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The RAL Front End Test Stand

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A design for a proton driver front end test stand at the Rutherford Appleton Laboratory (RAL) in the UK is presented. The aim is to demonstrate the availability of well chopped H^- beams suitable for future high power proton accelerators. Advantage is being taken of existing RAL R&D programmes on H^- ion sources and beam choppers, and also of a previous RFQ test stand project at RAL for testing a new preinjector RFQ for the ISIS spallation neutron source.

1. INTRODUCTION

High power proton accelerators, *i.e.* proton accelerators with beam powers in the megawatt range, have many applications, including drivers for spallation neutron sources, neutrino factories, transmuters (for transmuting long-lived nuclear waste products), energy amplifiers and tritium production facilities. The highest beam powers that have been achieved for proton accelerators in the 1 GeV range so far are 0.8 MW (0.8 GeV, long pulse) in the PSR (LANL) machine [1] and 0.75 MW (0.59 GeV, CW) in the PSI cyclotron [2]. However, for the short pulse operation necessary for neutron spallation sources and neutrino factory drivers, only much lower beam powers have been used so far, *e.g.* ~0.08 MW for PSR and 0.16 MW for ISIS (0.8 GeV, RAL) [3]. Both machines use H^- injection to accumulate intense short bunches and need an increase of at least a factor ~30 to reach the goal of ~5 MW for future high power proton accelerators (HPPAs). This factor is far from trivial, even though ~1 MW beams should start to be coming on stream over the next few years at SNS [4] and J-PARC [5].

The quality of the beam in an accelerator facility is essentially set at the beginning of the accelerator, *i.e.* at the front end of the accelerator, and the informal universal standard for unplanned beam loss along an HPPA is $1\,\mathrm{W\,m^{-1}}$. Since for a 10 MW beam this represents a fractional power loss of 10^{-7} per metre at the top energy, high quality beams are essential.

In order to contribute to the development of HPPAs, to help prepare the way for ISIS upgrades through the design of a new 180 MeV injector linac, and to contribute to UK design effort on neutrino factories [6], a front end test stand covering a variety of beam current and pulsed distribution régimes is being constructed at the Rutherford Appleton Laboratory (RAL) in the UK with the aim of demonstrating that beams of sufficiently high quality can indeed be produced. It is expected that experience gained through the design, construction and operation of a previous RFQ test stand [7] at RAL will proved useful.

2. FRONT END TEST STAND

The RAL front end test stand is made up of five main elements, a 60 mA H^- ion source, a low energy beam transport (LEBT) to match the beam from the ion source into the RFQ, a four-rod RFQ, a beam chopper, and a comprehensive set of diagnostics. The aim is to demonstrate production of a 60 mA, 2 ms, 50 pps chopped beam. Each of these elements as envisaged at present will now be described briefly in turn.

2.1. H^- ion source

A review of H^- ion sources has been given in [8]. At RAL an ion source development programme [9] is taking place, based on the operationally highly successful ISIS H^- ion source [10] and part funded by the European Union [11]. The intention is to increase the extracted H^- ion current from 35 mA to 60 mA and to increase the pulse length from $\sim$250 μs to 2 ms. The essential parts of the development programme are uprating the arc power[1] and the extraction voltage[2] after re-engineering the source on the basis of results from detailed electromagnetic [12] and thermal [13] modelling.

2.2. LEBT

The LEBT will be based on the three-solenoid design of the test stand [7] previously built and operated at RAL to test the RFQ[3] being installed on ISIS to replace the ageing Cockcroft-Walton preinjector. The solenoids in the ISIS RFQ test stand incorporated built-in Lambertson dipoles for beam steering, and the same arrangement will be adopted here. Of course, because of the solenoid environment surrounding the steering dipoles, the steerers do not produce simple x- and y-deflections. But, in fact, very little steering indeed was found necessary on the ISIS RFQ test stand. Not unexpectedly, during commissioning of the ISIS RFQ test stand it was found that a good vacuum in the LEBT was essential to minimise stripping of the H^- beam, and the LEBT had to be modified mechanically to accept a 1000 instead of a 200 litres s^{-1} turbomolecular pump.

[1]Pulsed arc drivers able to provide stabilised currents up to $\sim$130 A instead of the $\sim$50 A used on ISIS have been obtained.

[2]A pulser able to provide a stabilised extraction voltage of 25 kV at currents up to 2 A for pulse lengths of 3 ms has been obtained.

[3]The ISIS RFQ has a 4-rod structure, runs at 202.5 MHz, and has 35 keV and 665 keV input and output energies respectively. As part of the ESS programme, it was designed for 50 mA of beam current with a duty factor of 10%, but in use on ISIS the corresponding numbers are 30 mA and 2%. The ISIS RFQ was run for >2000 hours on its test stand before being installed on ISIS.

2.3. RFQ

The RFQ is based both on the design of the RFQ already tested at RAL [7] and now installed on ISIS and on the design of the 4-rod RFQ for the ESS (European Spallation [Neutron] Source [14]). The input and output energies are 75 keV and 2.5 MeV respectively, and the frequency is 234.8 MHz. The modelling of the focussing, bunching and acceleration of the beam through the RFQ is being carried out using the code [15] which has already been benchmarked against the ISIS RFQ [16]. One of the most important components of the RFQ system as a whole is the RF driver, which has to supply powers of 1–2 MW. One reason for the choice of 234.8 MHz for the RF frequency is to be able to use existing 704.4 MHz designs for side-coupled cavities in Linac4 [17] at CERN after a three-fold frequency jump at $\sim$80 MeV. A first set of beam dynamics calculations simulating the 234.8/704.4 MHz scheme are presented in [18].

2.4. Beam chopper

Bunched beam from the RFQ will be matched into a 2.5 MeV medium energy beam transport (MEBT) line consisting of a series of quadrupoles, RF cavities, and a fast beam chopper. The optical design of the MEBT will ensure that emittance growth is minimised. The chopper design, based on a proposal [19] for the ESS, addresses the challenging requirement for a fast ($\sim$2 ns) field transition time, combined with a long ($\sim$0.1 ms) chopped beam duration, by utilising two cascaded slow-wave E-field beam deflectors, in an innovative "fast-slow" configuration. This will consist of a fast transition time ($\sim$2 ns), short duration ($\sim$12 ns) chopper with a distributed element (transmission line) electrode, followed by a slower transition time ($\sim$12 ns), long duration ($\sim$0.1 ms) chopper with a water cooled, lumped element electrode structure that will also serve as a beam dump. The fast structure will pre-chop just three bunches at the beginning and end of each chopped beam interval, and in so doing will ensure that no partially chopped bunches result from the slower transition time of the downstream slow lumped element structure. Prototype planar and helical fast chopper structures have been designed [20], and a prototype fast pulse generator has been recently demonstrated [21]. This work is being partially supported by the EU [22].

2.5. Diagnostics

The main purpose of the front end test stand is to demonstrate the production of high quality beams suitable for high power proton accelerators, so the provision of suitable beam diagnostics is very important. Diagnostics between the ion source and the RFQ, after the RFQ and after the beam chopper are required. The diagnostics to be used include those already used satisfactorily on the ISIS RFQ test stand, *viz* centre-tapped beam current transformers generally built into vacuum vessel flanges, slit-and-cup emittance scanners, a coaxial target, a magnetic energy spectrometer, and a gas scattering energy spectrometer [23]. In addition, beam bunches will have to be measured with a dynamic range of $\sim 10^4$ to suitably demonstrate operation of the beam chopper.

3. RF SYSTEMS

The RFQ needs $\sim 1-2$ MW of RF power to drive it satisfactorily. At 234 MHz the RF frequency is too low to be easily practical for klystrons, whereas the same frequency is high for high power gridded tubes. The Thales TH628 Diacrode tube [24], so far used for frequencies up to 200 MHz, may be suitable for 234 MHz after modification. But, at least for some parameter régimes, it may be possible to use the elderly but proven Thales TH116 5 MW triode used on the ISIS 70 MeV injector linac [25].

4. SUMMARY

The front end test stand being built at RAL to contribute to the development of high power proton accelerators has been described. Design and development work is well under way, with first beam through the LEBT planned for 2007.

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