LASER-BASED BEAM DIAGNOSTICS FOR THE FRONT END TEST STAND AT RAL

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Abstract

The RAL Front End Test Stand is being constructed to demonstrate that a chopped H^- beam of 60 mA at 3 MeV with 50 pulses per second and sufficiently high beam quality as required for future high-power proton accelerators can be produced. Because of the high beam power and a preference for online beam monitoring non-intrusive, non-destructive beam diagnostics are desirable. Two novel instruments, based on the photo-detachment of the outer electron of the H^- ions with a laser, are being developed to precisely determine the transverse beam density distribution and the beam emittance at full beam power.

This paper discusses the proposed experimental layout of the devices and the progress that has been made towards realizing them. The design of the optical system is presented along with measurements of the laser beam propagation for the beam density distribution experiment. Investigations of the influence of laser beam misalignment along with measurements of the positioning accuracy of movable stages that will be used are given in light of the total expected errors.

INTRODUCTION

The instrumentation of high-intensity, low-energy ion beams is challenging as components that intercept the beam, such as scintillators or slits, are often damaged by localised heat caused by the low penetration depth of the beam into the material. Additionally, intrusive diagnostics do not allow for online monitoring of the beam.

For these reasons, two non-interceptive, laser-based beam diagnostics are under development for the RAL Front End Test Stand (FETS; for more details see [1]). The basis of the instruments is the use of a laser to detach the outer electron from some of the H^- ions and then using the secondaries created by this (electrons or the neutralised H^0 atoms) to diagnose the ion beam. This summer, a laser profile monitor that utilises the photo-detached electrons is going to be installed in the differential pumping vessel that follows the ion source. The second device that will measure the emittance at 3 MeV, the test stand's final energy, utilising the neutralised H^0 atoms is currently being designed.

The remainder of this paper will concentrate on the current status of the profile monitor (for a more detailed description of the two devices along with more information about the photo-detachment process, see [2]).

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LASER PROFILE MONITOR

By stepping a focussed laser beam across the ion beam and counting the photo-detached electrons, a profile of the ion beam can be built up as the number of electrons detached is proportional to the density of the ion beam along the path of the laser. For the FETS, as the ion source has a slit extraction and so the ion beam lacks cylindrical symmetry, it is desirable to measure the full 2D transverse density distribution of the ion beam rather than just x- and y-projections. This will be achieved by stepping the laser beam through the ion beam at a variety of different angles to collect many different projections (see figure 1) and then combining these using either the Algebraic Reconstruction Technique [3] or the Maximum Entropy algorithm [4]. However, for the first measurements this summer just the y-projection of the beam will be measured.

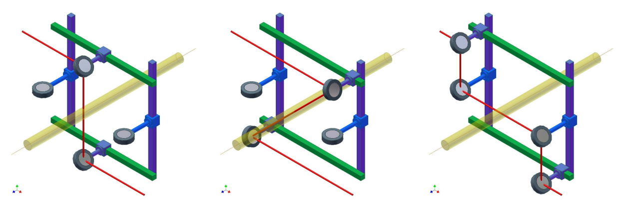

Figure 1: A schematic diagram illustrating how different projections of the ion beam (yellow) will be made by directing the laser beam (red) through it at different angles, guided by mirrors mounted on movable stages inside the vacuum vessel.

DETECTOR STATUS

To collect the detached electrons a detector, currently under construction, will be mounted in the low pressure tunnel of the differential pumping vessel. It is shown schematically in figure 2 and consists of a ring electrode, held on negative potential to suppress the unwanted background (detailed in the next sub-section); an accelerating sheath, to accelerate the detached electrons from their initial detached energy of ~ 40 eV to 2 keV; a dipole magnet, to separate the electrons from the remaining H^- ions; and a Faraday cup to collect the detached electrons.

Simulations of the detector design that included the effects of stray fields from the ion source's analysing dipole magnet have been performed using CST EM STUDIO and the General Particle Tracer (GPT) package. These simu-

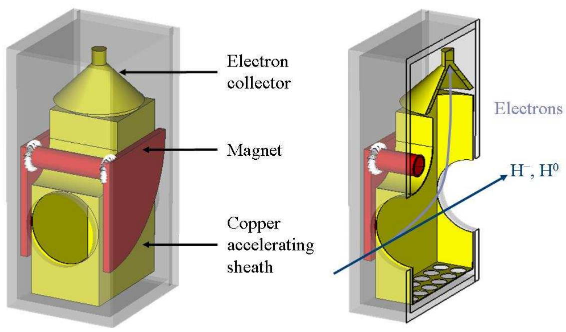

Figure 2: The profile monitor detector. The low pressure tunnel is represented by the grey box. The background suppression electrode is not shown in this figure.

lations showed that the influence of these stray fields reduce the collection efficiency of the profile monitor detector and so a re-design of the ion source dipole shielding, to reduce these fields to an acceptable level, has been carried out. Final simulations show that 100% collection efficiency should be achieved (see figure 3).

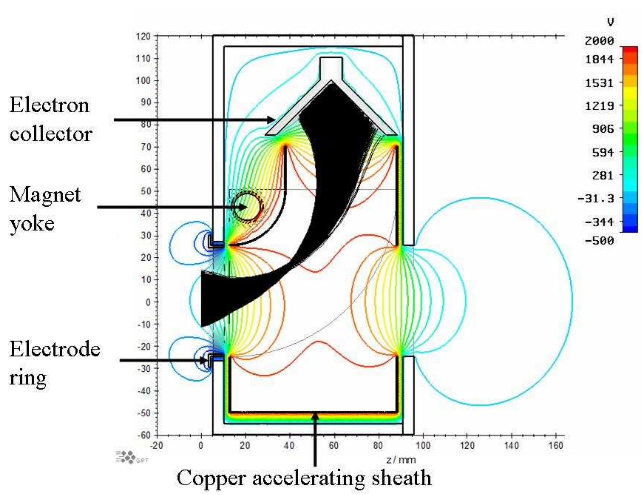

Figure 3: Simulation of the transmission though the electron detector. The electron trajectories are shown in black. A cut-away of the detector is also shown with the equipotential lines from the accelerating sheath and background suppression electrode in colour.

Background Reduction

The main background for the profile measurement comes from electrons produced by interactions of the ion beam with the residual gas. To assess the background levels, a simulation of how many of these electrons would be collected by the detector was carried out. In this simulation, the residual gas electrons were assumed to have the same parameters, $(\vec{r}, \vec{\beta})$, as the ion beam and were tracked through the detector. The simulations showed that the original detector design provided no discrimination between the background electrons and the signal electrons (the red points in figure 4). To minimise the number of background electrons that are captured, a ring electrode that will be held at a negative potential has been incorporated into the outer wall of the low pressure tunnel. This creates a potential barrier which prevents the electrons that are not produced near the photo-detachment region from being collected by the Faraday cup. The improved, reduced acceptance of the detector is shown by the blue points in figure 4.

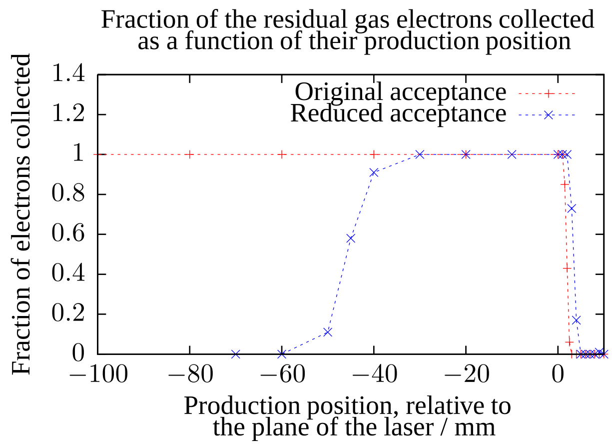

Figure 4: The longitudinal acceptance of the detector. Electrons collected from a non-zero production position correspond to background.

Readout Electronics

A Texas Instruments DDC112 current input 20-bit ADC and an Atmel ATMega128 microprocessor form the basis of the readout electronics for the Faraday cup. The expected signal size is $\sim 10^6$–10^8 electrons (~ 0.16–16 pC). Operating in the most sensitive regime of the DDC112 (-0.2–50 pC), the resolution has been measured to be 0.3 fC by injecting a test-charge onto the DDC112's integrating capacitor (see figure 5).

OPTICS STATUS

A 500 mW, 671 nm, CW diode-pumped solid state laser will be used to photo-detach the electrons for the profile measurement. Preliminary measurements give a beam radius of 1.5 mm and half angle divergence of 0.7 mrad at the laser aperture. In the first instance, no focussing elements will be included in the beam line, which will provide an estimated 3 mm radius laser beam at the interaction point. When photo-detachment has been demonstrated, focussing elements will be included to improve the resolution of the measurement. A schematic of the optical bench is shown in figure 6. Mirrors A and C will be used to adjust the horizontal and vertical angular offsets in the laser beam. After the first measurements, focussing elements will be inserted

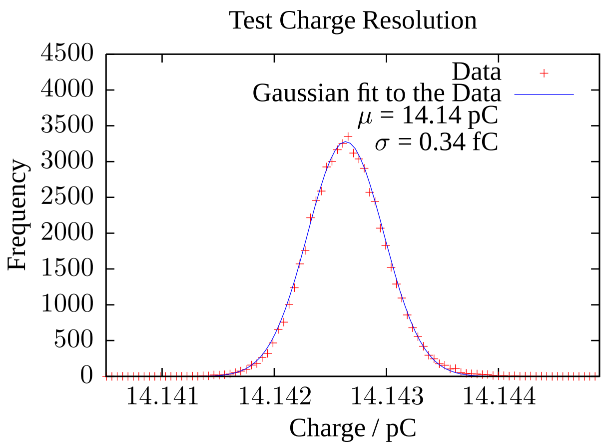

Figure 5: The resolution of the DDC112

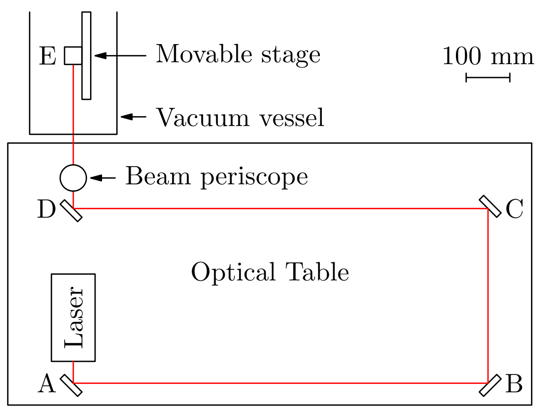

Figure 6: The initial layout of the optical bench. The laser path is shown in red.

between mirrors A & B and C & D to improve the spatial resolution. The beam will enter the vacuum vessel through a vacuum window and a beam periscope will be used for the fine adjustment of the laser beam height entering the vacuum vessel. Mirror E will be mounted on a movable stage and will deflect the laser beam through the ion beam. The mirror that will couple the laser out of the vacuum vessel is not shown.

To ensure that successive measurements are consistent, the output power of the laser will be monitored and the signal will be scaled accordingly.

Alignment Considerations

Even with a relatively simple optical beam path, the alignment requirements are quite challenging because the alignment of the laser beam where it intercepts the ion beam defines the resolution of the measurement. Factors such as the beam size, repeatability of the movable stage's positioning (of 10 μm), additional optical elements or angular offsets may effect the achievable precision. The better the knowledge of any systematic disagreements between the reference optical axes and the real physical axis (caused by misaligned optical elements), the smaller any corrections have to be. The most critical factors are the repeatability and variations of the angle at which the laser beam passes through the ion beam, as these have the most affect on the final measurement position. Whilst initial estimates of the accuracy required are of some value, to achieve the highest precision possible the optical beam path will be mapped out before any measurements are made.

The alignment accuracy required has been estimated using an extended matrix formalism [5], as opposed to the regular, four element matrix used to describe optical beam paths. In this formalism, an error vector $\mathbf{E} = [\Delta r, \Delta r']$ is introduced, where Δr represents an offset in position and $\Delta r'$ represents an angular offset. Only the initial optical elements, shown in figure 6, for measuring the y-projection of the ion beam are considered here. In estimating the effects of misalignment, the smallest possible imprecision of the mirror mounts is used to estimate the maximum possible misalignment for the two extremes, scanning over a 200 mm range.

Any error in the input position into the vacuum vessel and any displacement resulting from an angular offset manifest themselves as a shift in the laser position in the ion beam. Such a systematic offset is both simple to correct during post-processing and has been estimated to be $\Delta r = 1.59 \pm 0.011$ mm for the y-projection. This offset is related to the movement of the mirror inside the vacuum vessel over the full 200 mm range, caused by a constant angular error of $\Delta r' = 1.4$ mrad.

If the optical access is properly aligned, this offset will be reduced. However, additional effects not accounted for in this calculation may introduce further errors. Consequently, as well as the first photo-detachment measurements for the FETS, the laser profile monitor will be used to assess alignment strategies.

CONCLUSIONS

Progress towards the installation of a laser profile monitor, capable of measuring the full 2D density distribution of the FETS ion beam, is going well and is on schedule to see installation this summer and first measurements this autumn. The detector design is finalised and manufacturing has begun. The design of the initial optical system is well underway and the tolerances on the alignment of the various elements has been estimated as achievable.

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