

STATUS REPORT OF THE FETS PHOTO DETACHMENT EMITTANCE INSTRUMENT AT RAL

C. Gabor*, A.P. Letchford, STFC RAL, UK
 A. Bosco, G. Boorman, S.M. Gibson, JAI at Royal Holloway, University of London, UK
 P. Savage, Imperial College London, UK
 V. Scarpine, Fermilab, USA

Abstract

The Front End Test Stand at the Rutherford Appleton Laboratory (RAL) is being developed to demonstrate a chopped H^- beam of 60 mA at 3 MeV with 10 % duty cycle. Due to the high beam power it is advisable to use the technique of photo detachment to avoid intrusive methods. It is intended to apply this technique to perform emittance measurements at the output of the RFQ at full power. This requires a dedicated diagnostics dipole with a special-made vacuum chamber giving room for the different beam paths necessary to install a particle detector to measure the produced neutrals. Other aspects are the beam transport and influence of the dipole and its fringe field to the beam transport. Other considerations are the installation of the laser, the optics and the particle detector itself.

INTRODUCTION

The Front End Test Stand (FETS) under construction at the Rutherford Appleton Laboratory (RAL), UK, built in collaboration between ISIS, ASTeC, Imperial College London (IC), the University of Warwick, University College London (UCL) and the John Adams Institute (JAI) at Royal Holloway, University of London (RHUL).

This experiment aims to demonstrate the first stages necessary to produce a very high quality chopped H^- ion beam as required for future high power proton accelerator applications. The beam will be pulsed at 50 Hz, with pulse lengths of up to 2 ms, current of 60 mA and energy of 3 MeV. A good overview of the whole project with appropriate references can be found here [1, 2]. One of the key components of FETS is the non-destructive (or to be correct: minimal-invasive) diagnostics at 3 MeV beam energy. Using a laser to neutralize (photo-detachment) a small portion of the beam pulse is one of the most prominent candidate for H^- ion beams used by other facilities like JPARC and SNS. First ideas to use photo-detachment for the FETS project are described in [3]; the concept of Photo-Detachment Emittance Instrument is derived from the “proof-of-principle” experiment in Frankfurt [4]. The paper summarizes the most recent developments of this topic concentration on a scintillator test at Fermilab (FNAL) and a design of a laser delivery system which will be important if there are plans for a fast mode-locked laser for time resolved measurements.

* christoph.gabor@stfc.ac.uk

Layout of the PD-EMI

At the interaction point, laser light neutralizes (photo-detachment) a small portion of the H^- ions and a magnetic dipole field separates the produced species electrons and neutrals from the remaining ions. For a more exhaustive description see also [5] where also magnet and diagnostics chamber including a general concept of commission-

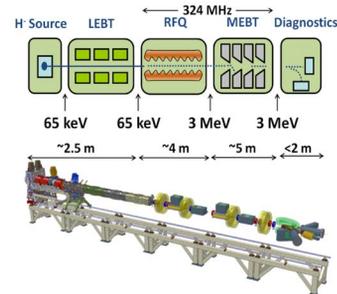


Figure 1: Sketch of the FETS project. Shown are the main components ion source, LEBT, RFQ, MEFT and photo-detachment diagnostics.

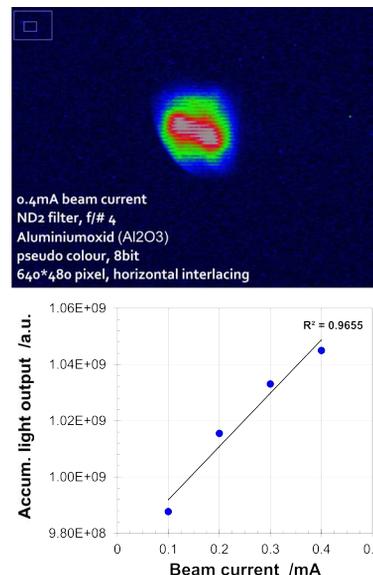


Figure 2: TOP: 2D beam distribution measured with Aluminiumoxide. BOTTOM: light output integrated over the profile versus beam current.

ing is described. In such an arrangement, the emittance of one transverse plane can be measured directly. Typically the dipole bends in horizontal plane, hence the orientation of the laser beam is also parallel to the x-axis which means yy' is measured directly. Applying the methods of image reconstruction as outlined in [6, 7], the missing xx' emittance can be calculated as long as sufficient variation of the twiss parameters can be provided by the MEBT quadrupoles [8]. For best results, this means the output of the MEBT should be known (by simulations for example) in order to match the beam transportation through the dipole and diagnostics chamber for best results. It might be worth to mention that this set-up is ideal to investigate coupling of the two different planes, e.g. a skew (QUAD) dublet would not only provide the necessary phase advance but also shifts the x-plane into the vertical plane where a more direct measurement is possible. Therefore, activities on this field are on hold as long as the new MEBT layout is not finalized.

SCINTILLATOR TESTS

The scintillator tests have been performed at Fermilab in the US at the HINS test stand ([9]). The beam energy is 2.5 MeV which is sufficiently close to the FETS energy. It is also important that wire scans and current measurements were possible reasonable close to the installation of the scintillator. The target holder was mounted under an angle of 45° using a 8bit analogue CCD camera. The low dynamic range of the camera made it necessary to use filters to dim the light (and was not related in any way to a saturated scintillator). The focus was on general light output and its linearity depending on beam current variation. It was also important to check that the radiation level was tolerable for the CCD camera. Due to the low energy of the beam the penetration depth is shallow, therefore a high energy deposition per volume can lead to destruction. This requires a less sensitive scintillator material to guarantee some survivability but reduces the efficiency of the light conversion.

In 2 some of the most important results are summarized. The top picture shows a 2dim beam profile with some interlacing in horizontal direction. The distribution is shown in pseudo-colours and was taken with Aluminiumoxide without any further elements (purity of 99.99%). The current was variable between approx. $100 \mu\text{A}$ up to 1 mA.

OPTICAL SYSTEM

Fibre-laser Description

The laser system chosen for the photo-detachment experiment is a Q-switched, diode pumped, all-fibre Master Oscillator and Power Amplifier (MOPA) laser, model ML-30-PL-R-TKS manufactured by Manlight S. A. S. (Lannion, France). The oscillator generates 110 ns pulses at a repetition rate selectable between 30 and 100 kHz. The fibre amplifier is pumped by a diode laser that either runs in CW mode or is modulated by an external signal with

a repetition rate of up to 5 kHz. The pulses generated by the oscillator cannot be phase-locked to an external reference, however the envelope of the amplified pulses may be synchronized via the external modulation signal. Thus the timing of the pulse train can be adjusted to match the duty cycle of the accelerator, thereby reducing the average laser power that needs to be handled. The laser parameters are summarized in Table 1.

Table 1: Summary of Fibre-laser Parameters

Wavelength	1064 nm
Average power	28 W
Repetition rate	30 - 100 kHz
Pulse energy @ 30 kHz	0.93 mJ
Pulse duration (FWHM)	110 ns
Pulse peak power	8.5 kW
Spatial beam quality (M^2)	< 1.7

At the wavelength of 1064 nm the corresponding photon energy of 1.16 eV is sufficient to detach one of the weakly bound (0.75 eV) electrons and neutralize the H^- ion. The laser pulse duration of 110 ns is significantly longer than the macro-bunch spacing of ~ 3.1 ns, enabling each laser pulse to interact with ~ 35 micro-bunches. This eliminates the need for synchronization at the nanosecond level and ensures a high number of signal events per laser pulse.

Laser Measurements

An example of the amplified laser pulses is shown in Figure 3 (left and centre), for which the pump was modulated with a 2 ms square wave at 50% duty cycle. The rise time to reach the amplification steady state was $434 \mu\text{s}$, after which the pulse-to-pulse stability was 7% RMS. The average laser power versus amplifier current is plotted in Figure 3 (right) for two amplification regimes, CW and 50% duty cycle with the pump modulated at 250 Hz. Ideally, the duty cycle of the laser-amplifier should be reduced to match that of the accelerator, while maintaining the pulse peak power. This will be achieved either internally by controlling the pumping regime or by means of an external modulator.

Figure 4 reports the measurement of the spatial mode quality M^2 for the two orthogonal axes (left and right) and an image of the laser spot at the focus (centre). The laser was focused by a plano-convex singlet lens of 500 mm focal length. The laser spot images were acquired by a CCD camera with $6.7 \mu\text{m}$ square pixel size, mounted on a motorized translation stage. The M^2 factors were calculated by fitting the data with the beam propagation equation for non-ideal Gaussian beams [10], resulting in 1.3 for the horizontal axis and 1.7 for the vertical axis.

Beam transport

The laser system will be installed in an air-conditioned room outside the radiation shielding. Light will be conveyed over 100 m to the interaction region via optical fibre. The transport fibre (Nufern PLMA-GDF-20/130) has

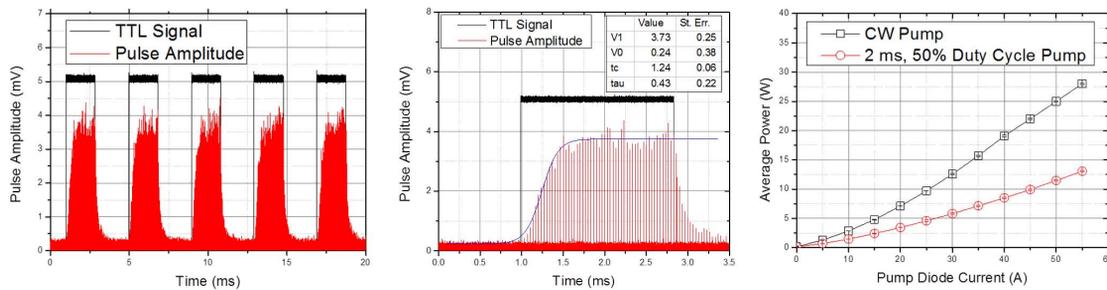


Figure 3: Amplified laser pulses with 250 Hz square wave modulation (left). Zoomed view showing the amplification rise time (centre). Fibre-laser power versus amplifier pump current right).

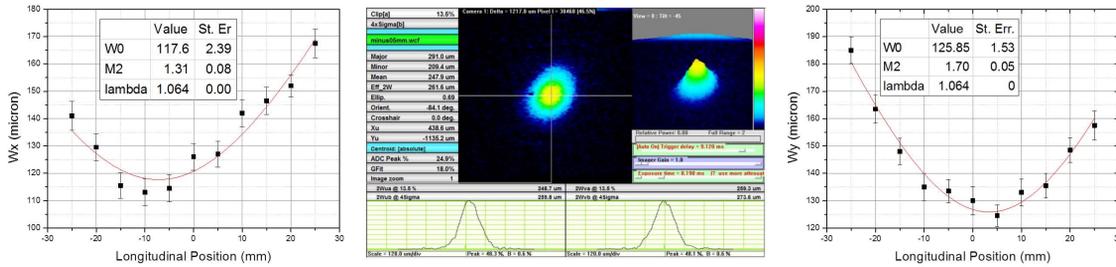


Figure 4: Measurements of spatial quality of the fibre-laser beam output. Longitudinal variation of horizontal (left) and vertical (right) beam profiles. CCD image at the lens focal plane (centre).

a core size of 20 μm and a numerical aperture $\text{NA}=0.08$. The beam parameter product is equivalent to a Gaussian beam with $M^2 = 2.35$. An optical assembly consisting of a collimating aspheric lens and a motorized variable beam expander produces a beam with a diameter adjustable from 1 to 8 mm. This flexibility on the laser output enables control of the thickness of the laserwire delivered to the interaction chamber and ensures compatibility with the full range of H^- beam sizes.

CONCLUSION

The scintillator test was very successful. Obviously some uncertainty will remain because the total current was too high compared to the expected flux of produced neutrals. On the other hand, the camera had no image intensifier and filters were necessary to reduce the light. A more detailed summary of the results should be subject of a further publication. Laser commissioning and delivery system are well under way and the magnet design can be finalized as soon as the MEBT layout is fully known.

ACKNOWLEDGMENT

The authors want to thank Fermilab (USA) and in particular the FNAL staff B.M.Hanna and J.M.Steimel for support and running the HINS test-stand for the scintillator measurements. Without V.Scarpines efforts to extend the beam time for HINS the experiment would not have been possible. Also thanks to GSI/ IAP Frankfurt (both Germany) and Eiko Gütllich for helping out with scintillator material and fruitful discussions.

REFERENCES

- [1] A.P.Letchford et al., "Status of the RAL Front End Test Stand", IPAC 2013, Shanghai, May 2013, THPWO086
- [2] C.Plostinar, A.P.Letchford, et al., "Current status of the Status of the RAL Front End Test Stand", LINAC 2012, Tel-Aviv, Israel, September 2012, THPB004
- [3] C.Gabor, D.A.Lee, J.K.Pozimski, A.P.Letchford, "Laser-based beam diagnostics for the front end test stand (FETS) at (RAL)", EPAC 2006, Edinburgh, May 2006, TUPCH019
- [4] C.Gabor, "Untersuchungen zur zerstörungsfreien Emittanzmessung an einem Testaufbau für negative Ionen", Goethe-Universität Frankfurt, IAP, PhD-thesis, 2007
- [5] C.Gabor, G.Boorman, A.Bosco, P.Savage, A.P.Letchford, "Design of a photo-detachment emittance instrument for FETS", ICFA High Brightness (HB) 2012, Beijing, China, 2012
- [6] C.Gabor, J.K.Pozimski, A.P.Letchford, C.R. Prior, "Emittance Measurement Instrument for a high Brilliance H^- ion beam", LINAC 2008, Victoria, British Columbia, Canada, TUP084
- [7] D.S.Sivia, J.Skilling, "Data Analysis — A Bayesian Tutorial", 2nd edition, Oxford University Press, 2006
- [8] C.Gabor, A.P.Letchford, J.k.Pozimski, "MEBT design for the RAL front end test stand", DIPAC 2009, Basel, Switzerland, TUPB22
- [9] V.E.Scarpine, S.Chaurize, B.M.Hanna, S.Hays, J.Steimel, R.C.Webber, D.Wildman "The Fermilab HINS Test Facility and Beam Measurements of the Ion Source and 325 MHz RFQ", DIPAC 2011, Hamburg, Germany, TUOA03
- [10] E.Hecht, "Optics", Ch. 13, Addison-Wesley Longman, Inc., 2002.