A LASER-BASED BEAM PROFILE MEASURING INSTRUMENT FOR THE FRONT END TEST STAND AT RAL

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Abstract

The RAL Front End Test Stand is being constructed to demonstrate production of a high-quality, chopped 60 mA H^- beam at 3 MeV and 50 pps. In parallel to the accelerator development, non-destructive laser-based beam diagnostics are being designed. This paper reports on the realisation of a laser-based profile instrument that will be able to reconstruct the complete 2D transverse beam density distribution by scanning a laser beam through the ion beam at a variety of angles and then computationally combining the results. Commissioning results are presented alongside plans for future developments.

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. The ion source and LEBT are currently being commissioned; the ion source's status is described in [1].

As part of the diagnostics suite, novel laser-based beam diagnostics are being developed. These include a device to measure the transverse and longitudinal emittance [2, 3] at the full beam energy after the MEBT and one that will measure the 2D correlated transverse beam density distribution after the ion source. The status of the beam density distribution instrument is described in this paper.

Basis of the Instrument

The instrument is based around the photo-detachment of the outer electron of the H^- ions by a laser beam, via the process $H^- + \gamma \rightarrow H^0 + e^-$. A laser with a beam diameter smaller than that of the ion beam ($\sim$1 mm compared to the ion beam diameter of $\sim$50 mm) will be used to detach the electrons from a section of the ion beam. A series of mirrors mounted on movable stages inside the vacuum vessel will allow the laser beam to interact with different sections of the ion beam. The electrons will be separated from the H^- ions (and the neutralised H^0) by a dipole magnet and captured by a Faraday cup. Because of the low velocity (and therefore magnetic rigidity) of the electrons detached from the 65 keV H^- ions (note that the momentum transfer from the photon to the electron is negligible), the electrons will be accelerated to 2 keV as they enter the dipole magnet to reduce any deflection by stray fields. The measurements will be combined computationally using the Algebraic Reconstruction Technique [4, 5] to give the correlated transverse beam density distribution of the ion beam.

For a more detailed description of the basis of the instrument, see [2, 6].

INSTALLATION STATUS

The vessel in which the beam density distribution measurement will be made and the components required to make the measurement are complete and installed. They are shown in see Figure 1.

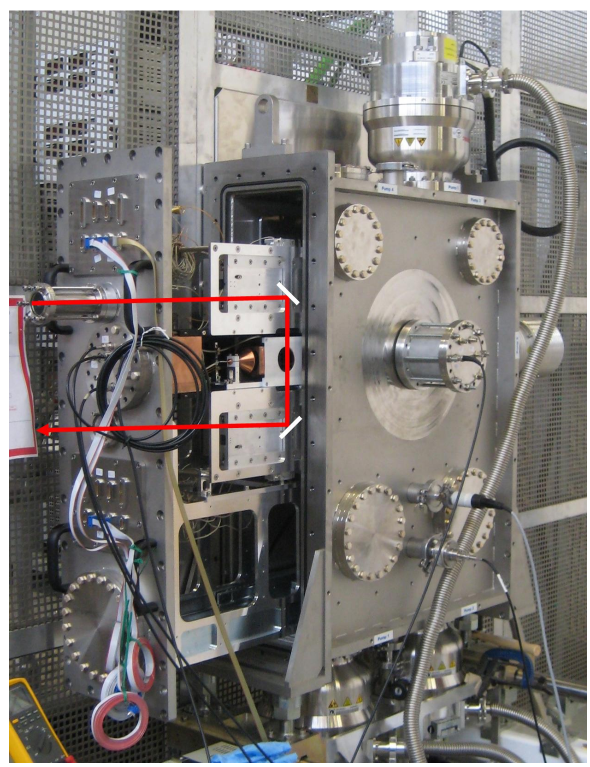

Figure 1: The vacuum vessel and the components required to make the beam density distribution measurement. In the centre of the picture the detector's copper Faraday cup can be seen. The central position of the mirrors is shown schematically in white, with the corresponding laser path in red.

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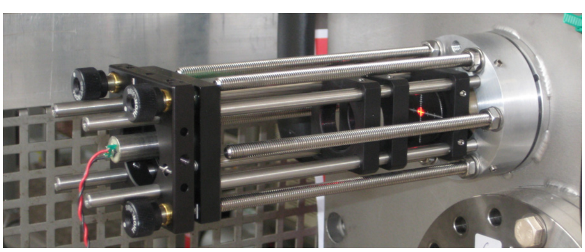
OPTICS STATUS

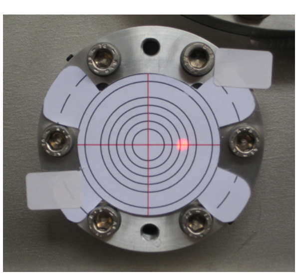
The laser that will be used in the beam density distribution measurement is a 500 mW, frequency-doubled, diode-pumped Nd:VO$_4$ laser, operating at 671 nm. At this frequency, the cross-section for the process $H^- + \gamma \rightarrow H^0 + e^-$ is $\sim$90% of its maximum value. The laser is housed in an interlocked enclosure alongside the beamline.

The laser beam will be moved through the H$^-$ beam at a variety of angles by mirrors mounted on pairs of linear and rotary stages inside the vacuum vessel. Initially, two of the four pairs of stages are installed (the back of which can be seen in Figure 1). This will give coverage of half (180°) of the beam.

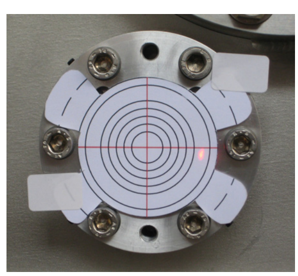
Due to the high power of the Nd:VO$_4$ laser, a lower power laser is being used to align the internal components of the vessel. In initial tests of the alignment, the output position of the laser was found to vary by 7 mm as the linear stages were scanned over their complete range (corresponding to a change in the path length of 400 mm). This corresponds to a mis-alignment of 0.0175 radians. This level of mis-alignment is tolerable as the beam is 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 2. 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).

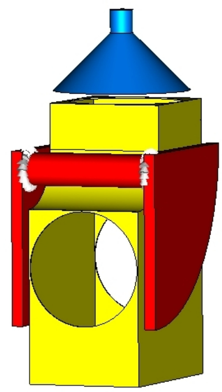


(c) For this picture the stages were moved to the furthest position from the vessel wall with the windows mounted in (such that the extra path length is 400 mm). Note that the spot has moved by $\sim$7 mm, compared to it's position in Figure 2b.

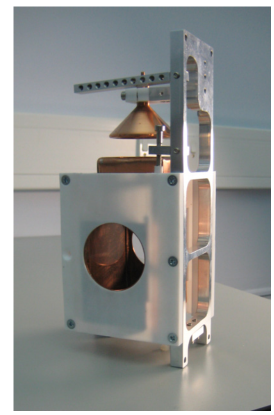
Figure 2: The optical alignment setup and results of initial alignment tests.

DETECTOR STATUS

The 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 3. 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 3: The detector, viewed from upstream. The electrons are deflected up into the Faraday Cup whilst the H$^-$ ions pass straight through. The detector is $\sim$16 cm high.

Magnetic Field Measurements

Before being constructed the detector was simulated and it's performance assessed [6]. Subsequently, the bending component of the dipole magnet's field has been mapped at the Insertion Device Laboratory, Daresbury [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 4.

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 discrepancy between the simulated and actual performance is expected.

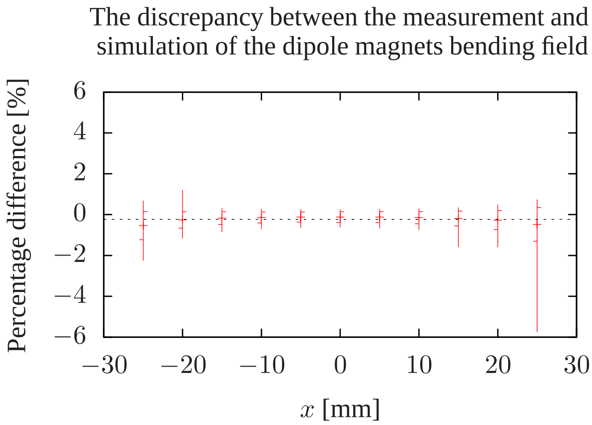


Figure 4: This graph shows the percentage difference between the simulated and measured values of the x-component (the bending component) of the dipole's magnetic field. Each measurement has been compared to the simulated value at the same position and then the percentage differences in each x-plane have been averaged. The crosses (+) show the average percentage difference for each plane. The ticks (⊣, ⊢) show $\pm 1\sigma$ from the average point. The ends of the lines show the maximum and minimum discrepancies. The dashed line shows the discrepancy, averaged over all points. Note that the errors in the measurement of the field are not considered here.

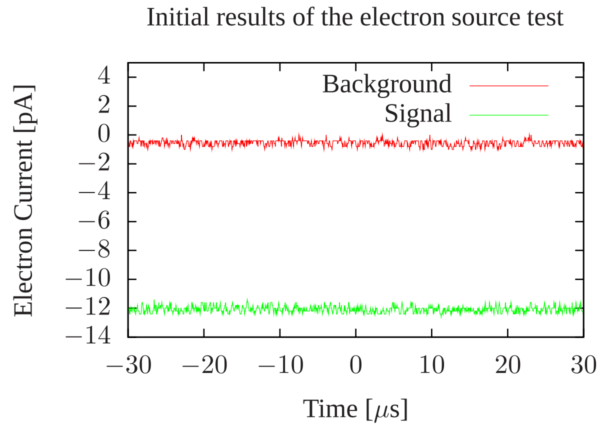


Figure 5: An oscilloscope trace showing that electrons are being detected when the filament is on (signal) and not when it is off (background).

Electron Source Test

Due to delays in commissioning the ion source, a program of testing the detector's performance with an electron source (a light bulb filament) is being carried out. The filament has been positioned in the location where the laser beam-ion beam interaction will take place and placed on the potential that the photo-detached electrons will have in this position. The Faraday cup has been connected to a current amplifier and the signal observed on an oscilloscope. Some transmission has been observed (see Figure 5) but the transport properties are not completely understood at this stage. More data, additional analysis and a further appreciation of the differences between the filament source and the photo-detached electrons (such as the particle distribution) are required before this program of testing will reap it's full benefit.

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%. First results from a program testing the detector's transmission using an electron source have been presented but more work is required on this to obtain the maximum benefit.

With all the components installed, the instrument should be able to perform beam measurements soon after the ion source is commissioned. If there are further delays to the ion source commissioning, the electron source test work will be continued and expanded.

In the longer term, the extra two pairs of stages will be added to enable all 360° of the ion beam to be covered.

REFERENCES

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