STATUS REPORT ON THE RAL FRONT END TEST STAND

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Abstract

High power proton accelerators (HPPAs) with beam powers in the several megawatt range have many applications including drivers for spallation neutron sources [1], neutrino factories [2], waste transmuters and tritium production facilities. 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, the University of Warwick and the Universidad del Pais Vasco. 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 conditions. This paper describes the status of the RAL Front End Test Stand

THE FRONT END TEST STAND

The RAL Front End Test Stand (FETS) project is funded by the Science and Technology Facilities Council (merger of PPARC and CCLRC) as part of their HPPA and MegaWatt Spallation Source studies, and through work package 2 of the UK Neutrino Factory (UKNF) proposal. The project aims to achieve two different 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. The secondary goal of the FETS is to help promote accelerator physics and technology as a discipline within UK universities.

From the accelerator point of view the FETS is intended to prove that a high intensity H^- beam with sufficient beam quality as required for future high power proton drivers can be produced, and cleanly chopped to allow low loss injection into a circular machine. 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. The time structure of the beam in the linac downstream of the Radio Frequency Quadrupole (RFQ) is determined by the RF frequency (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 extended beam loss in the linac and the ring. The ideal is perfect chopping where the chopper switches on and off in the time between two successive beam bunches, typically ~2ns. This very fast switching requirement coupled with the increasing stiffness and power of the beam at higher energies favours a chopping downstream of the RFQ at around 2.5 – 3 MeV. 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 greater than those currently achieved, the fractional beam loss must be reduced by a similar factor.

The set up of the FETS under construction is shown in figure 1. It consists of five main components: a 60 mA H^- ion source, a low energy beam transport utilizing solenoids and a differential pumping scheme, a 324 MHz 4 vane 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. Additionally a program to develop novel conventional and non destructive beam diagnostics based on photo detachment has been started [3, 4, 5].

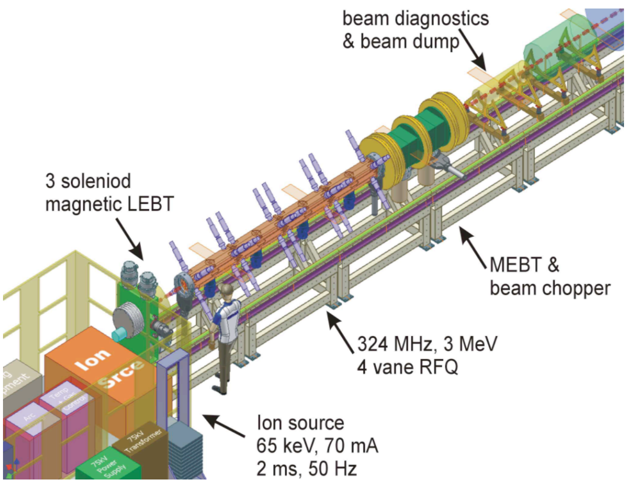

Figure 1: Schematic drawing of the FETS and its components. The FETS will be installed in R8 which has just been refurbished for that purpose and the main infrastructure is in place and available.

ION SOURCE DEVELOPMENT

The ISIS H^- Penning Surface Plasma Source (SPS) is regarded as one of the leading operational ion sources in the world. It routinely produces 35 mA of H^- ions during a 200 µs pulse at 50 Hz for uninterrupted periods of up to 50 days.

Detailed thermal modelling has allowed the duty cycle of the ion source to be extended to meet the requirements of FETS. Pulse lengths of 1.5 ms at 50 Hz have been demonstrated [6]. Pulse lengths of 2 ms are possible but are currently limited by the capability of the discharge power supply. Output currents of up to 80 mA have been achieved by increasing the size of the extraction aperture in the plasma electrode and modifying the extraction electrode.

A retarding potential energy analyser [7] has been developed. The energy spread of the beam from the source has been investigated and found to be 17.6 eV ± 1.5 eV for standard operating conditions.

Measurements have shown the x and y emittance of the beam from the source to be about 0.9πmmmrad (normalised). This is about 3 times too large for FETS. Work is currently concentrating on reducing the emittance, this will further increase the amount of usable beam current available. Areas under investigation are the extraction region, analysing magnet and the post acceleration gap (see figure 2).

A moveable pepper pot emittance/profile measurement device has been developed to characterise the beam. It allows the emittance to be measured at different points along the axis of the beam, facilitating the study of space charge effects with a buffer gas delivery system. This apparatus, combined with horizontal and vertical slit-slit emittance scanners provides a unique set of diagnostics to fully assess source geometry modifications.

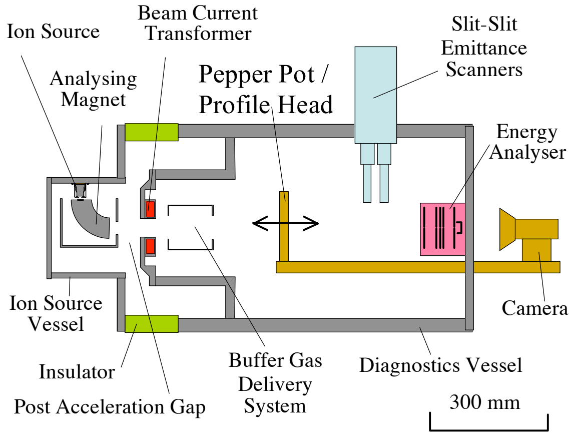

Figure 2: Set up of the Ion Source Development Rig. (Note: the energy analyser has to be removed to use the pepper pot/profile measurement device.)

LEBT DESIGN

A three solenoid LEBT system similar to the one used at the ISIS injector is under consideration. An optimised solenoid design has been made and the 3D magnetic field distribution has been determined using CST code. Figure 3 shows a schematic of the solenoid layout and the typical axial field distributions at different transverse radii.

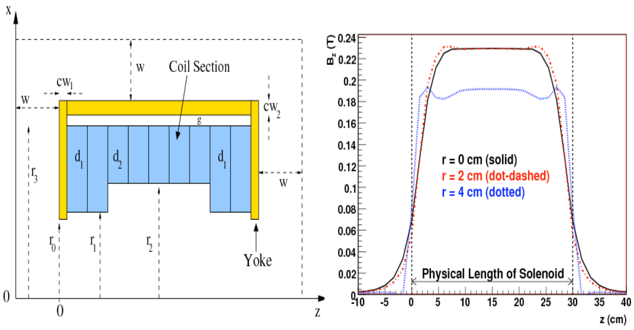

Figure 3: Design study of a 2-5-2 solenoid for the LEBT (left) and the calculated (using CST) magnetic field strength distribution (in z) along the z axis (right).

GPT code is used to simulate the particle transport of the LEBT. The field strengths of the three solenoids and the drift spaces between them are altered to optimise the beam injection into the RFQ. One result of these simulations is shown in figure 4. From the preliminary data from the first pepper pot system [8] the result is surprisingly good and a total transmission into the RFQ acceptance of 50% is predicted. This optimisation will be improved and refined using data from the new pepper pot system in order to achieve a near final design of the LEBT.

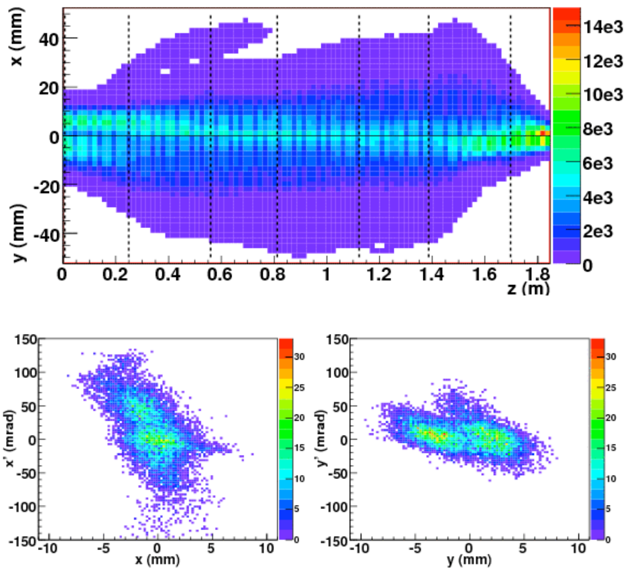

Figure 4: Trajectory plot (above) and output emittances ($\varepsilon_{x,rms}$=0.91πmmmrad; $\varepsilon_{y,rms}$=0.66πmmmrad) in the transversal plane (below) based on LEBT simulations, using the input data from the first pepper pot device ($\varepsilon_{x,rms}$=0.85πmmmrad; $\varepsilon_{y,rms}$=0.86πmmmrad). Dotted vertical lines show the drift and solenoid boundaries.

The mechanical design of the LEBT is quite progressed and a delivery of the solenoids is expected for spring 2008. The vacuum requirements have been defined, with pumps and equipment already purchased.

RFQ

A 324MHz four vane RFQ cold model consisting of 4 individual parts that were brazed together has been built to form a complete RFQ assembly shown in figure 5. Measurements of the RF properties of the cold model were performed before and after the brazing, together with measurements of the mechanical properties on a CMM machine to monitor the production process. Detailed results of RF measurements and electric field profile measurements using a bead-pull perturbation method are shown in [9]. A comparison of the calculated and measured frequencies and Q values are summarized in table 1.

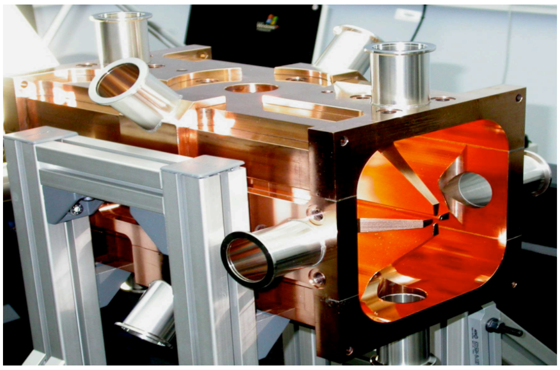

Figure 5: RFQ cold model after brazing.

Table 1: Comparison between simulated and measured results on 400mm long RFQ cold model.

	Frequency [MHz]	Unloaded Q
Simulation result (MWS)	319.7	9306
Measured before brazing	322.4±0.2	546±20
Measured after brazing	318.954±0.001	5616±50

MEBT AND CHOPPER

The MEBT chopper line is one of the key parts of the RAL Front End design. It consists of a series of quadrupoles, RF re-bunching cavities, and a beam chopper system (see figure 6). Extensive particle dynamics studies using TraceWin, Partran [10], and GPT [11] for different setups, have been investigated. All simulations have been performed using a uniform beam distribution tracked through the IPHI-RFQ, the two different MEBT lines and through Linac 4. A detailed analysis of the comparison between the results for the

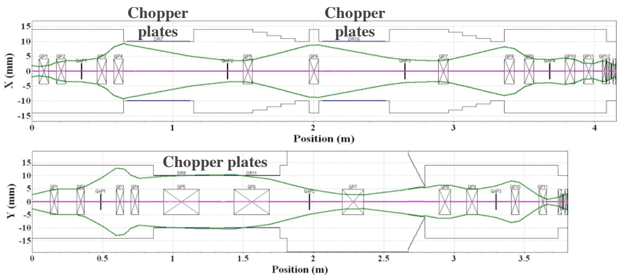

Figure 6: MEBT Beam Envelopes (5 RMS from Partran) in the chopping plane for RAL (top) and CERN (bottom) with the beam chopper switched off.

CERN and the RAL MEBT-Chopper design will be given in [10]; some of the results are summarized in Table 2. Although CERN and RAL have adopted different chopping schemes, end-to-end simulations indicate that they are similar in many respects. Slightly better results have been obtained when using the RAL chopper line, mainly due to the different MEBT optics in the two cases.

Table 2: Comparison of emittance growth and transmission between CERN and RAL MEBT designs.

	MEBT	LINAC4	Total
		RAL	
ε_x growth (%)	2.85	11.45	14.63
ε_y growth (%)	9.92	5.80	16.30
ε_z growth (%)	0.05	15.97	16.05
Transmission (%)	98.31	100	98.31
		CERN	
ε_x growth (%)	12.18	6.30	19.25
ε_y growth (%)	6.05	12.73	19.55
ε_z growth (%)	9.63	9.66	20.25
Transmission (%)	94.55	100	94.55

SUMMARY

The development of the Front End Test Stand has made significant progress in the last year. The infrastructure is prepared, the klystron delivered and the power supply is on order. The installation of the first parts of the setup start autumn 2007 and first beam is expected early 2008.

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