STATUS OF THE LASER-BASED BEAM PROFILE INSTRUMENT FOR THE RAL FRONT END TEST STAND

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Abstract

The RAL Front End Test Stand is under construction with the aim of demonstrating production of a high-quality, chopped 60 mA H^- beam at 3 MeV and 50 pps. In addition to the accelerator development, novel laser-based diagnostics will be implemented. This paper reports on a device that will be able to measure multiple profiles of the beam density distribution in such a way that the full 2D density distribution can be reconstructed. The device is currently being commissioned. The status of the device is presented together with results of the commissioning and plans for future development.

INTRODUCTION

The Front End Test Stand is currently under construction at RAL. It will eventually consist of a high-brightness, 65 keV H^- ion source; a three solenoid Low Energy Beam Transport (LEBT); a 324 MHz, four-vane Radio Frequency Quadrupole (RFQ) that will accelerate the beam to 3 MeV; a Medium Energy Beam Transport (MEBT) section incorporating a beam chopper; and a comprehensive suite of diagnostics.

First beam was achieved from the ion source on 30 April (see Figure 1 and [1] for details). Regular operation is anticipated to begin by the end of June 2009, at which time beam commissioning of the laser-based profile monitor described in this paper will begin. A laser-based emittance monitor that will measure the emittance after the MEBT at 3 MeV is also under development; it is described in [2].

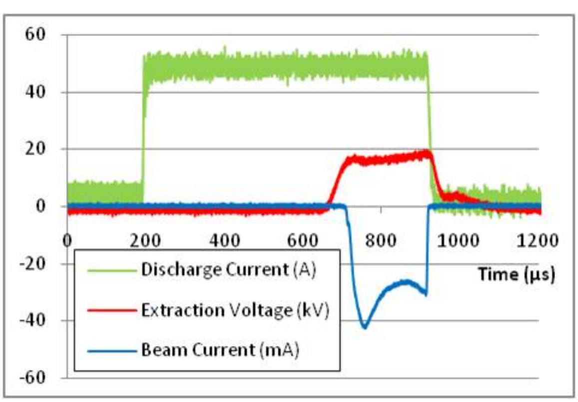


Figure 1: An oscilloscope trace of the first beam from the FETS ion source [1]

LASER-BASED H^- BEAM DIAGNOSTICS

Lasers can be used to diagnose H^- beams by the photo-detachment of the outer electron of the H^- ions, via the process $H^- + \gamma \rightarrow H^0 + e^-$. The detached electrons or neutralised H^0 atoms can then be used to diagnose the beam; in the case of the profile monitor, the electrons are used. (The emittance monitor uses the neutralised H^0 atoms.) The detached electrons are separated from the ions (and the neutralised H^0) by a dipole magnet and the number of electrons is measured by a Faraday cup. This technique is illustrated in Figure 2. For the instrument described in this paper, due to the low energy of the electrons detached from the 65 keV H^- ions, it is also necessary to accelerate the electrons (in this case by a 2 kV electric field) to reduce any possible deflection by stray fields.

By having a laser with a beam diameter significantly smaller ($\sim$1 mm) than the ion beam diameter ($\sim$50 mm), stepping the laser beam across the ion beam and counting the number of electrons detached at each laser position, a projection of the ion beam onto a plane can be built up. A series of mirrors mounted on movable stages inside the vacuum vessel be used to step the laser beam across the ion beam. Additionally, the mirrors can be rotated and so the laser beam can pass through the ion beam at a variety of angles such that a projection onto any arbitrary plane can be measured. This is illustrated in Figure 3. A series of measurements at a variety of angles can be combined tomographically to give a full, correlated 2D beam profile. For this instrument, the measurements will be combined using the Algebraic Reconstruction Technique [3, 4].

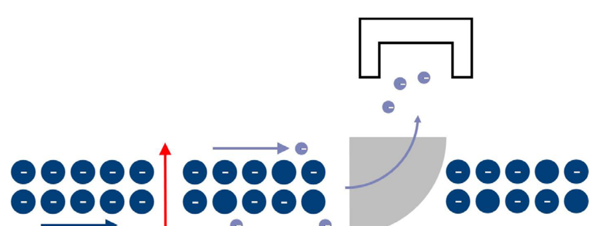


Figure 2: An illustration of the laser-based profile monitor principle. The laser (red) detaches some electrons (light blue) from the H^- ions (dark blue), which are then deflected by a dipole magnet (grey) into a Faraday cup.

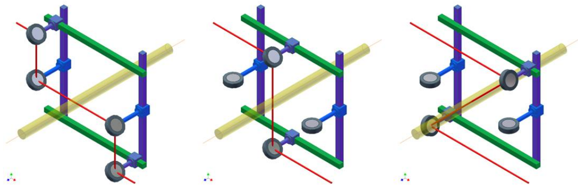


Figure 3: Three possible mirror configurations. The mirrors can rotate about their centrelines and move along x or y, depending on their positioning. The laser beam is shown in red and the ion beam in yellow

INSTALLATION AND OPTICS STATUS

The vessel in which the beam profile measurement will be made and the components required to make the measurement are complete and installed. They are shown in Figure 4. A vessel that will house the pepperpot system constructed for the characterisation of the FETS ion source [5] is also complete. This will allow for comparison between the initial laser-based profile measurements and ones from a scintillator screen.

Initially, two of the four pairs of stages will be installed (the back of the linear stages can be seen in Figure 4), giving coverage of half (180°) of the beam.

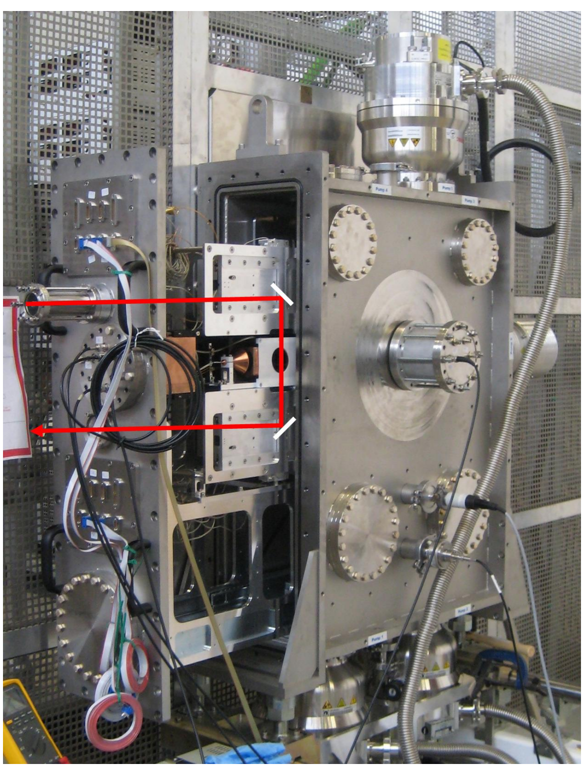
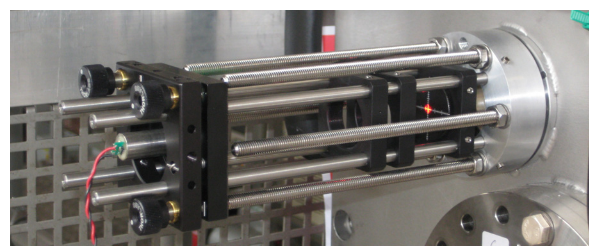
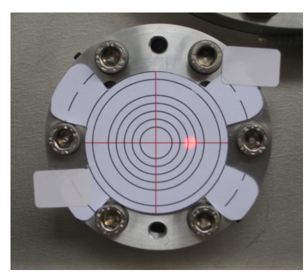


Figure 4: The vacuum vessel and the components required to make the beam density distribution measurement. In the centre of the picture the detector's copper Faraday cup can be seen. The central position of the mirrors is shown schematically in white, with the corresponding laser path in red.

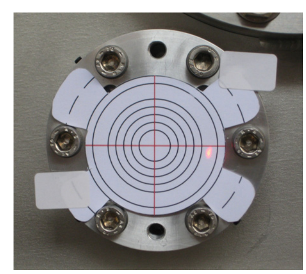
Due to the high power of the Nd:VO_4 laser that will be used to make the beam profile measurements, a lower power laser is being used to align the internal components of the vessel. In initial tests of the alignment, the rotary stages were configured to send the laser beam vertically down, as shown in Figure 4. The linear stages were then moved over their full travel (corresponding to a change in the path length of 400 mm) and the output position of the laser was found to vary by 7 mm. This corresponds to a mis-alignment of 0.0175 radians. This level of misalignment is tolerable as the beam does get coupled out from the vessel but may be corrected with shims between the stages and the frame on which they are mounted. A photograph of the alignment test setup is shown in Figure 5. It is anticipated that for the final alignment check a quantitative study will be performed using a position-sensitive laser power meter.



(a) The alignment laser jig, mounted on the laser input window. The output window is positioned 220 mm below the input window.



(b) A target mounted on the output window. The target's radii are 5 mm, 7.5 mm, 10 mm and so on. The movable stages are nearest to the vessel wall that the windows are mounted in (i.e. this is the configuration with the shortest path length).

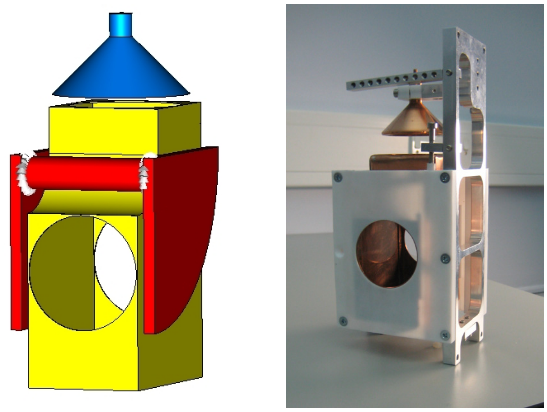


(c) For this picture the stages were moved to the furthest position from the vessel wall with the windows mounted in (such that the extra path length is 400 mm). Note that the spot has moved by ~7 mm, compared to it's position in Figure 5b.

Figure 5: The optical alignment setup and results of initial alignment tests.

DETECTOR STATUS

The electron detector assembly consists of a copper sheath to accelerate the electrons, a dipole magnet to deflect them and a Faraday cup to collect them. It is shown in Figure 6. It is a compact assembly as the beamline length available for the vessel in which it is mounted is only 200 mm. The vessel has to be this short to prevent the divergent ion source beam becoming larger than the aperture of the first solenoid of the LEBT.



(a) A schematic of the detector. The magnet is shown in red, the accelerating sheath in yellow and the Faraday cup in blue.

(b) A photograph of the detector, shown in it's mechanical assembly. The magnet is not shown in this picture.

Figure 6: The detector, viewed from upstream. Electrons are deflected up into the Faraday Cup whilst the H^- ions pass straight through. The detector is ∼16 cm high.

Magnetic Field Measurements

In the design phase, the detector was simulated and it's performance assessed [6]. Subsequently, the bending component of the dipole magnet's field has been mapped at Daresbury Laboratory [7] to verify the simulation. The field was mapped on a 5 mm grid in the region where the electrons will be subjected to the dipole's field. The discrepancy between the measurement and simulation, averaged over all of the measurement points, is 0.23%. A summary of the results are shown in Figure 7.

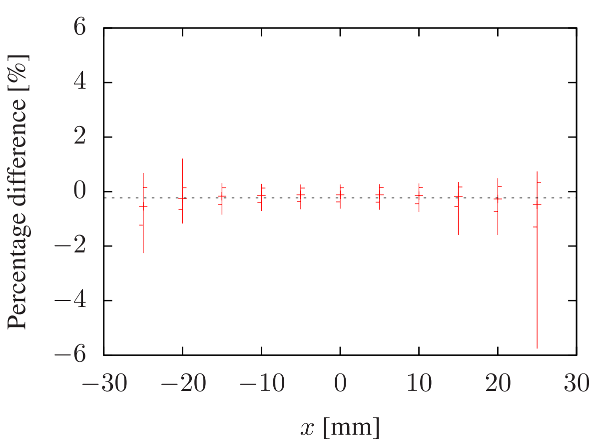


Figure 7: The discrepancy between the simulated and measured values of the x-component of the dipole's field. Each measurement was compared to the simulated value at it's position and then the discrepancies in each x-plane were averaged. The crosses show the average percentage difference for each plane; the ticks, $\pm 1\sigma$ from the average point; and the extent of the lines, the maximum discrepancies.

The largest discrepancies are seen in the region nearest to the pole pieces. Any discrepancies are expected to be largest in this region due to possible difficulties meshing the surface of the pole pieces in the simulation. Additionally, as most of the beam is transported through the middle section of the dipole, the discrepancies near the pole pieces do not affect the beam transport as much. Consequently, the measured dipole field is sufficiently close to the simulated field that no measurable difference between the simulated and actual performance is anticipated.

CONCLUSIONS & OUTLOOK

The status of an laser-based instrument to measure the full, correlated transverse beam density distribution of the H^- beam after the ion source of the Front End Test Stand has been presented, along with some commissioning results.

The movable components have been shown to have a mis-alignment of 0.0175 radians which, whilst sufficient for the measurement of the ion beam's profile, may be improved. The field of the dipole magnet used in the detector has been compared to the simulated field. The average discrepancy between the two fields is 0.23%, which should not influence the detector's performance noticeably.

With all the components installed, commissioning with beam will begin when the ion source is in regular operation (anticipated for the end of June) and the instrument should be able to perform beam projection measurements routinely soon after that.

In the longer term, the extra two pairs of stages will be added to enable all 360° of the ion beam to be covered and then full, correlated 2D profile measurements will be able to be made.

REFERENCES

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[7] `http://www.astec.ac.uk/id_mag/id_lab.htm`