A FAST BEAM CHOPPER FOR THE RAL FRONT END TEST STAND

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Contribution to the EPAC’06, Edinburgh, UK

Work supported by the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395).

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INTRODUCTION

Proton driver specifications for the next generation of spallation neutron sources, neutrino factories, and waste transmutation plants, call for more than an order of magnitude increase in beam power, typically from ~ 0.16 to ~ 5 MW [1]. For the linac-accumulator or linac-synchrotron schemes, beam loss at ring injection and extraction, and the consequent activation of components, can be minimised by a programmed population of ring longitudinal phase space, produced by 'chopping' the linac beam at low energy. The 'chopper' is required to produce precisely defined gaps in the bunched linac beam, 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 .

THE FETS PROJECT

The FETS project, a UK based collaboration involving RAL, Imperial College London, and the University of Warwick, will test a fast beam chopper in a high duty factor MEBT line [2]. The key components, as shown in

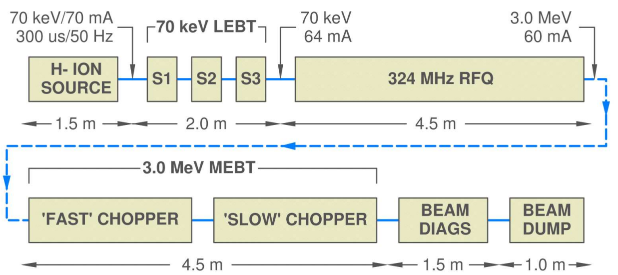

Figure 1: FETS beam line block schematic

Figure 1 are: an upgraded ISIS 'Penning' ion source, a three solenoid Low Energy Beam Transport (LEBT) line, a high duty factor 324 MHz Radio Frequency Quadrupole (RFQ), a novel 'Fast-Slow' beam chopper, and a suite of beam diagnostic instruments. The specification, as shown in Table 1, calls for significant technical development,

† 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).

Table 1: Key FETS parameters

Parameters		Parameters	
Ion species	H^-	RFQ input energy	70 keV
RFQ output energy	3.0 MeV	Beam current	60 mA
Pulse duration	0.3 - 2 ms	RF frequency	324 MHz
Pulse repetition frequency			50 Hz
MEBT chopper field transition time (10-90 %)			2 ns
Chopped beam duration			0.1-100 μs
Chopper pulse repetition frequency			1.3 MHz

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 [3], respectively.

'FAST-SLOW' CHOPPING

A block, and timing schematic for the proposed 'Fast-Slow' chopping scheme, is shown in Figure 2. The novel configuration was developed for the European Spallation Source (ESS) [4, 5], and addresses the conflicting requirement for a fast transition time (~ 2 ns), long duration (~ 100 us) chopping field, with a tandem combination of 'fast' transition time, short duration, and slower transition time, long duration, E-field choppers. In this scheme, the upstream 'fast' chopper removes just three or four bunches at the beginning and end of each chopped beam interval, creating two 12 - 15 ns gaps in the bunch train. These gaps ensure that no partially chopped beam results from the slower field transition time of the downstream 'slow' chopper.

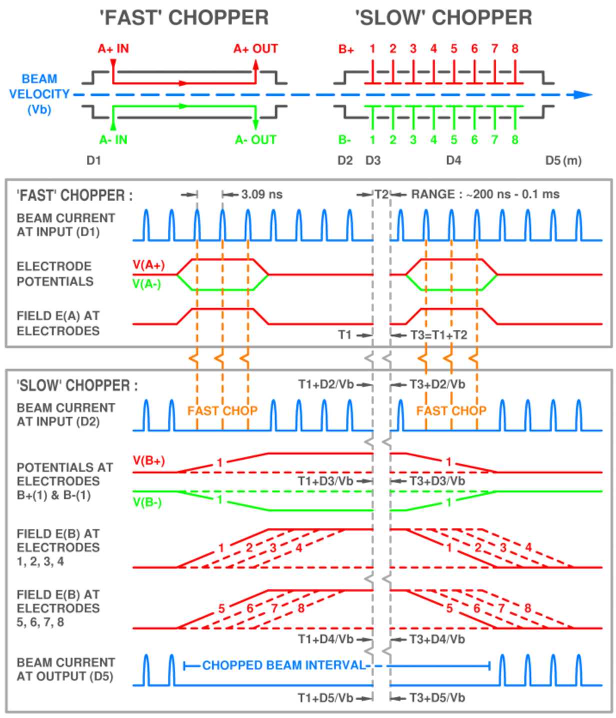

Figure 2: 'Fast-slow' chopper timing schematic

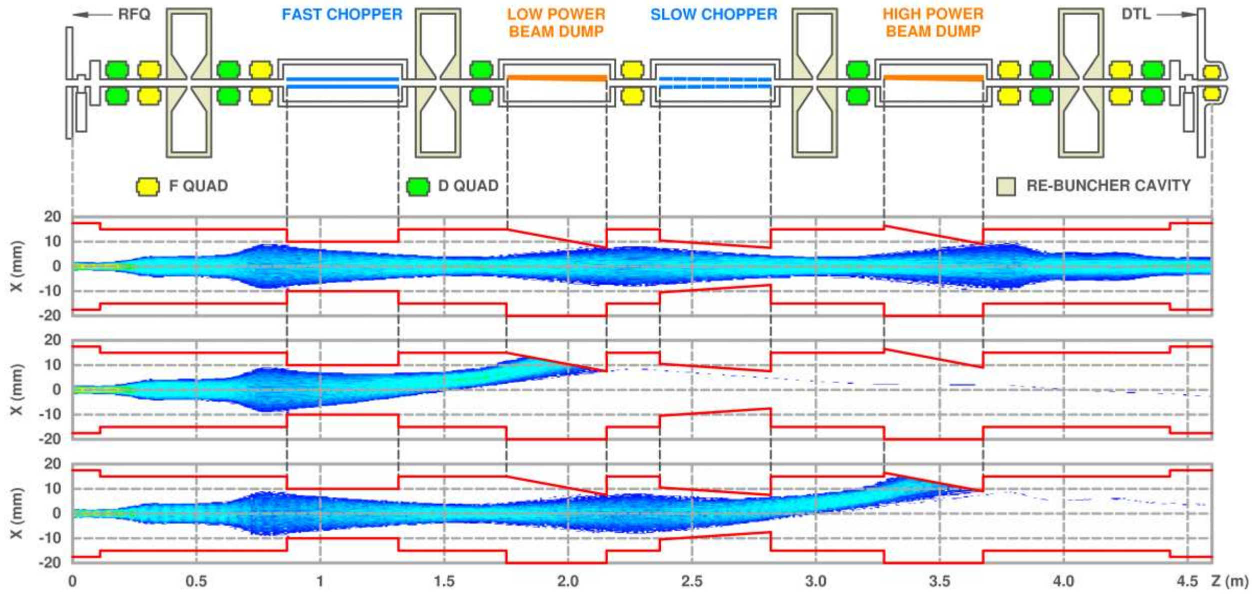

Figure 3: FETS Scheme A / Beam-line layout and GPT trajectory plots

FETS MEBT CHOPPING SCHEMES

The RAL 'Fast-Slow' chopping scheme for the 2.5 MeV, 280 MHz, ESS MEBT is evolving to address the requirements of the 3.0 MeV, 324 MHz, FETS project. Three candidate optical designs have been identified, and two of these, schemes A and B, make use of the optical amplification of beam deflection in a downstream defocusing quadrupole, to significantly lower the chopper field requirement, a key feature of the proposed Linac 4 MEBT design at CERN [6]. The preliminary schemes [7, 8] have been refined in the GPT code [9], and key features of the designs for schemes A, B, and C are shown in Figures 3, 4, and 5, respectively. In each of these Figures, three plots, scaled in the z-plane to a schematic of the component layout, show simulated beam trajectories for the conditions of no chopping, 'fast' chopping, and 'slow' chopping, respectively. Input and output doublet matching sections, and CCL type re-bunching cavities [10] control emittance growth in the transverse and longitudinal planes. Plots of simulated beam distributions in phase space, at the input and output of all three schemes, are shown in Figure 6.

Scheme A

In this case, the configuration of the 'fast' and 'slow' choppers is symmetrical, each operating independently and each followed by a defocusing quadrupole and a dedicated beam dump. 'Fast' and 'slow' chopping fields are uniformly low, but emittance growth is higher than in scheme B.

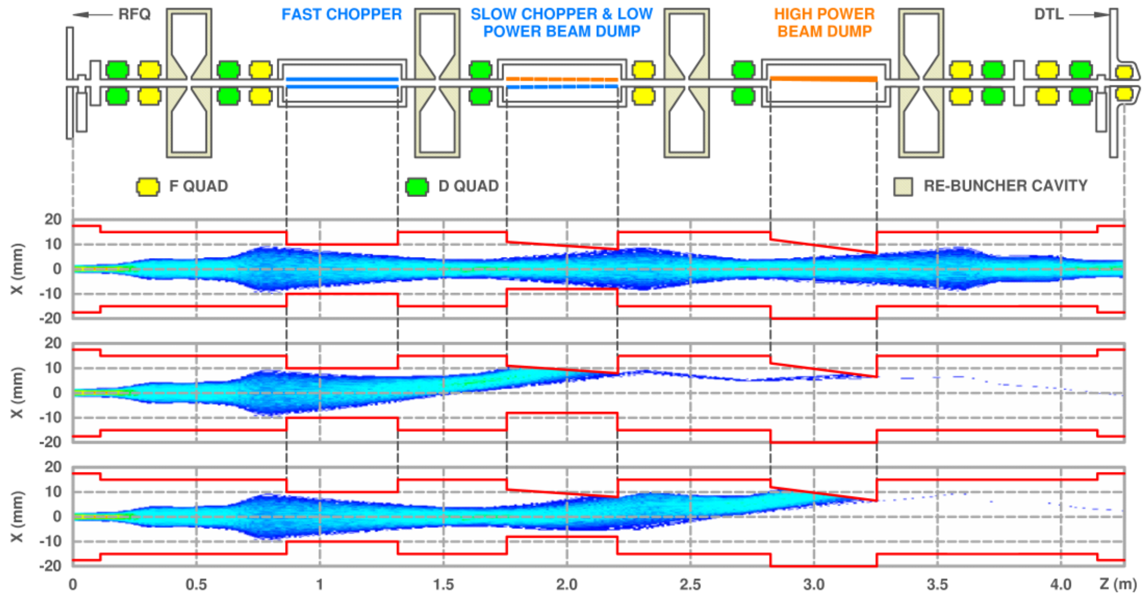

Figure 4: FETS scheme B / Beam-line layout and GPT trajectory plots

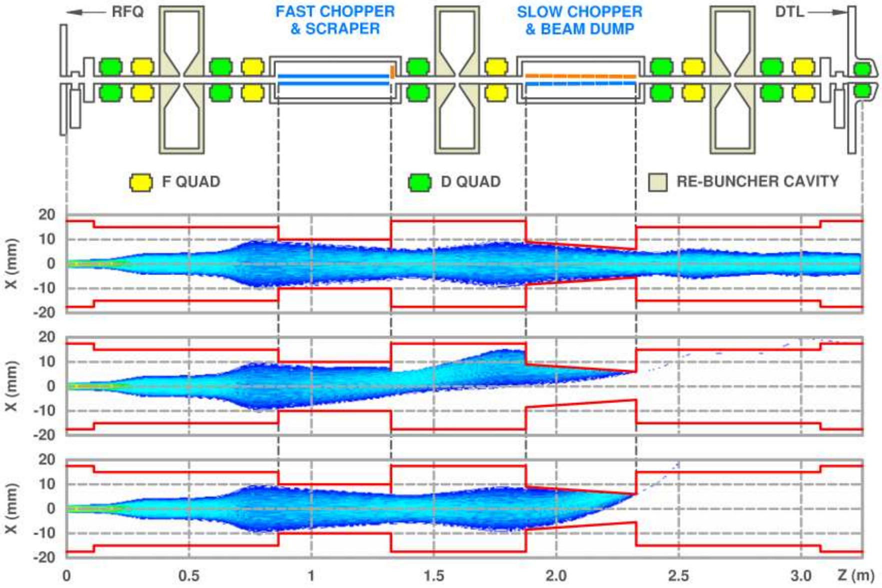

Figure 5: FETS scheme C / Beam-line layout and GPT trajectory plots

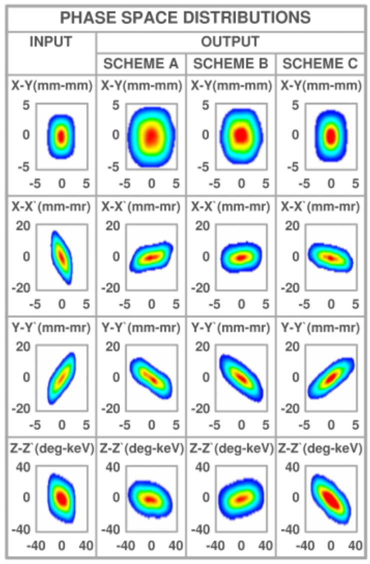

Figure 6: FETS phase space plots

Scheme B

In this scheme the configuration of the 'fast' and 'slow' choppers is asymmetrical, with the 'slow' chopper functioning as a low duty cycle beam dump for the 'fast' chopper. However, chopper fields are synergistic, and as a result the fast chopping field is minimised. Emittance growth is lower than scheme A, and similar to scheme C.

Scheme C

The configuration of the 'fast' and 'slow' choppers is, in this case, similar to the original ESS chopper design, with the 'slow' chopper functioning as a low duty cycle dump for the 'fast' chopper, and a high duty cycle dump for the 'slow' chopper. The slow chopping field is significantly higher than schemes A and B.

SUMMARY

Three candidate optical designs for the FETS MEBT chopper line have been identified, and refined. Schemes A and B address three weaknesses in the original ESS MEBT optical design, these being, the high chopper field requirement, the absence of a dedicated chopper beam dump, and an overly compact component layout. The results of these studies are encouraging, in that they indicate that schemes A and B can address the above mentioned weaknesses without incurring excessive emittance growth in the MEBT line.

Table 2: FETS MEBT parameters (GPT)

Parameters	Scheme A	Scheme B	Scheme C
Beam line length (mm)	4600	4260	3250
Beam current (mA)	40	40	40
RMS input emittance in X/Y (π-mm-mr) & Z planes (π-deg-MeV)	0.25 / 0.25 0.18	0.25 / 0.25 0.18	0.25 / 0.25 0.18
RMS emittance growth in X/Y & Z planes (%)	6 / 13 2	4 / 8 0	5 / 8 0
Quadrupole length / aperture (mm)	70 / 35	70 / 35	70 / 35
Cavity field max. (keV/mm) / gap (mm)	4.5 / 21.5	4.5 / 21.5	5.0 / 21.5
Fast chopper electrode effective length & gap (mm)	450 x 0.82 20	450 x 0.82 20	450 x 0.82 20
Fast chopper potential (kV)	± 1.3	± 1.2	± 1.4
Slow chopper electrode effective length & gap (mm)	450 x 0.85 18	450 x 0.85 18	450 x 0.85 14
Slow chopper potential (kV)	± 1.5	± 2.0	± 5.0
Beam dump length (mm)	2 x 400	2 x 450	450

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