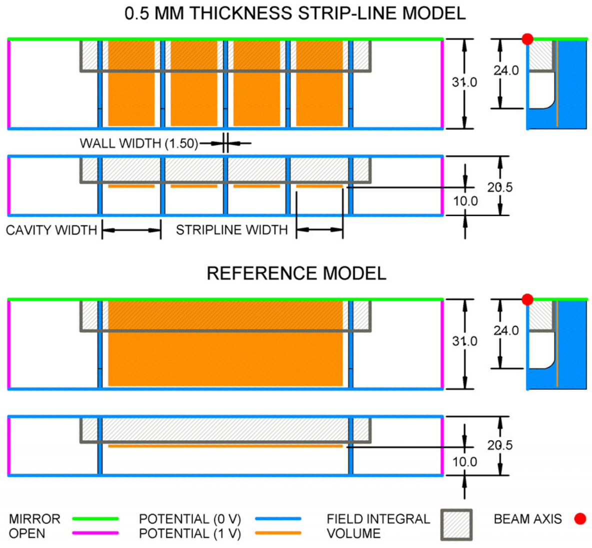

Figure 6: EMS strip-line and reference model

the beam deflecting component of E-field but also minimised the number of parts in the electrode structure, with a view to striking a balance between functional efficiency, manufacturing cost, and the requirement to address a dimensional conflict specific to the coaxial to strip-line transition of the helical structure. The optimisation process was restricted to the evaluation of the volume integral of E-field for a range of 50 Ohm strip-line structures with strip-line width as the single variable. The process consisted of two parts; the first was an evaluation of cavity width as a function of strip-line width with characteristic impedance, strip-line thickness, and cavity height held at 50 Ohms, 0.5 mm and 20.5 mm, respectively; the second was an evaluation of the volume integral of the deflecting component of E field as a function of strip-line width. The relationship between cavity width and strip-line width as determined by structure simulation in the CST MWS code [11] is shown in Figure 5, and indicates a significant departure from linearity for values of strip-line width above ~ 20 mm. The relationship between the 'coverage factor' and strip-line width, as determined by structure simulation in the CST EMS code [11], and derived by normalising the volume integral of field evaluated for the strip-line model with that for the reference model as shown in Figure 6, suggests that a significant increase in strip-line width will result in a relatively small reduction in coverage factor, as shown in Figure 7 and Table 2.

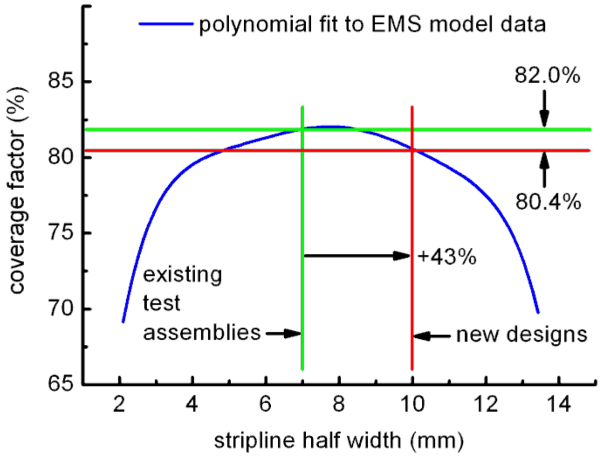

Figure 7: Strip-line width vs. coverage factor

Table 2: FETS slow-wave electrode parameters

Design parameter	Old	New	
H^- beam energy	3.00		MeV
Beam width / 100%	18.0		mm
Beam aperture	19.0		mm
Strip-line width / thickness	14.5 / 0.5	20.0 / 0.5	mm
Cell periodicity	19.00	27.42	mm
Cells / 450 mm structure	23	16	No.
Cell delay	0.7949	1.067	ns
Coverage factor: Centre/edge	82 / 81	80 / 79	%
Characteristic impedance	~ 50		Ω
Bandwidth	0 – 500		MHz
Breakdown voltage	≥ 3		kV

SUMMARY

The design and manufacture of the helical and planar multi strip-line 'short length' prototypes will build on, and address some issues arising from, the experience gained from the manufacture and test of the single strip-line test assemblies. An increase in strip-line width will reduce the number of cells per structure, the number of parts, and the cost of manufacture. This study shows that a significant increase in strip-line width will result in a relatively small reduction in coverage factor, and indicates that a value of ~ 20 mm may represent an optimal upper limit.

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