

THE RAL FRONT END TEST STAND

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Abstract

High power proton accelerators (HPPAs) with beam powers in the megawatt range have many possible applications including drivers for spallation neutron sources, neutrino factories, waste transmuters and tritium production facilities. These applications typically propose beam powers of 5 MW or more compared to the highest beam power achieved from a pulsed proton accelerator in routine operation of 0.16 MW at ISIS. The UK's commitment to the development of the next generation of HPPAs is demonstrated by a test stand being constructed in collaboration between RAL, Imperial College London and the University of Warwick. The aim of the RAL Front End Test Stand is to demonstrate that chopped low energy beams of high quality can be produced and is intended to allow generic experiments exploring a variety of operational regimes. This paper describes the status of the RAL Front End Test Stand which consists of five main components: a 60 mA H⁻ ion source, a low energy beam transport, a 324 MHz Radio Frequency Quadrupole (RFQ) accelerator, a high speed beam chopper and a comprehensive suite of diagnostics. The aim is to demonstrate production of a 60 mA, 2 ms, 50 pps, chopped H⁻ beam at 3 MeV.

BACKGROUND

Beam chopping will be an important feature of the next generation of HPPAs. Operational maintenance requirements dictate that beam loss in future machines must be kept to levels comparable to those of current facilities in order to avoid component activation. With beam powers an order of magnitude or more greater than those currently achieved, fractional beam loss must be reduced by a similar factor.

Beam Chopping

In circular machines a significant source of beam loss occurs when the continuous linac beam is trapped and bunched in the ring RF bucket. Trapping efficiency can be improved with higher harmonic RF systems but to achieve the improvements necessary for MW scale beams, the linac beam must be chopped at the ring revolution frequency. This chopping allows the ring RF bucket to be precisely filled resulting in very low levels of trapping and bunching loss.

The linac beam has RF structure everywhere downstream of the RFQ, this structure typically being at some 100s of MHz. If the chopping is not precisely synchronised with the linac beam RF bunch structure, partially chopped bunches can result in the linac. With

less charge than normal and possibly off axis or off energy, these partially chopped bunches may lead to beam loss in the linac. The ideal is perfect chopping where the chopper switches on and off in the time between two successive linac beam bunches, typically ~2ns. This very fast switching requirement coupled with the increasing stiffness and power of the beam at higher energies dictates that chopping is carried out at the front of the linac, downstream of the RFQ at around 2.5 – 3 MeV.

Front End Test Stand

The RAL Front End Test Stand (FETS) project aims to achieve several goals. The primary goal is to demonstrate a high quality, high current, chopped beam. This objective is not directed at a single proposed facility but tries to be as generic as possible. FETS is jointly funded by the Council of the Central Laboratory of the Research Councils (CCLRC), as part of their HPPA and MegaWatt Spallation Source studies, and by the Particle Physics and Astronomy Research Council (PPARC) through work package 2 of the United Kingdom Neutrino Factory (UKNF) proposal.

The secondary goal of FETS is to help promote proton accelerator technology as a discipline within UK universities. High energy and particle physics has been well served by universities who are enthusiastic users of accelerator facilities and contributors to detector and physics projects. Accelerator technology has traditionally been less well served however. It is hoped that the FETS collaboration will help to spread CCLRC's accelerator expertise to UK universities and promote accelerator physics and technology as a discipline.

TEST STAND COMPONENTS

The front end test stand consists of an H⁻ ion source, magnetic low energy beam transport (LEBT), 324 MHz RFQ and medium energy beam transport (MEBT) chopper line.

Ion Source

FETS will use the well proven and highly successful Penning type H⁻ surface plasma source (SPS) from ISIS [1]. This ion source routinely produces currents in excess of 40 mA at a duty factor of ~1% and its use with an RFQ pre-injector has been previously demonstrated [2].

The FETS specification calls for a 60 mA beam in pulses up to 2ms long at up to 50 pps with an RMS emittance of 0.3 π mm mrad. An ongoing source development programme has resulted in the successful extraction of a 70 mA beam (Figure 1) and pulses up to

1.2 ms long at 50 pps (Figure 2) although not yet simultaneously.

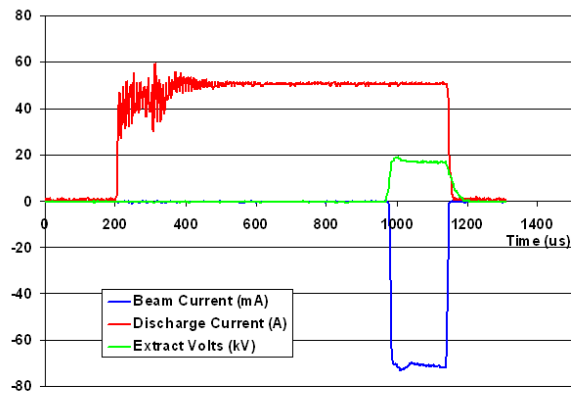


Figure 1: A 70 mA, 200 μ s long H ion source beam pulse. Repetition rate was 50 pps.

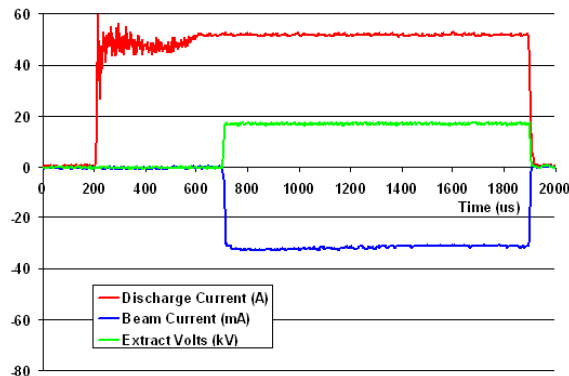


Figure 2: A 30 mA, 1.2 ms long H ion source beam pulse. Repetition rate was 50 pps.

Results of thermal modelling and experiment indicate that the required 10% duty factor is achievable [3][4]. Work to minimise the emittance and sustain consistently higher beam currents is ongoing. Recent results from experiments to measure the ion source energy spread are presented in [5].

LEBT

A 3 solenoid magnetic LEBT has been chosen for FETS. In part this decision was informed by the successful combination of such a LEBT with the Penning ion source in the ISIS RFQ pre-injector upgrade [6]. Three solenoids are chosen over two as it gives greater tuning flexibility and offers the possibility of equalising the asymmetrical emittances produced by the slit extraction geometry of the Penning source [7]. An electrostatic Einzel lens LEBT, although offering some advantages, was rejected for this application due to fears about operating such a LEBT in close proximity to the highly caesiated ion source.

The magnetic design of the solenoids, completed using the CST MAFIA code, is far advanced. Beam optics designs which give a good match into the RFQ have been

simulated using the General Particle Tracer (GPT) code based on ion source beam parameters from previous work [8]. Figure 3 shows the simulated LEBT beam envelopes.

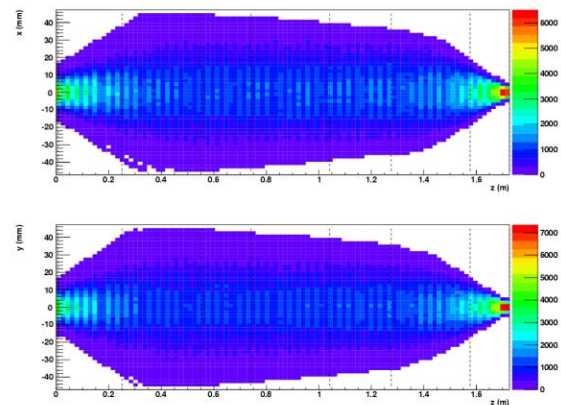


Figure 3: Simulated LEBT beam envelopes. Top – horizontal, bottom – vertical.

To better understand the beam parameters at the start of the LEBT, a new fast CCD camera based pepper-pot emittance measuring system has been commissioned on the ion source development rig [8].

RFQ

A frequency of 324 MHz has been chosen for the FETS RFQ. The frequency was the subject of much debate but ultimately the choice was determined by the ready availability of the Toshiba E3740A klystron developed for the JPARC linac.

Effort so far has concentrated on a 4-vane RFQ resonator design as this frequency is at the upper end of the range for a 4-rod design. However the mechanical simplicity and lower cost of the 4-rod resonator mean that such a design will be investigated before a final decision over the structure is taken. Table 1 gives the main parameters of the RFQ.

Table 1: RFQ parameters

Frequency	324	MHz
Input Energy	65	keV
Output Energy	3.0	MeV
Voltage	85	kV
Length	4.2	m
Input rms emittance	0.3	π mm mrad
Beam current	60	mA

A cold model of the 4-vane RFQ design is under construction. The cold model will allow for comparisons with electromagnetic CAD models as well as for experiments in tuning the structure [9][10]. An automated

bead-pull system has been developed. Figure 4 shows the RFQ cold model.

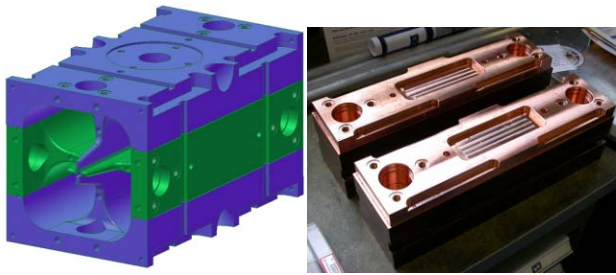


Figure 4: Left – the 4 vane RFQ CAD model. Right – the 4 vane RFQ cold model in manufacture.

Chopper and MEBT

The FETS beam chopper is based on the novel tandem chopper design originally developed for the European Spallation Source (ESS) study [11]. This design tackles the problem of achieving very fast rise time plus long flat-top by using a ‘fast’, short pulse to create a gap in which a ‘slow’, long pulse can rise.

The custom fast pulse generator electronics has been developed in collaboration with a local company. The very high speed switch allows the pulser to achieve the required 1.4 kV pulses with rise and fall times <2 ns. The ‘slow’ pulse generator, built around a commercially available switch, has also demonstrated the required performance.

The beam is chopped in a slow-wave E-field deflector. Initially a meander line structure was investigated but recent work has concentrated on a helical structure which is more easily tuned and offers higher average field values [12]. Figure 5 shows the elements of the helical structure.

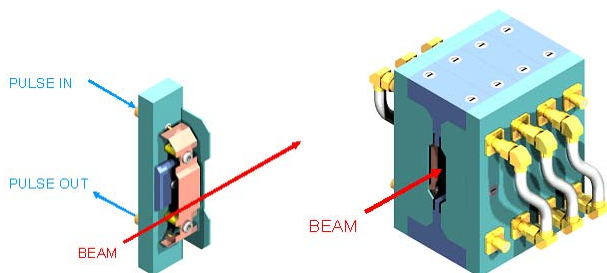


Figure 5: Left – a single element of the helical chopper structure. Right – several elements are connected via adjustable delay lines to construct the slow-wave deflector.

Three MEBT optics designs are being studied concurrently, the designs differing in their overall lengths [13]. The shortest, at under 2m, exhibits the least emittance growth but contains several engineering challenges [14]. The slow chopper deflector is also the beam dump and the rebunching cavities and quadrupoles have to be very compact. The longest design, at 4m long, exhibits the most emittance growth but is more realistically achievable.

Diagnostics

High quality diagnostics are essential to fully exploit the test stand. In addition to a suite of traditional diagnostics devices, non-destructive laser stripping techniques will also be employed. Non-destructive techniques are attractive due to the high beam power. A laser stripping transverse emittance measurement system is under investigation as is a laser wire beam tomography system for determining beam density profiles [15].

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