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LASERWIRE EMITTANCE SCANNER AT CERN LINAC4

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Abstract

Linac 4 presently under construction at CERN is designed to replace the existing 50 MeV Linac 2 in the LHC injector chain and will accelerate the beam of high current negative hydrogen ions to 160 MeV. During the commissioning a laserwire emittance scanner has been installed allowing non-invasive measuring of the emittance at 3 MeV and 12 MeV setups. A relatively low power infrared fibre coupled laser was focused in the interaction region down to ~150 µm and collided with the ion beam neutralising negative ions. At each transverse laser position with respect to the ion beam the angular distribution of the neutral particle beamlets was recorded by scanning a diamond detector across the beamlet at a certain distance from the interaction point while the main beam of the H^- ions was deflected using the dipole magnet installed upstream the detector. Measuring the profile of the beamlet by scanning the laser across the beam allows to directly measure the transverse phase-space distribution and reconstruct the transverse beam emittance. In this report we will describe the analysis of the data collected during the 3 MeV and 12 MeV operation of the Linac 4. We will discuss the hardware status and future plans.

INTRODUCTION

The Linac 4 project located at CERN in Geneva, Switzerland was started in 2003 [1] and aims to build a 160 MeV H^- linear accelerator that will replace the existing proton Linac 2 as the injector to the Proton Synchrotron Booster (PSB). Injection of H^- instead of protons into the PSB would reduce the beam losses and provide more flexible operational conditions. At the end of commissioning the injection beam provided by Linac 4 is expected to double the brightness and intensity of the beam from the PSB. Linac 4 project is an essential step in the High Luminosity LHC upgrade required to future improvement of the CERN accelerator complex towards higher performance [2, 3]. Main parameters of the Linac 4 are presented in Table 1.

To successfully inject the beam from Linac 4 into PSB the transverse emittance at the machine top energy of 160 MeV has to be measured precisely. The conventional slit and grid beam diagnostics is precluded due to the excessive stopping range of a high energy H^- ions at 160 MeV in any possible slit material. Other methods, like the three - profile measurement, can be heavily affected by space charge effects and cannot handle the nominal Linac 4 pulse length of 400 µs. To overcome these problems a non-destructive method based on laserwire technology has been developed.

Table 1: Main Linac4 Parameters

Parameter	Value	Units
Overall Linac length	76.33	m
Output energy	160	MeV
Bunch frequency	352.2	MHz
Maximum repetition rate	2	Hz
Beam pulse length	400	µs
Max. beam duty cycle	0.08	%
Average pulse current	40	mA
Beam transverse emittance	0.4π	mm mrad
Beam power	5.1	kW

EXPERIMENTAL SETUP

In order to characterize the H^- ion beam at different stages of the LINAC4 commissioning a movable, temporary test bench has been used. After finishing the commissioning of the 3 MeV and 12 MeV stage the test bench was placed at the exit of the copper and first DTL section respectively. It was used to characterize the ion beam using various diagnostic tools such as beam current transformers, wire scanners, beam position monitors, bunch shape and halo monitors, a slit and grid emittance meter and a spectrometer line [4, 5].

The laserwire interaction is taking place inside the vacuum chamber that was initially designed to accommodate the movable graphite slit which is a part of the slit and grid emittance scanner [6]. The laser enters the vacuum chamber through a vacuum window, specially coated to reduce back reflections in the infrared range of wavelengths. After interaction the laser beam is dumped into one of the slit blades. Such location of the laserwire proved to be very useful because it allows to perform measurements using two different methods and cross-check the results.

The laserwire system consists of a remotely controlled pulsed laser mounted in a rack in the accelerator tunnel connected via an optical fibre to a laser delivery system which controls the size and position of the laser beam delivered to the interaction point (IP). A detection system was installed downstream of a dipole magnet to record the angular distribution of the neutralized particles from the H^- beam.

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Table 2: Main Parameters of the Laser System

Parameter	Value	Units
Operation mode	CW or pulsed	–
Wavelength	1080	nm
Pulse repetition rate (external trigger)	30 - 100	kHz
Average output power (CW pump)	28	W
Pulse duration	150	ns
Output power stability	< 2	%
External TTL modulation frequency	up to 5	kHz

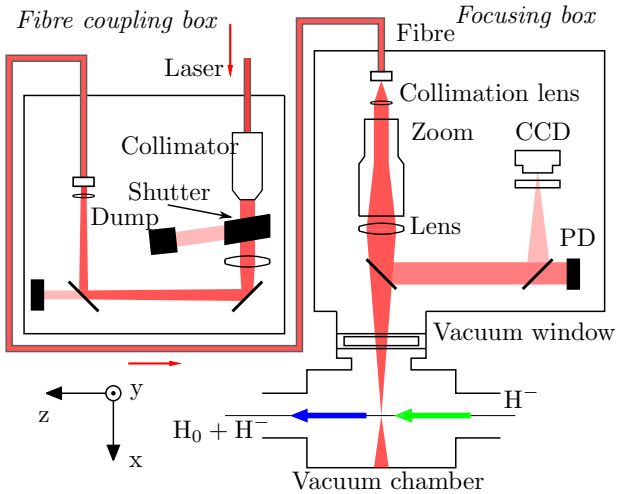

Figure 1: Schematic diagram of the laser delivery system.

Laser System

The laser is a Q-switched, diode pumped, Yb doped fibre Master Oscillator Power Amplifier (MOPA) manufactured by "Manlight S.A.S". The oscillator generates ~ 80 ns pulses (FWHM) at the repetition rate selectable between 30 and 100 kHz, at wavelength of 1080 nm with a pulse peak power of 8.5 kW and maximum output power of 28 W in CW mode. A summary of the laser parameters is presented in Table 2.

To deliver the laser beam to the IP a special delivery system has been designed. The collimated output from the fibre-laser passing through a safety shutter and a collimation lens was monitored by a photodiode and then coupled into a 5 m long optical fibre which was used to transport the light to the beam focusing system. For 12 MeV setup a 10 m long fibre has been used due to the shifted position of the test bench. To optimize the coupling efficiency the input side of the fibre was mounted on a 3D translation stage. From the output of the fibre light was passing through a beam expander, that has a range of magnification from 1 to 8X and a focusing lens with a focal length of 500 mm all mounted on a pair of translation stages which control the vertical and longitudinal position of the laser focus with micrometre resolution. The schematic of the laser delivery system is presented in Fig. 1.

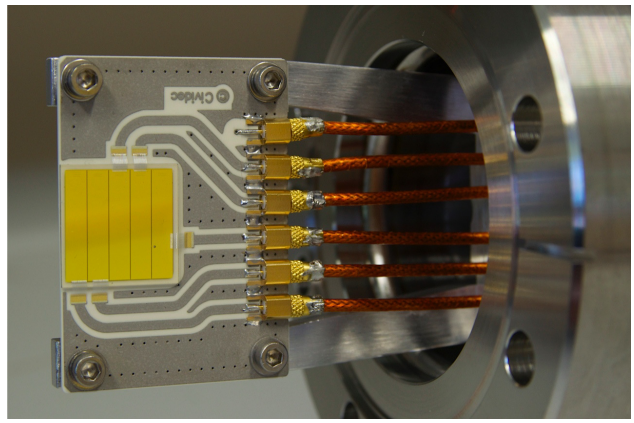

Figure 2: Photo of the "CIVIDEC" five strip diamond detector.

By lowering the vertical stage the laser beam can be delivered via fold back mirrors to the second photodiode and a CCD camera. In order to avoid the CCD camera saturation a filter wheel with a set of attenuators was placed in front of the camera. Both, the camera and the filter wheel can be translated along the laser beam axis using a linear translation stage. This option is useful to measure the laser transverse profile at and around the focal length corresponding to the particle interaction region. Both, laser coupling and delivery optics were placed in the interlocked light-tight enclosures for safety reason.

Detector

After the interaction with the laser beam, a beamlet of neutral H^0 particles was passing through the spectrometer magnet and then was intercepted by the diamond detector that was installed approximately 3 m downstream the laser-wire IP. The detector was mounted on a vertical translation stage which allows to move it across the beamline so the spatial profile of the neutralized beamlet can be determined.

In the experiment a 20×20×0.5 mm^3 "CIVIDEC Instrumentation" [7] polycrystalline diamond detector with five aluminium strips has been used. The photograph of the detector is presented in Figure 2. The diamond detector has been chosen because of the following advantages in comparison with other detectors: good sensitivity (internal gain of the diamond detector is about 10^4 electrons per H^0); response time in the nanosecond range; radiation hardness (> 10^{15} particles cm^{-2}).

RESULTS

After establishing a detectable collision between the laser beam and the ion beam the laserwire station was ready to perform measurements.

The laser was scanned vertically across the ion beam with variable step size in order to accurately sample the shape of the distribution. At each laser position, the diamond detector was scanned across the beamlet of neutral particles. At each step, diamond detector data were acquired in 30,1 µs

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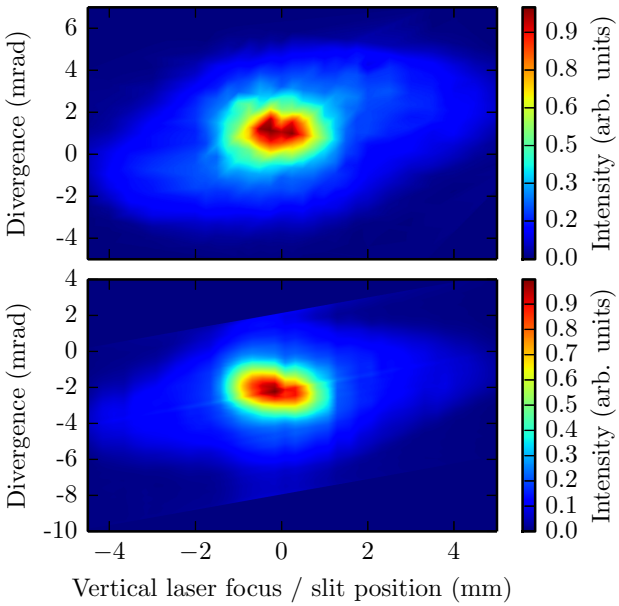

Figure 3: Vertical transverse phase space of the 3 MeV H^- beam measured by the laserwire (top) and conventional slit and grid (bottom) methods.

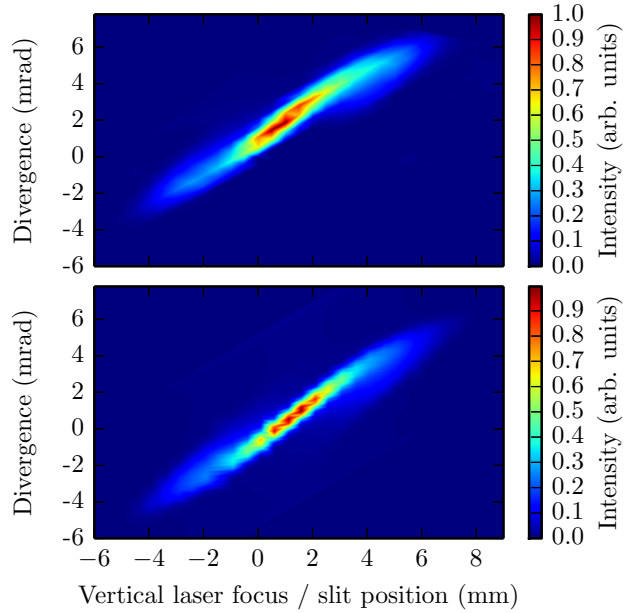

Figure 4: Vertical transverse phase space of the 12 MeV H^- beam measured by the laserwire (top) and conventional slit and grid (bottom) methods.

segments, for one accelerator macropulse. Each detector scan corresponding to a certain laser position was stored in separate data file. Such technique allows to directly sample the phase space distribution. The data from these files then were analysed by integrating the detector signal over the Linac 4 macropulse. The integrated and averaged signal then was used to plot the phase space distribution. The laserwire results were verified with the independent measurements from conventional slit and grid emittance meter. Measured phase-space distributions for 3 MeV and 12 MeV setups are presented in Fig. 3 and Fig. 4 respectively.

From these phase space data the geometrical RMS emittance was calculated using well known method [8]. The emittance value for 3 MeV setup was found to be 0.222 π ± 0.015 mm mrad measured by the laserwire and 0.243 π ± 0.002 mm mrad measured by the slit and grid method. For 12 MeV setup the emittance values were 0.239 π ± 0.003 mm mrad measured by the laserwire and 0.232 π ± 0.006 mm mrad measured by the slit and grid method.

As one can see from the pictures, despite the lower spatial resolution of the laserwire data (3.5 mm electrode size of the diamond detector in respect to 0.75 mm wire spacing for the grid), the phase-space shape and orientation in both pictures are in a good agreement. vertical position of the centroids on both pictures are slightly different. It can be explained by the fact that the exact position of the laser and the detector center were not perfectly aligned with respect to the center of the ion beam.

SUMMARY AND OUTLOOK

The laserwire system capable of measuring the H^- beam at two commissioning stages of Linac 4 has been successfully demonstrated. The main advantages of described system are the use of low power, commercially available laser source and delivery of the laser pulses to the IP through the flexible optical fibre. Obtained results from laserwire scanner demonstrate very good agreement with conventional slit and grid diagnostic both for 3 MeV and 12 MeV H^- beam. These encouraging results represent the first step towards the design of a laserwire system for the Linac 4 top energy.

For the final system it is foreseen to install two independent laserwire stations. Both shall be able to measure the phase space and, consequently, the emittance and profile of the beam in vertical and horizontal plane. The design of the the laser optics and diagnostic will remain similar with some minor modifications. For example, due to high radiation level the laser source will be relocated to a hutch on top of the accelerator tunnel. Additional optical path will be required in order to perform the scan in the horizontal plane. A longer fibre (~ 20 m) will be required to deliver the laser pulses to the IP. As for the detection system, the diamond detector is still considered as a primary instrument for the final system. The resolution of the detector can be improved by increasing the number of readout channels. To measure profile of the H^- beam another possibility with detection of the stripped electrons is considered.

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