

# A LASERWIRE BEAM PROFILE MEASURING DEVICE FOR THE RAL FRONT END TEST STAND

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## Abstract

The Front End Test Stand (FETS) [1] at the Rutherford Appleton Laboratory (RAL) is being developed to demonstrate a chopped  $H^-$  beam of 60 mA at 3 MeV with 50 pps and sufficiently high beam quality for future high-power proton accelerators. As such, it requires a suite of diagnostic instruments to provide detailed measurements of the ion beam properties [2]. Due to the high beam brightness and a desire to have online instrumentation while the accelerator is operational, a series of non-intrusive and non-destructive diagnostics based on laser-detachment are being developed.

In this paper, the principle behind the laser-based diagnostic instruments is given and the progress [3] that has been made towards the construction of a laserwire instrument that can measure the beam profile at an arbitrary angle is described. In particular, the results of field distribution and particle tracking simulations are shown and the design of the instrument and the vacuum vessel in which it will be mounted are presented. The software that will be used to reconstruct the 2D transverse beam density distribution from the beam profiles is also described.

## INTRODUCTION

The RAL Front End Test Stand will consist of a 60 mA  $H^-$  ion source, a magnetic LEPT, a 324 MHz RFQ and a MEBT with a beam chopper at a beam energy of 3 MeV. The length of the macro-pulse will be up to 2ms at a repetition rate of 50Hz (10% duty cycle). The aim is to demonstrate the performance of the ion source and RFQ and to test the high speed chopper [4], which will have a rise time of less than a nanosecond to produce a beam pulse structure suitable for the next generation of high power proton accelerators [5]. The chopper will be placed inside the MEBT [6], which is used to match the ion beam into further linac structures should they be constructed.

From the point of view of beam diagnostics, a device that can make high resolution measurements and withstand the large beam power is desirable. A possibility that meets these requirements is non-destructive laser-based beam diagnostics that has no mechanical parts intercepting the beam.

Such non-intrusive diagnostic devices have other advantages over conventional beam diagnostics. For example, on-line monitoring whilst the accelerator is operational is possible; there is almost no influence on beam parameters like the space charge potential (i.e. there is no production of unwanted secondary particles); their lifetime is greatly increased; and they can offer additional information about the phase space.

## LASER-BASED BEAM DIAGNOSTICS

Negative ions can be neutralised by detaching the additional electron with a photon (for  $H^-$  ions, the binding energy of the outer electron is  $\sim 0.75\text{eV}$  [7, 8]). By using a dipole magnet to separate the different species after neutralisation a variety of beam parameters can be measured.

For the FETS project two diagnostic instruments based on laser detachment are being developed: a device to measure the 6D emittance after the RFQ and MEBT; and a beam profile monitor that will measure the 3D beam density distribution after the ion source. The principle behind the emittance measuring instruments is described in the following subsection before further details about the laserwire beam profiler are given.

### The FETS laser-based emittance measurement

A device to measure the emittance of the beam behind the RFQ, before and after the MEBT and chopper, is being developed. It is shown schematically in figure 1.

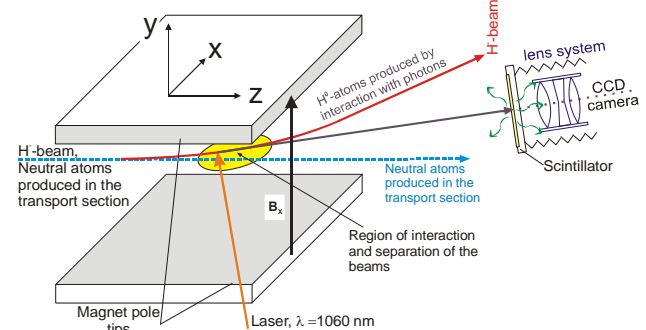


Figure 1: The principle of the photo-detachment emittance measurement. The laser detaches the additional electron of the  $H^-$  ions inside a magnetic field and the distribution of the produced neutral  $H^0$  atoms is detected.

A proof-of-principle experiment has been performed at IAP Frankfurt. The focus was on the basic properties of such a device and the interpretation of the transfer function to calculate the emittance. This experiment showed that this method is suitable for the emittance measurement of high brightness ion beams. The experimental results showed that this method gave a good agreement with traditional slit-slit devices while providing additional information about the phase space. See [9, 10] for further details of this experiment.

Typical parameters in the MEBT are foreseen to be a beam radius of 5 mm and a divergence angle of  $\pm 25$  mrad. To aid the design of the diagnostic dipole magnet, beam envelope calculations have been performed with the aim of reducing particle losses and to check if additional beam optics are required after the MEBT. The current magnet

design has a pole piece separation of 150mm and a reference path length of 500mm. These values have been chosen so that there is enough space for the ion beam and for movable stages to guide the laser beam to and from the ion beam. The predicted performance of the emittance measurement device is an angular resolution of  $<0.1$  mrad with a position resolution, determined by the laser, of approximately 0.5 mm.

### *The FETS laserwire beam profile monitor*

By stepping a laser across the  $H^-$  beam and measuring the number of electrons detached a 1D projection of the beam can be measured. The number of electrons can be measured by separating them from the remaining  $H^-$  ions and deflecting them into a Faraday cup (see figure 2).

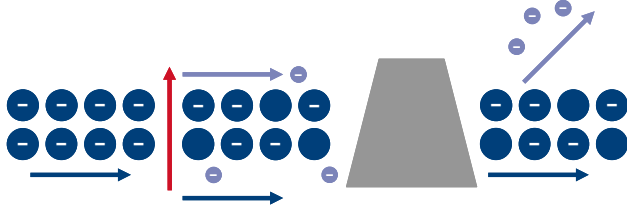


Figure 2: The principle of the laserwire instrument. Electrons (light blue) are detached from the  $H^-$  ions by a laser (red) and then the species are separated by a dipole magnet (grey).

Projections of the beam can be taken at several different angles by varying the angle at which the laser passes through the ion beam. These projections can then be used to reconstruct the 2D ion beam density distribution. By using a laser pulse that is shorter than the ion beam pulse duration and delaying the laser pulse relative to the ion beam it will be possible to reconstruct the 3D beam density distribution from several 2D distributions.

Initially the FETS laserwire will use a 500 mW, 671 nm DPSS laser, focussed to a beam diameter of 1.5 mm. This waist gives the narrowest possible parallel laser beam through the ion beam. In each 2 ms pulse the laser will neutralise, at most,  $10^{-7}$  of the total  $H^-$  ions giving a peak signal of  $\sim 7 \times 10^7$  electrons.

## LASERWIRE COMPONENTS

### *Vacuum vessel*

The FETS laserwire device will be mounted in the first differential pumping vacuum vessel after the ion source. The beamline length, and so space available for the laserwire scanner, is constrained on one side by the need to prevent the ion beam expanding beyond the acceptance of the LEBT and on the other by the need to adequately pump the vessel. A beamline length of  $\sim 220$  mm has been chosen to enable a CF160 pump port to be used.

The tank will contain mirrors mounted on rotatable and movable stages, to enable projections of the beam at an arbitrary angle to be measured. It will also contain the dipole and detector enclosure. The current design of this vessel is shown in figure 3.

Beam Instrumentation and Feedback

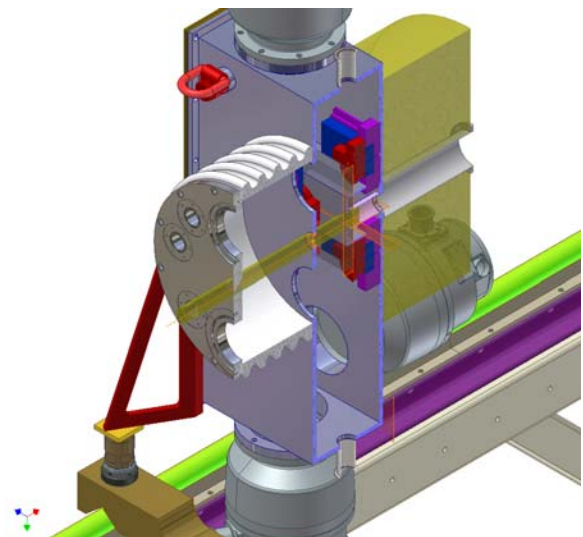


Figure 3: A cut-away of the mechanical design of the laserwire instrument and vacuum vessel. The ion source insulator column is shown to the left, the LEBT to the right.

### *Dipole enclosure*

The FETS ion source will extract an  $H^-$  beam at 65 keV. As the momentum transferred from the photons to the detached electrons is negligible the detached electrons are reasonably assumed to be travelling with the same velocity as the  $H^-$  ions. At this velocity the magnetic field required to deflect the electrons is comparable to that of the Earth ( $\sim 2$  Gs). To increase the required magnetic field, and so prevent unwanted deflection of the electrons, an additional electrostatic acceleration of 2 kV will be included in the dipole enclosure. This raises the required magnetic field to 23 Gs. The design of the detector (post acceleration, dipole magnet and Faraday cup) is illustrated in figure 4.

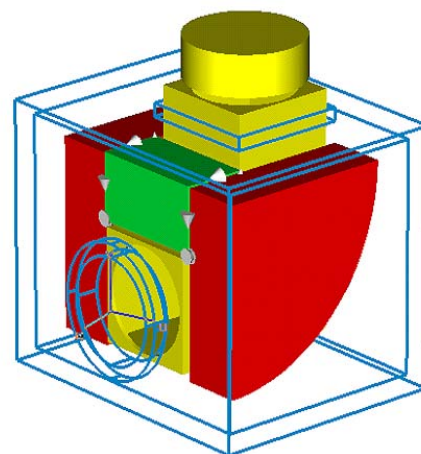


Figure 4: Detector design for the FETS laserwire. Shown in red is the iron yoke and pole pieces, in green are the windings (100 Amp-turns), outlined in blue is the magnetic shielding (at ground), in yellow are the copper accelerating sheath (held at 2 kV) and Faraday cup. The beam aperture is 50 mm and overall length is  $\sim 130$  mm.

Profile and Transverse

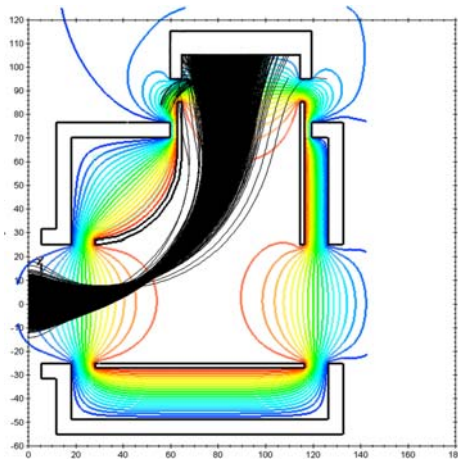


Figure 5: Results of the CST EM STUDIO and GPT simulations. Particle tracks (black) and equipotential lines at 100 V intervals (coloured) are shown through a section of the detector shown in figure 4.

Simulations of the magnet enclosure have been performed using CST EM STUDIO. Particle tracking through the modelled fields was then performed using the General Particle Tracer (GPT) code using preliminary results from the FETS pepperpot device (see [2] for details) for the input distribution. The simulations gave an electron transmission greater than 99% without adversely affecting the H<sup>-</sup> beam. A plot is shown in figure 5. The results from these simulations are being used to refine the dipole enclosure design and are being incorporated into the design of the vacuum vessel.

## 2D BEAM DENSITY DISTRIBUTION RECONSTRUCTION

The Algebraic Reconstruction Technique (ART; see [11]) will be used to reconstruct the 2D beam density distribution. It is an iterative, algebraic approach to image reconstruction, as opposed to an approach that makes use of Fourier Transforms. The ART is preferred to Fourier Transform-based methods for the FETS laserwire due to difficulties in untangling the effects of the laser beam profile on any given projection. It also requires fewer projections (typically 20) to give a good reconstruction.

The ART works by reconstructing the density distribution on a grid, with each pixel within the grid having a density assigned to it. Masks corresponding to the laser's paths through the ion beam, incorporating the laser's beam profile, are constructed. These masks are then cast across the grid and the pixels' values, weighted by the mask's local values, are summed. These summed values are then compared to the measured values from the laserwire device. Any discrepancy between the two values is distributed, according to the weighting of the mask, across the corresponding pixels. The next laser strip is then considered. The algorithm stops when a  $\chi^2$  condition is met. Figure 6a shows a 2D profile of the ion beam captured by the pepperpot device. A reconstruction of this image using the ART is shown in figure 6b.

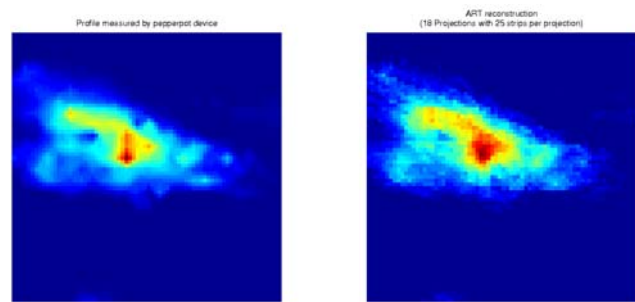


Figure 6a (left): A 2D profile measured by the pepperpot device  
 Figure 6b (right): The reconstructed 2D profile from 18 projections, each comprising of 25 strips, after 100,000 iterations.

## OUTLOOK

The design of a laserwire beam profile measuring device is progressing well. It is anticipated that it will be installed at RAL this calendar year with results to follow soon after.

A first design of a laser-based emittance measurement shows promising results. The instrument is expected to be available with the RFQ in approximately three years time. First experimental work this summer will concentrate to develop a precise laser guiding system to improve reliability in terms of homogenous transfer function as well as measurement resolution.

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