A FIBRE COUPLED, LOW POWER LASERWIRE EMITTANCE SCANNER AT CERN LINAC4

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Abstract

The new LINAC4 will accelerate H^- ions to 160 MeV and ultimately replace the existing 50 MeV LINAC2 in the injector chain for the LHC upgrade. During commissioning in 2013, a laserwire scanner and diamond strip detector were installed for non-invasive emittance measurements of the 3 MeV H^- beam. Synergy with the 3 MeV H^- Front End Test Stand at RAL, has stimulated collaborative development of a novel laserwire system. A low peak power (8 kW) pulsed laser is fibre-coupled for remote installation and alignment free operation. Motorized focusing optics enable remote control of the thickness and position of the laserwire delivered to the vacuum chamber, in which the laser light neutralises a small fraction of H^- ions. Undeflected by a dipole magnet, these H atoms drift downstream, where their spatial profile is recorded by a highly sensitive diamond strip detector with ns-time resolution. We present first tests of the laserwire emittance scanner, including measurements of the photo detachment signal with respect to the background from residual gas interactions. The first laserwire transverse beam profile and emittance measurements are compared with conventional slit-grid diagnostics.

INTRODUCTION

The campaign to upgrade the injector chain for the High Luminosity LHC has started with the construction of the 160 MeV H^- LINAC4 [1] that will replace the existing 50 MeV proton LINAC2 as the injector to the PS-Booster. When complete, the high injection beam energy provided by LINAC4 is expected to double the beam brightness out of the PS-Booster. It will be necessary to monitor the transverse emittance of the beam during operation, however, the use of conventional slit and grid beam diagnostics is precluded due to the excessive ion stopping range at 160 MeV. Therefore a novel laserwire emittance scanner has been proposed [2] that offers non-invasive and non-destructive beam diagnostics, fed by a low power, fibre coupled laser. Only a small fraction of the H^- ions are neutralised in the narrow slice of the particle beam that traverses the path of the laser. This beamlet of neutralised particles is undeflected by a dipole magnet and drifts to a downstream diamond detector, where the spatial profile is recorded. Scanning the transverse positions of the laserwire and diamond sensor enables the transverse emittance of the particle beam to be reconstructed.

The laserwire diagnostic proposed for LINAC4 is conceptually similar to the laserwire emittance scanner planned for the Front End Test Stand [3–5], a high power, 3 MeV H^- accelerator under construction at RAL. The similarities have prompted collaborative development by CERN , RHUL and FETS of the laserwire hardware, control and analysis [6]. In 2013 a portable, laser beam delivery system was jointly developed for tests in early 2014 during the 3 MeV commissioning phase of the LINAC4. The following sections describe the laserwire scanner, its operation and the proof-of-principle tests that demonstrate emittance measurements for the first fibre-coupled, low power laserwire for H^- beams.

EXPERIMENTAL SETUP

The laserwire emittance scanner consists of a remotely housed, pulsed laser connected via an optical fibre to a motorized focusing optics, which control the thickness and position of the laserwire delivered to the accelerator. A diamond detector downstream of a dipole magnet records the photo-detachment signal from the neutralised H^- beam.

Laser and Optical Beam Delivery

The laser is a Q-switched, diode pumped, all-fibre Master Oscillator Power Amplifier (MOPA), that generates 110 ns pulses at a repetition rate selectable between 30 and 100 kHz, at a wavelength of 1080 nm, with a pulse peak power of 8.5 kW and measured maximum output power of 28 W in CW mode. [6, 7]. The wavelength is chosen to match the peak in photo-neutralisation cross-section after correcting for the Lorentz shift at 160 MeV [2]. The collimated output from the fibre-laser passes through a safety shutter and is monitored by a photodiode (PD1), as in Figure 1 and then coupled into an optical fibre that conveys light to the laser beam delivery system, shown in Figure 2. The safety screens enclose the fibre-collimation optics, motorized beam

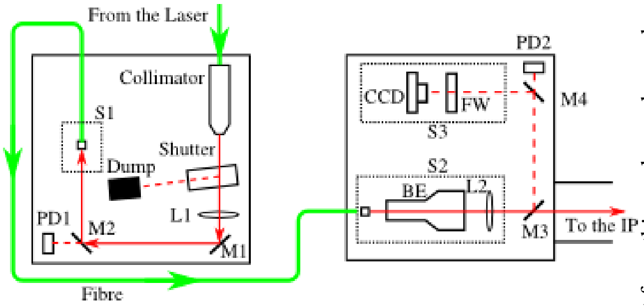

Figure 1: Layout of the fibre-laser beam delivery optics.

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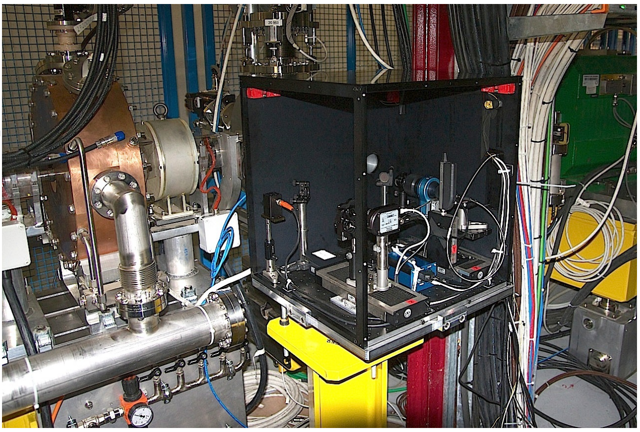

Figure 2: Motorized laser beam delivery system adjacent to LINAC4 (with safety covers removed).

expander and focusing lens, all mounted on a pair of translation stages that control the vertical and longitudinal position of the laser beam, with micron-level resolution. The laser beam is brought to a focus centred on the particle beam inside the interaction chamber. A factor x8 magnification and f=500 mm lens focuses the laserwire radius to ~75 μm at the interaction region, such that only a small slice of ~1 mm particle beam can be neutralised. The laserwire is either sent directly to the interaction chamber, or by lowering the vertical stage can be diverted by via fold back mirrors to illuminate a second photodiode and a CCD camera, which itself can be translated along the laser beam axis. This is useful for in-situ measurement of the laser beam transverse profile at and around the focal length corresponding to the particle interaction region. Further details of this system and the characteristic laser profiles are given elsewhere [6, 7].

Diamond Detector

The beamlet of neutralised H^0 particles pass straight though the spectrometer magnet and are intercepted by the five strip diamond detector shown in Figure 3. Diamond was selected for its sensitivity ($\sim 10^4$ electrons/H^0), bandwidth (3 ns time constant), and radiation hardness ($> 10^{15}$ MeV neq cm^{-2}) [2]. The detector is mounted on a translation stage to permit vertical movement into the beamline, so that the spatial profile of the neutralised beamlet can be determined (and retracted from the main beamline when the spectrometer magnet is off). A detector with finer granularity is envisaged for the final system, to eliminate the need to move the detector and reduce the measurement time. The detector was biased at 600 V and the readout channels were individually instrumented with linear amplifiers, which were found to give the most reliable signal in the analysis below.

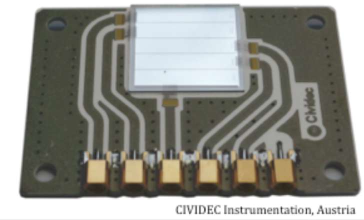

Figure 3: Detector consisting of 500 μm thick polycrystaline diamond with five 3.5x18 mm aluminium electrodes.

Control, DAQ and Timing

The laserwire emittance scanner is controlled via NI-PXI LabView to automate scans of the laserwire position for different diamond detector positions. During 3 MeV beam commissioning the LINAC4 352.2 MHz bunches arrive in a macro-pulse of 400 ms every 1.2 s. The laserwire intercepts the macro-pulse with a train of laser pulses at 60 kHz, in which each 110 ns laser pulse can interact with 38 bunches. A reduced pulse peak power of < 1 kW at the interaction region was sufficient to generate a good signal. The data acquisition window was synchronized to the LINAC4 macro-pulse at $\frac{1}{1.2}$ Hz. Data from the diamond detector and photodiodes were acquired at a 1 GHz rate in short 1μs bursts (acquisition segments) that were synchronized with the 60 kHz pulses generated by the laser.

PHOTO DETACHMENT SIGNAL AND RESIDUAL GAS BACKGROUND

With the laserwire traversing the centre of the particle beam, the diamond detector signal acquired in 30 segments during one accelerator macro-pulse is shown in Figure 4. The lower plot shows the train of 60 kHz laser pulses, recorded by the photodiode before the fibre coupling. Corresponding peaks are observed in the diamond signal, due to the photo-detached H^0. The peak height is modulated by the beam current, which varies during the macro-pulse. The change in pedestal level between laser peaks is due to neutrals from upstream residual gas background interactions

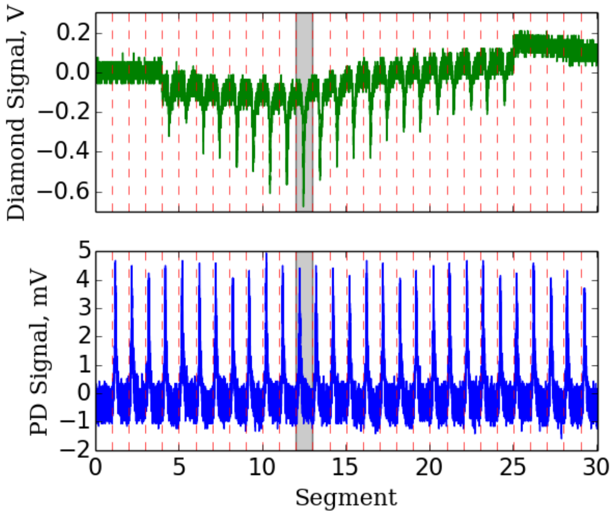

Figure 4: Lower: laser pulse train at photodiode, PD1. Upper: corresponding diamond detector signal, readout with an inverting amplifier, during one LINAC4 macro-pulse .

and is present in the diamond detector signal, independent of whether the laser is powered. The time resolution of the diamond detector enables good discrimination between signal peaks and background. A zoomed region for one segment around the diamond signal is shown in Figure 5.

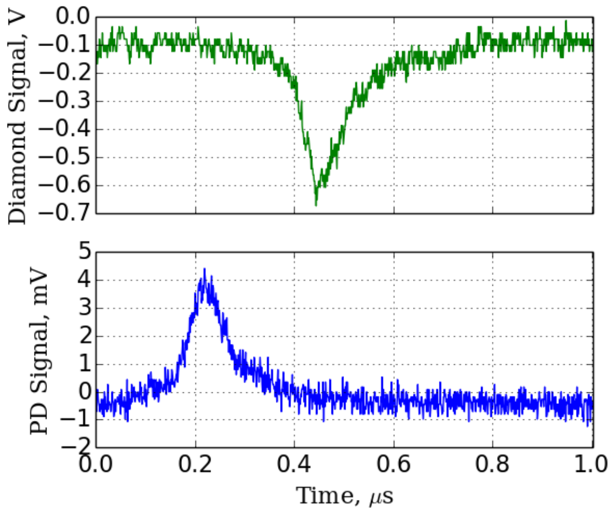

Figure 5: A zoomed region from Figure 4 shows the rapid response of diamond detector signal to a single 110 ns laser pulse. The arbitrary offset is due to oscilloscope delay settings during the segment acquisition.

BEAM PROFILE AND EMITTANCE RESULTS AT 3 MeV

Automated vertical scans of the horizontal laserwire were performed for different diamond detector positions. At each step, diamond detector data were acquired in 30, 1 μs segments, for one accelerator macro-pulse. The laserwire position was then moved ready to acquire a subsequent accelerator pulse.

The data were analysed by first applying a smoothing filter (width = 10 samples) to the diamond signal to reduce noise. A linear fit to the residual gas background pedestal was then performed for each segment, and subtracted from the photo detachment signal region, before integration over the window containing the peak. The background subtracted signals were averaged over five of the laser pulses (in segments 10 to 14) from the same LINAC4 macro-pulse.

The integrated and averaged signal is plotted versus the laserwire vertical position in Figure 6, to give the vertical transverse profile of the LINAC4 beam. The laser-results were verified with independent measurements from conventional slit scanner at the same location as the laser wire, and measured by a downstream SEM-grid [8, 9]. Very good agreement is found for the beam-core. The beam halo values are slightly bigger when measured with the laser system.

Laserwire beam profile measurements were recorded for a range of diamond detector positions and the results used to reconstruct the transverse emittance of the LINAC4 beam. A comparison with the emittance measured by the slit-grid method is shown in Figure 7. Despite the lower spatial resolution of the laser data in these first tests, the ellipse size and orientation is in good agreement. The measured emittance values are the same to within 10%.

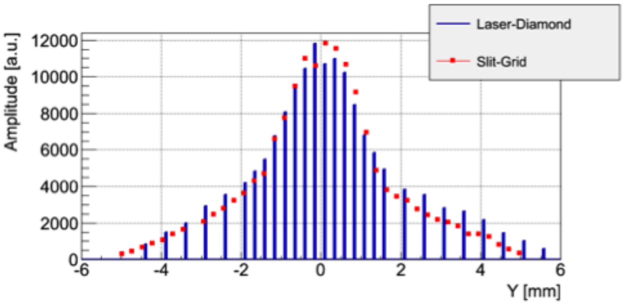

Figure 6: Vertical profile of the 3 MeV H^- beam as measured by the laserwire-diamond system and slit-grid methods.

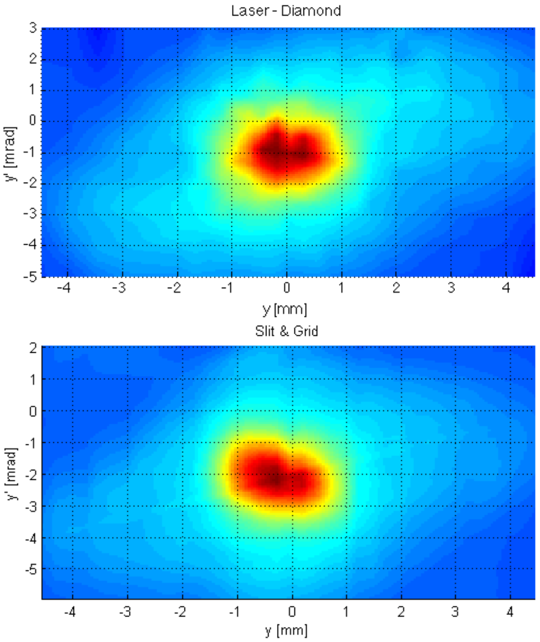

Figure 7: Vertical transverse emittance of the 3 MeV H^- beam as measured by the laserwire-diamond (upper) and conventional slit-grid (lower) methods.

CONCLUSION

The first low-power, fibre coupled laserwire for H^- beams has been collaboratively developed and tested at the LINAC4 during 3 MeV commissioning. First beam profile and emittance measurement results from the laserwire scanner demonstrate very good agreement with conventional slit-grid diagnostics. While further tests are planned for 12 MeV commissioning, these results already encourage prospects for a final laser emittance station at 160 MeV.

ACKNOWLEDGMENT

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