FETS-REP-04-001

A FAST BEAM CHOPPER FOR NEXT GENERATION HIGH POWER PROTON DRIVERS

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Abstract

A description is given of refinements to the beam line design of a 'Tandem' chopper system, developed to address the requirements of the European Spallation Source (ESS). Particle tracking using the 'General Particle Tracer' (GPT) code has enabled efficient optimisation of beam apertures, and the analysis of beam power density distributions on chopper beam dumps. Preliminary results of 'proof of principle' testing on a prototype fast high voltage pulse generator are presented.

INTRODUCTION

The identification and development of a successful beam chopper design is regarded as key for the ESS [1], and for all next generation high intensity proton driver schemes that adopt the linac-accumulator, or linac-synchrotron schemes [2]. Beam loss at ring injection and extraction, and the consequent activation of components, may be minimised by a programmed population of the ring longitudinal phase space. This may be achieved by the inclusion of a fast beam chopper in the linac front-end. The chopper is required to produce precisely defined gaps in the bunched linac beam, and as partial chopping of bunches is to be avoided, the chopping field must rise and fall within, and be synchronous with, the bunch interval. In principle, beam chopping is most efficiently implemented at ion source energies (30-60 keV), where the required deflecting field, and the beam dump power dissipation are minimised. In practice, however, chopping transition times in space charge neutralised H^- beams, are limited by positive ion diffusion velocities to values of ~ 50-100 µs [3]. The ESS 50 keV beam transport line will operate in this neutralised regime, and so, all ESS chopping functions have been restricted to the 2.5 MeV medium energy beam transport (MEBT) line location.

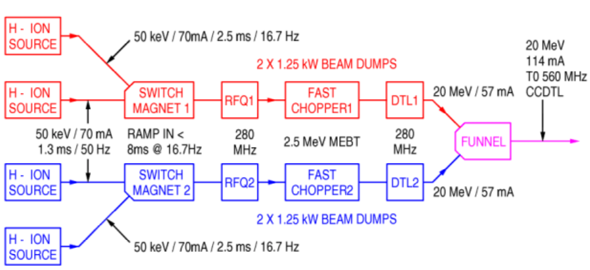

Figure 1: ESS front-end schematic.

Components of the ESS front-end, are shown in schematic form in Figure 1. ESS front-end specifications call for significant technical development, and the design is considered to be generic for all next generation spallation sources and neutrino factories [4].

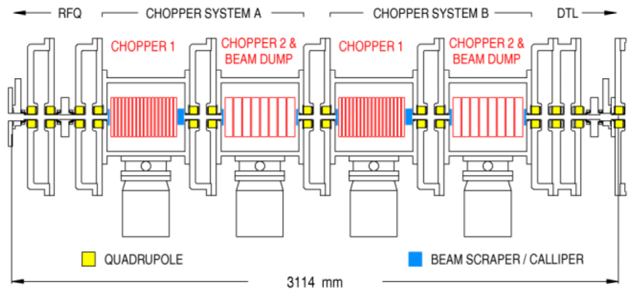

Figure 2: ESS 2.5 MeV MEBT with 'Tandem' chopper.

MEBT DESIGN

A schematic drawing of the ESS MEBT line and some key design parameters are shown in Figure 2 and Table 1 respectively. The configuration has evolved from a previously reported design [5], and utilises two slow-wave E-field chopper systems operating in 'Tandem'. The design reduces beam dump power dissipation, and high voltage pulse generator repetition frequency by a factor of two, without incurring excessive emittance growth.

Table 1: Key parameters for the ESS MEBT line

	Short pulse	Long pulse
Ion species / input energy	H^- / 2.497 MeV	
Bunch frequency / λ	280 MHz / 1.071 m	
Relativistic β / βλ	0.07277 / 0.07792 m	
Input bunch phase extent	± 30 degrees	
Macro-pulse current	57 mA (peak)	
Repetition rate	50 Hz	16.66 Hz
Beam duty cycle	6 %	4.2 %
Quadrupole aperture	28 mm internal diameter	
Input emittance in x / y *	0.2054 / 0.2034	
Input emittance in z *	0.4222 or 0.1333 π deg MeV	

* normalised r.m.s. in π mm mrad

The previous optical design has been revised [6], and the simulated r.m.s beam radii and emittances are shown in Figure 3. Input matching from the RFQ, use of regular lattice functions with the same beam aspect ratios in the channel cells, and a final six parameter output matching section, result in an acceptably low level of emittance growth and halo development. Optical amplification of beam deflection has not been attempted, and chopping fields are therefore higher than in other designs [7].

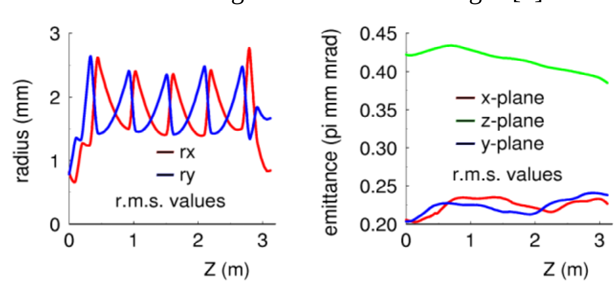

Figure 3: Simulated r.m.s beam size and emittances.

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CHOPPING SCHEME

Key parameters, and a timing schematic for one sub-system of the 'Tandem' chopper configuration are shown in Table 2, and Figure 4, respectively.

Table 2: Key parameters for the ESS chopper system

	Pre-chopper	Chopper
Chopping factor	30 % (ring stacking regime)	
Electrode voltage	± 2.2 kV	± 6.0 kV
Electrode length	340 mm	360 mm
Electrode gap	14 mm	11 mm
Deflection angle	16 mrad	66 mrad
Pulse transition (10-90%)	~ 2 ns	~12 ns
Pulse duration	12 ns	240 ns-0.1 ms
Pulse repetition frequency	2.4 MHz	1.2 MHz
Burst duration	1.5 ms	
Load impedance	50 Ω	35 pF / 60 nH
Repetition rate	50 Hz (two systems @ 25 Hz)	
Beam power on dump	2.5 kW (two systems @ 1.25 kW)	

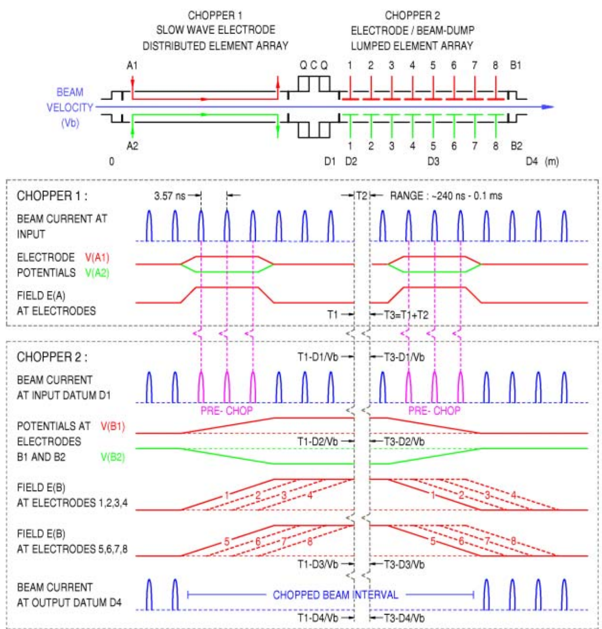

Figure 4: Two stage (fast-slow) chopping scheme.

'Tandem' sub-systems are identical in operation and function alternately at a repetition frequency of 25 Hz. Each sub-system consists of an upstream fast chopper with a slow-wave electrode structure [8], and a downstream (slower) main chopper with water-cooled lumped element electrodes, that also serve as a beam dump. Slow-wave chopper 1 produces a uni-polar pulsed field that deflects just three adjacent bunches through ~ 16 mr. into scraper S2, S3 and chopper 2 beam dump electrodes, creating two ~ 14 ns duration gaps in the bunch train at the beginning and end of each chopped beam interval. These gaps ensure that no partially chopped bunches result from the slower field transition time of chopper 2. Figures 5, 6 and 7 show GPT [9] simulations of particle tracking with space charge for the cases of fast (pre-post) chopping, main chopping, and no chopping, respectively. Eight pairs of adjustable scrapers control beam halo, beam displacement during fast chopping, and function as diagnostic beam 'callipers'.

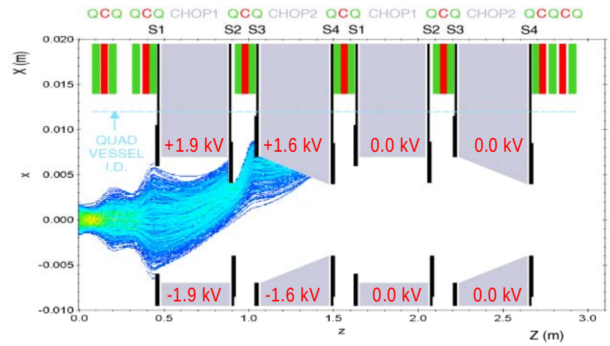

Figure 5: Fast chopping / Bunch 1-3 and 63-66 chopped.

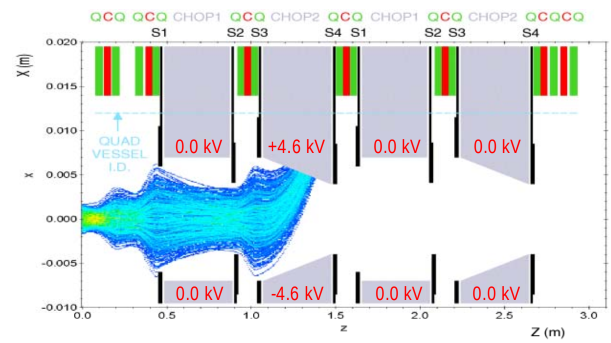

Figure 6: Slow chopping / Bunch 4-62 chopped.

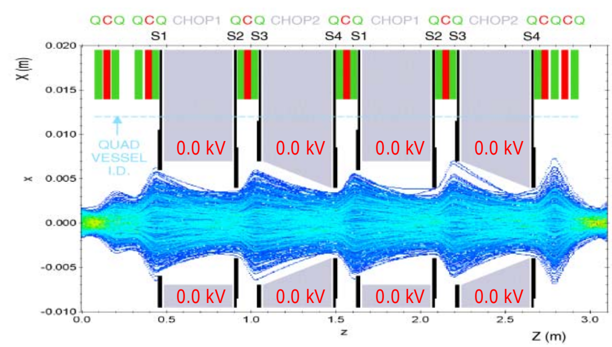

Figure 7: No chopping / Bunch 67-158 un-chopped.

A plot of the time averaged beam power density distribution on the chopper 2 beam dumps, based on data from the GPT simulation, is shown in Figure 8. The analysis predicts a peak power density of ~ 2.5 MW/m^2, and an acceptable mean value of ~ 0.6 MW/m^2.

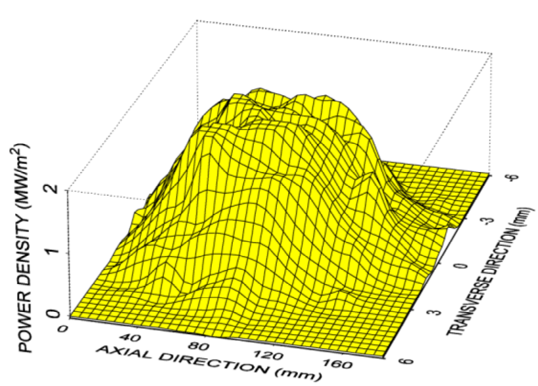

Figure 8: Power distribution on chopper beam dumps.

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MODULATOR DESIGN

A block schematic of the proposed prototype modulator design for one 'Tandem' chopper sub-system is shown in Figure 9. Systems A1 / A2 drive the A1 / A2 distributed slow-wave electrodes of chopper 1 (see Figure 4), and output fast transition (~ 2 ns), short duration (~ 12 ns) quasi-trapezoidal, uni-polar high voltage pulses (± 1.4 kV) into 50 Ω loads. The modular configuration makes extensive use of high power transmission line transformers (TLT's) for efficient wide-band impedance transformation and combination of the outputs of 18 solid-state high voltage pulse generator cards, consisting of two, nine card modules. Additional modules, and TLT's can be added, to increase output pulse amplitude to ~ ± 2.2 kV.

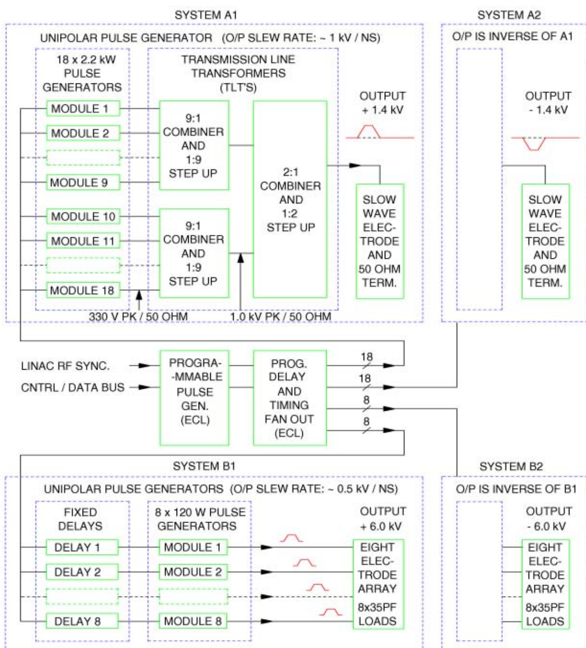

Figure 9: Fast and slow pulse generator block diagram.

Systems B1 / B2 drive the B1 / B2 lumped element slow wave electrodes of chopper 2, and output ~ 12 ns transition, uni-polar, trapezoidal, high voltage pulses (+6.0 and –6.0 kV) into eight pairs of 35 pf / 60 nH loads. Pulse duration will be programmable in the 240 ns to 0.1 ms range. The 120W air-cooled modules will be close-coupled to the electrodes, to preserve pulse fidelity.

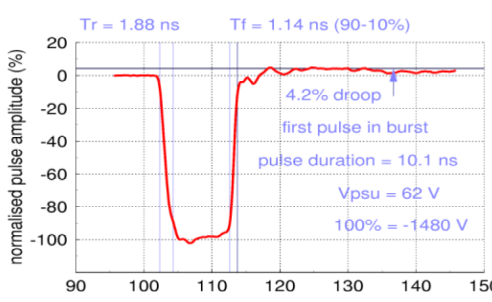

Figure 10: Fast pulse measurement at 10 ns / division.

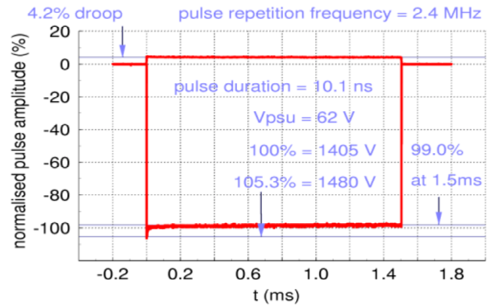

Figure 11: Fast pulse measurement at 0.1 ms / division.

Measurements of the output waveform of a prototype fast pulse generator are shown in Figures 10 and 11. These indicate that, with the exception of pulse droop, all key waveform specifications have been met. Modifications, to reduce pulse droop are ongoing.

SUMMARY

The design of a 'Tandem' chopper system for the ESS 2.5 MeV MEBT has been refined. Analysis indicates that beam dump power density has been reduced to a tolerable level. Fast pulse generator measurements are encouraging.

ACKNOWLEDGEMENT

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