STATUS OF THE RAL FRONT END TEST STAND

A. Letchford, M. A. Clarke-Gayther, D. Faircloth, S. R. Lawrie, M. Perkins, P. Wise (STFC/RAL/ISIS, Didcot, Oxon, UK), A. Kurup (Fermilab, Batavia; Imperial College of Science and Technology, London, UK), S. Alsari, S. Jolly, D. A. Lee, P. Savage (Imperial College of Science and Technology, London, UK), J. K. Pozimski (Imperial College of Science and Technology, London; STFC/RAL, Didcot, Oxon, UK), C. Gabor, C. Plostinar (STFC/RAL/ASTeC, Didcot, Oxon, UK), J. Back (University of Warwick, Coventry, UK), F. J. Bermejo (Bilbao, Bilbao), R. Enparantza, I. Ariz, P. Romano, A. Sedano (Fundación TEKNIKER, Eibar (Gipuzkoa), V. Etxebarria (University of the Basque Country, Bilbao), H. Hassanzadegan, N. Garmendia (ESS Bilbao, Bilbao), M. Eguiraun (ESS-Bilbao, Zamudio)

Abstract

The Front End Test Stand (FETS) under construction at the Rutherford Appleton Laboratory is the UK's contribution to research into the next generation of High Power Proton Accelerators (HPPAs). HPPAs are an essential part of any future Spallation Neutron Source, Neutrino Factory, Muon Collider, Accelerator Driven Sub-critical System, Waste Transmuter etc. FETS will demonstrate a high quality, high intensity, chopped H-minus beam and is a collaboration between RAL, Imperial College and the Universtity of Warwick in the UK and the Universidad del Pais Vasco and ESS-Bilbao in Spain. This paper describes the current status and future plans of FETS.

BACKGROUND

Beam chopping will be an important feature of the next generation of HPPAs. The requirement to minimise the need for remote handling of accelerator components dictate that beam loss in future machines must be kept to levels comparable to those of current facilities in order to avoid activation. With beam powers an order of magnitude or more greater than those currently achieved, fractional beam loss must necessarily be reduced by a similar factor.

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 chopped beam allows for the ring RF bucket to be precisely filled with little trapping loss. The low levels of beam between bunches can also reduce loss at ring extraction.

FRONT END TEST STAND

Originally conceived simply as a chopper beam test, FETS has since expanded its objectives to become a generic test stand for technologies related to the front end of several proposed projects which require a high power proton driver. These projects include but are not limited to Spallation Neutron Sources, a Neutrino Factory, Muon Collider, Accelerator Driven Sub-critical Systems and Waste Transmuters.

A secondary objective of FETS was to encourage the study of accelerator technology by a new generation of accelerator engineers and physicists in UK universities. The quality of the work being produced by the mostly young team working on FETS is testament to the success in this objective.

FETS has also resulted in a fruitful collaboration between RAL/ISIS the ESS-Bilbao project in Spain. The exchange of ideas, experience and hardware is proving extremely beneficial to both sides.

TEST STAND COMPONENTS

FETS has been extensively described elsewhere [1][2][3][4]. It consists of an H^- ion source, magnetic low energy beam transport (LEBT), 324 MHz Radio Frequency Quadrupole accelerator (RFQ), medium energy beam transport and chopper line (MEBT) and comprehensive diagnostics. The rest of this paper describes the status and future plans for each component of the test stand.

Ion Source

FETS uses a modified version of the Penning type surface plasma ion source which has been developed over many years on the ISIS facility [5]. Since achieving first beam in April 2009 the ion source has been running routinely, producing currents of 50mA or more. In order to reach the required performance specification for FETS, extensive studies have been carried out into the beam formation and extraction process [6], its transport through the 90º analysing magnet [7] and the post acceleration gap optics [8]. To facilitate these studies, improved beam diagnostics have been developed [9][10].

From a starting point of transverse emittances of >0.8 π mm mrad normalised rms, these combined efforts have achieved emittances as low as 0.3-0.35 π mm mrad [11], getting close to the FETS specification of 0.25 π mm mrad normalised rms.

Although power supply limitations prevent the extraction of full 2ms beam pulses at 50Hz as required by the FETS specification, long discharge pulses have been generated and the beam parameters investigated at various points along the discharge [12]. It is hoped that a long pulse extraction power supply will be available in the not too distant future.

Low Energy Beam Transport

FETS employs a 3 solenoid magnetic LEBT to transport and match the beam from the ion source into the RFQ at 65 keV [13]. The 3 solenoids are identical and designed for an on axis peak field of 0.4T and a bore diameter of 90mm. The solenoids were manufactured by Elytt Energy and their associated power supplies by JEMA. Both were supplied to FETS as part of our collaboration with ESS-Bilbao.

Installation and commissioning of the LEBT has been completed with the first LEBT beam being achieved in spring 2010. Measurement of the solenoid magnetic field showed extremely good agreement with the design predictions. Preliminary measurements of the beam parameters at the end of the LEBT also agree well with the design specification [11][14]. Beam currents in excess of 50mA have been transported through the LEBT with little emittance growth and just a few percent stripping losses.

Over the coming months the LEBT will be fully characterised. Coupled with further ion source improvements the goal is to achieve a well matched, low emittance beam with little aberration at the RFQ entrance.

Radio Frequency Quadrupole

The FETS RFQ is a 324 MHz, 4-vane RFQ with a final energy of 3 MeV. The total length is 4.2m for an inter-electrode voltage of 85 kV which results in a peak surface field of approx 1.7 times the Kilpatrick field. Beam dynamics simulations indicate a transmission of >95% for a current of 60mA.

A short cold model of a section of the RFQ, without vane modulations, was constructed to investigate the RF properties of the resonator and compare with the design theory [15]. This model has subsequently been used to develop a resonant frequency auto-tuning system [16] and will be used to confirm the operation of the low level RF control system.

Considerable effort is going into investigating different methods of RFQ manufacture. Particular areas of attention are the technique to be used to join the RFQ segments and the method of water cooling. Alternatives to the usual vacuum brazing technique such as laser or electron beam welding appear to have some advantages as does a purely bolted assembly from the point of view of repairability [17]. Alternative water cooling methods which don't require long, gun drilled passages also offer some advantages [18]. Manufacturing tests of these ideas will be undertaken in the near future with an aim of finalising the design and starting manufacture of the RFQ before the year end.

A novel integrated CAD, electro-magnetic and beam dynamics design method is being investigated for the FETS RFQ [19]. A full engineering CAD model of the modulated vane tips is imported into an electro-magnetic field solver to generate a field map through which the particles are tracked using the GPT code. Comparisons are underway between the field maps produced by CST EM Studio and COMSOL Multiphysics.

RF Control

A digital IQ RF control loop has been designed and built at the Universidad del Pais Vasco in Bilbao [20]. Based around an analogue front-end and 14 bit FPGA, the system works directly on the 324 MHz RF signal with no IF. On tests with a simple pillbox test cavity, control of pulsed RF with <±0.5% amplitude error and <±0.5º phase error has been demonstrated. Further tests on the RFQ cold model will be completed soon.

Beam Chopper

The FETS fast-slow beam chopper has been described in detail elsewhere [21][22]. This novel combination of two distinct chopper types, working in tandem, allows both very fast rise time and long flat-top pulses to be generated without losing the fidelity of the sharp pulse edges as the wave propagates through the deflector.

Having previously demonstrated the feasibility of the fast pulse modulators, prototyping of the deflectors is now well under way. Two types of deflector are under investigation: a 'planar' type, essentially a meander line deflector and a 'helical' type consisting of discrete deflector plates connected by external delay lines. Unit parts of both type of deflector have been manufactured and tested to evaluate different fabrication techniques. The next step will be to prototype complete assemblies before producing a final, fully engineered design complete with vacuum chamber, pumps, ports etc.

MEBT

The beam chopper and associated beam dumps are located in the MEBT. Achieving low emittance growth under the influence of strong, non-linear space charge in a lattice which has to accommodate the long chopping elements – which inherently break the periodicity of the lattice – is challenging. The baseline FETS MEBT design [23] is 4.5m long and contains 11 quadrupoles, 4 rebunching cavities, a fast and slow chopper deflector and two beam dumps. In particle dynamics simulations using a distribution from an RFQ simulation as input, the emittance growth is no more than 5% in the transverse plane. Beam loss for the un-chopped beam is ~1.5% while the chopping efficiency is ~99%.

In addition to standard electromagnetic quarupoles (EMQ), hybrid quarupoles are also being investigated [24]. The hybrid magnet is a combination of permanent magnet quadrupole (PMQ) and laminar EMQ (Lambertson quad.) which allows for a limited range of adjustment in a compact size.

The rebunching cavities are high shunt impedance, CCL type cavities [25]. Prototyping is about to begin with a cold model being manufactured by Tekniker, part of the ESS-Bilbao consortium.

Beam Diagnostics

Particular attention is being paid on FETS to non-destructive diagnostics based on laser photo-detachment of electrons from the H^- ions [26]. The first laser profile measurement experiments have been completed on the beam downstream of the FETS ion source with disappointing results. Due to the high residual gas pressure so close to the source and the limited laser power available, the electron signal was swamped by signals produced by beam interactions with the residual gas in the detector. With a higher power laser borrowed from IAP Frankfurt, new optics plus improved detector and electronics it is hoped to successfully measure a beam profile in the near future.

Beam Dump

With an average beam power of 18kW at full duty factor and an energy above the neutron production threshold for some engineering materials, considerable attention has been paid to the FETS beam dump. In order to limit the shielding requirements and radiation doses to personnel, reducing both prompt and induced activity from the beam dump has been a high priority.

Ultra high purity Aluminium (99.99%) with extremely low levels of impurities, in particular Copper, has been selected as the material for the beam dump which has been manufactured by Tekniker [27]. Although the radiological and thermal properties are good, the mechanical strength of pure Al is poor. The solution is a cold worked cone formed by spinning which increases the yield stress up to 7 times in tests. Cooling water flows over the outside of the cone and keeps the surface temperature below 150ºC to avoid annealing the cold worked metal.

REFERENCES

[1] D.J.S. Findlay et al, "The RAL Front End Test Stand", Proc. NuFact04, Osaka University, Japan, Aug 2004

[2] J.J. Back et al, "Progress at the RAL Front End Test Stand", Nucl Phys B (Proc Suppl) 155 309-311

[3] A. Letchford et al, "Status of the RAL Front End Test Stand", LINAC'08, Victoria BC, September 2008

[4] A. Letchford et al, "Status of the RAL Front End Test Stand", EPAC'08, Genoa, June 2008

[5] D. Faircloth et al, "The Front End Test Stand High Performance H- Ion Source at RAL", Review of Scientific Instruments, Volume 81, Issue 2, 2010

[6] S. Lawrie et al, "Plasma Meniscus and Extraction Electrode Studies of the ISIS H- Ion Source" Review of Scientific Instruments, Volume 81, Issue 2 , 2010

[7] S.Lawrie et al, "Redesign of the Analysing Magnet in the ISIS H− Penning Ion Source", AIP Conf. Proc. Volume 1097, pp. 253-262, 2009

[8] D. Faircloth et al, "Study of the Post Extraction Acceleration Gap in the ISIS H- Penning Ion Source", EPAC'08, Genoa, June 2008

[9] S. Lawrie et al, "Improving the ISIS Emittance Scanner Software", EPAC'08, Genoa, June 2008

[10] S. Jolly et al, "Data Acquisition and Error Analysis for Pepperpot Emittance Measurements", DIPAC'09, Basel, September 2009

[11] S. Lawrie et al, "Assessing the Transmission of the H- Ion Beam on the Front End Test Stand", IPAC2010, Kyoto, May 2010

[12] D. Faircloth et al, "Pulse Lengthening Experiments on the FETS Ion Source", IPAC2010, Kyoto, May 2010

[13] S. Jolly et al, "LEBT Simulations and Ion Source Beam Measurements for the Front End Test Stand (FETS)", EPAC'06, Edinburgh, June 2006

[14] J. Back et al, "Commissioning of the Low Energy Beam Transport of the Front End Test Stand", IPAC2010, Kyoto, May 2010

[15] S. Jolly et al, "Detailed Study of the RF Properties of the FETS RFQ Cold Model", EPAC'08, Genoa, June 2008

[16] S. Alsari et al, "A Tuning System for the FETS RFQ", IPAC2010, Kyoto, May 2010

[17] P. Savage et al, "The Mechanical Engineering Design of the FETS RFQ", IPAC2010, Kyoto, May 2010

[18] S. Lawrie et al, "Combined Electromagnetic-Thermal-Structural Simulation of the Four-metre Radio Frequency Quadrupole to be Installed on the Front End Test Stand", IPAC2010, Kyoto, May 2010

[19] S. Jolly et al, "Integrated Design Method and Beam Dynamics Simulations for the FETS Radio Frequency Quadrupole", IPAC2010, Kyoto, May 2010

[20] H. Hassanzadegan, "Design and Implementation of a Pulsed Digital LLRF System for the RAL Front End Test Stand", IPAC2010, Kyoto, May 2010

[21] M. Clarke-Gayther, "The Development of a Fast Beam Chopper for Next Generation High Power Proton Drivers", EPAC'08, Genoa, June 2008

[22] M. Clarke-Gayther, "The Development of a Fast Beam Chopper for Next Generation High Power Proton Drivers", IPAC2010, Kyoto, May 2010

[23] C. Plostinar, "MEBT design progress for the Front End Test Stand", IPAC2010, Kyoto, May 2010

[24] C. Plostinar et al., "A hybrid quadrupole design for the RAL Front End Test Stand (FETS)", EPAC'08, Genoa, June 2008

[25] C. Plostinar et al, "Design progress of the re-bunching RF cavities and hybrid quadrupoles ofr the RAL Front End Test Stand (FETS)", EPAC'06, Edinburgh, June 2006

[26] C. Gabor et al, "Diagnostic Experiments on a 3MeV H- Test Stand at Rutherford Lab", Review of Scientific Instruments, Volume 81, Issue 2 , 2010

[27] R. Enparantza et al, "Beam stop design and construction for the front end test stand at ISIS", IPAC2010, Kyoto, May 2010