DESCRIPTION OF LASER TRANSPORT AND DELIVERY SYSTEM FOR THE FETS LASERWIRE EMITTANCE SCANNER

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Abstract

A beam emittance monitor for H- beams based on laser-induced ions neutralization is being developed at the Front End Test Stand (FETS) at the Rutherford Appleton Laboratory (RAL). In this paper we present a full account of the laser system that will be used for the photo-detachment experiment, the optical transport system and the final delivery assembly. All the relevant measurements such as power, spatial and temporal characteristics of the laser, fiber coupling efficiency and final delivery laser beam parameters will be reported.

INTRODUCTION

Laser-based diagnostics of accelerator beams have been of interest for at least the last two decades [1, 2]. The promise of non-invasive operation at extremely high accelerator beam parameters is an attractive aspect of these diagnostic technologies. Originally envisaged for operation with electron machines [3], the technology of the laserwire profiler has recently found its way into H^- accelerator diagnostic, for profile and more generally emittance measurements of the beam [4]. Among the latest developments in this technology, the idea of laser transport by means of optical fiber has been of increasing interest thanks to the obvious simplification of the system and virtually alignment-free optical delivery.

LASER SYSTEM

The laser system that will be used for the photo-neutralization of the H^- beam is a master oscillator and power amplifier (MOPA) fibre laser emitting 110 ns pulses at λ = 1080 nm with a peak power of 8 kW. It is composed of a Q-switched Yb:fibre oscillator that produces low energy pulses at a repetition rate of 30 kHz and a diode pumped fibre amplifier. The amplifier pump diode laser can be modulated by a TTL signal with a repetition rate of up to 5 kHz, enabling the train of amplified pulses to be synchronised to an external source. A summary of the laser parameters is reported in Table 1.

Laser Measurements

A measurement of the laser average power versus diode current both with CW pumping and with the pump driven by a TTL signal at 250 Hz and 50% duty cycle is shown in Fig. 1 (top). The maximum average power is 28 W.

Table 1: Summary of Laser Parameters

Laser Parameter	Value
Wavelength	1080 nm
Average Power (CW Pump)	28 W
Repetition rate	30 - 100 kHz
Energy per pulse	0.9 mJ @ 30 kHz
Pulse duration (FWHM)	110 ns
Pulse peak power	8 kW
Beam quality:	Gaussian profile. M^2_x =1.8, M^2_y =1.6,

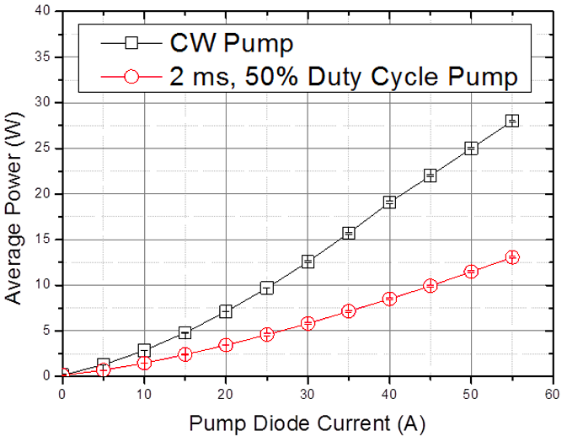

Figure 1: Measurement of laser average power.

As shown in Fig. 2, the rise time necessary to reach the amplification regime was 434 µs, after which the pulse-to-pulse stability was 7% RMS.

In routine operation, the duty cycle of the laser-amplifier should be reduced to match that of the accelerator, while maintaining the pulse peak power. This will be achieved either internally by controlling the pumping regime or by means of an external modulator.

Figure 3 reports the measurement of the spatial mode quality M^2 for the two orthogonal axes. The laser beam was focused by a plano-convex singlet lens of 500 mm

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focal length. The laser spot images were acquired by a CCD camera with 6.7 µm square pixel size mounted on a motorized translation stage. The M^2 factors were calculated by fitting the data with the beam propagation equation for non-ideal Gaussian beams [4], resulting in 1.81 for the horizontal axis and 1.61 for the vertical axis.

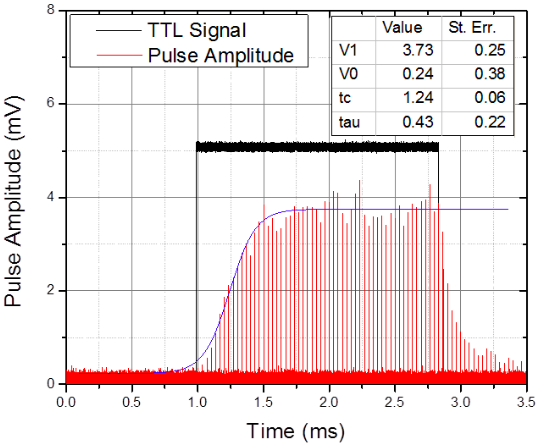

Figure 2: Amplification traces with pulsed pumping.

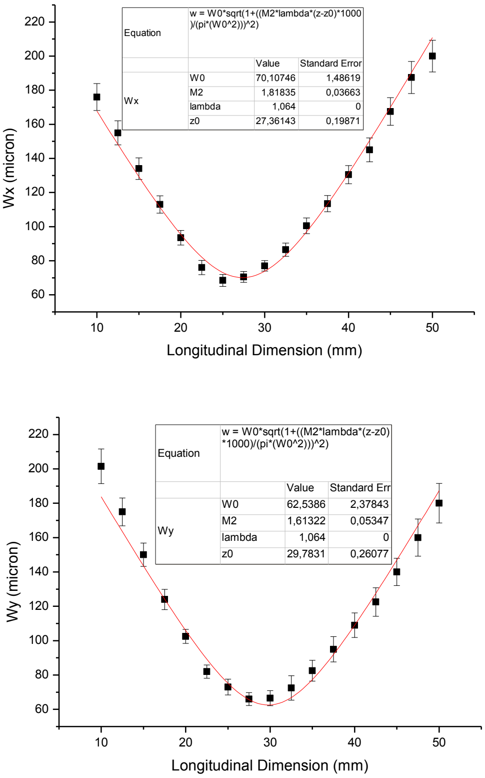

Figure 3: Measurements of the laser horizontal (top) and vertical (bottom) spatial quality.

LASER TRANSPORT

The laser will be conveyed to the interaction area over a distance of 100 m via an optical fiber. An assembly of two remotely controlled motorized translation stages will enable the system to scan across the H^- beam along its vertical profile (Fig. 4). A motorized beam expander will control the output size of the collimated laser beam in order to enable the system to operate with different spatial characteristics of the ions beam. A photograph of the final focus assembly is shown in Fig. 4.

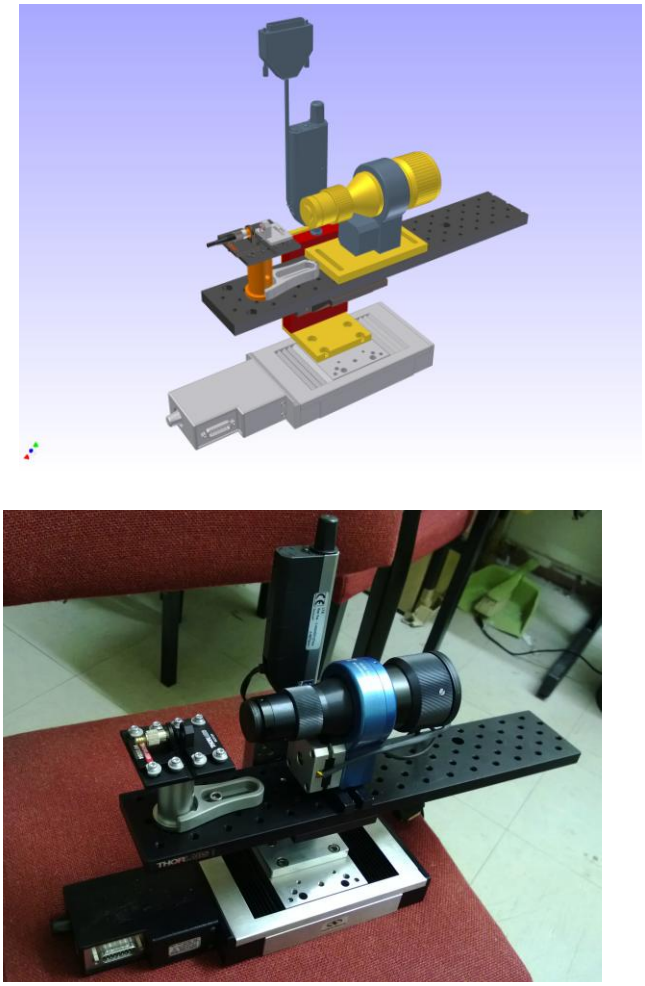

Figure 4: CAD model (top) and photograph (bottom) of the laser beam delivery assembly.

The optical fibre used for the beam transport is a large mode area (LMA) fibre with a core size of 20 µm and a numerical aperture NA=0.08 (equivalent M^2 = 2.35). A lens with a focal length of 6.25 mm is set to collimate the beam to a waist w_0 = 0.5 mm (1 mm diameter). The variable beam expander has a range of magnification from 1 to 8X so the final beam will be collimated to a diameter adjustable from 1 to 8 mm with a step of 1 mm. In Table 2 is reported the laser spot-size and the Rayleigh range for the different settings of the beam expander.

Table 2: Collimated Laser Size Directly After the Beam Expander and Rayleigh Range for Different Beam Expander Settings, Without Focusing Optics

W_0 (mm)	Rayleigh range (m)
0.5	0.31
1.0	1.25
1.5	2.82
2.0	5.02
2.5	7.85
3.0	11.30
3.5	15.39
4.0	20.10

The values in Table 2 represent the size of the collimated laser beam directly after the beam expander, without any further focussing optics. The optical delivery system offers the possibility to include a planar convex focusing lens after the beam expander to enable the waist of the laser beam to be longitudinally centred on the particle beam position. This would create smaller spot laser sizes to overlap with the particle beam position. For example, in the case that a 500 mm focal length lens is selected, the size of the waist that interacts with the particle beam and the corresponding Rayleigh lengths are given in Table 3. A collimating lens of f6.4mm and a beam with M^2 of 1.7 is assumed. It can be seen that spot sizes as low as 70 µm are achievable. Increasing the focal length of the collimation lens can further reduce the spot size, however, care must be taken to avoid reducing the Rayleigh length to within the nominal transverse size of the particle beam under study.

From these results it is seen that the delivery optics will cover a wide range of particle beam sizes can be measured, with either an automated change of the beam expander, or by changing the lens combination. From these studies a collimating lens of focal length 6.4 mm and a nominal beam expander setting of x3 and a focussing lens of focal length 500 mm has been selected as the baseline design.

Table 3: Laser Spot Size at the Focus of a 500mm Focusing Lens After the Beam Expander and the Corresponding Rayleigh Range for Different Beam Expander Settings. A 6.4 mm Collimating Lens After the Fibre Is Assumed

W_0 (mm)	Rayleigh range (mm)
0.56	549.1
0.28	127.3
0.18	61.0
0.14	34.3
0.11	22.0
0.09	15.2
0.08	11.2
0.07	8.5

Laser Measurements After Fibre Transport

Two main measurements have been performed on the laser beam output from the optical fibre: coupling efficiency and transverse mode quality.

The coupling efficiency has been calculated as the ratio between output and incident average optical power. The measurements have been recorded at low power (90 mW) and high power operation (4.5 W). In both cases the recorded efficiency was over 65%. The value for the average power used in the efficiency measurement at high power setting corresponds to the highest diode current settings and a duty cycle of 15% and it is a higher limit for the average power beyond which the fibre would be at risk of surface damages. The FETS H- accelerator is expected to produce macro-pulses with a pulse length of 2ms and a repetition rate of 50 Hz. The duty cycle is therefore 10% and the laser average power at which the laser will operate during the photo-detachment experiment is about 3W, well below the fibre damage threshold.

The spatial mode quality of the laser beam at the output of the fibre has also been assessed. Results are reported in Fig. 5. The beam expander was set to a magnification factor of 3X. The output beam from the beam expander had a diameter $2w_0$ = 3 mm and the laser spot was focused on the CCD camera with a lens with a focal length of 500 mm. In Fig. 5 are reported the plots for the horizontal (top) and vertical (bottom) profiles. The resulting M2 value after the fibre transport are respectively 1.75 and 1.76.

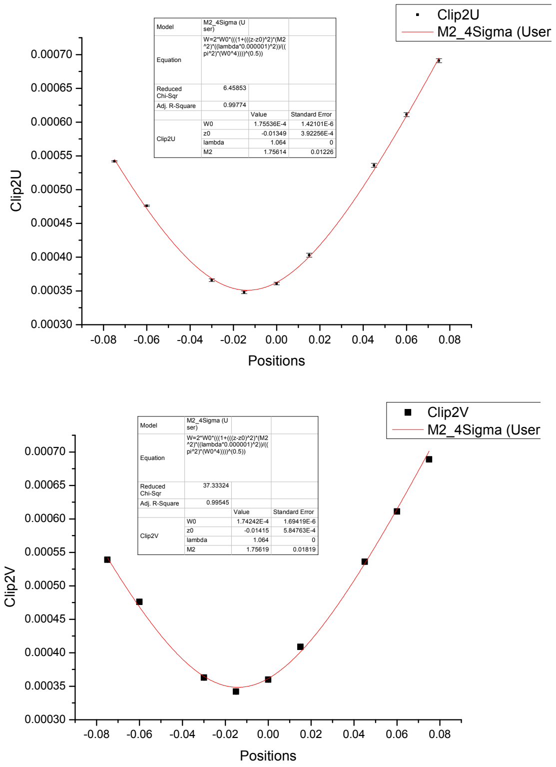

Figure 5: Measurements of the laser horizontal (top) and vertical (bottom) spatial quality after the fibre.

The laser beam profile taken by the CCD camera is shown in Fig. 6. The shape of the beam shows only a slight ellipticity (it is 95% spherical) and has a very near Gaussian profile.

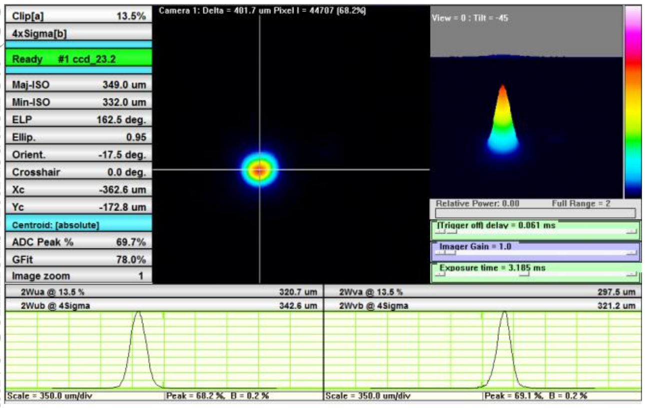
Clip[a] 13.5%
4xSigma[b]
Ready #1 ccd_23.2
Maj-ISO 349.0 um
Min-ISO 332.0 um
ELP 162.5 deg.
Ellip. 0.95
Orient. -17.5 deg.
Crosshair 0.0 deg.
Xc -362.6 um
Yc -172.8 um
Centroid: [absolute]
ADC Peak % 69.7%
GFit 78.0%
Image zoom 1
Camera 1: Delta = 401.7 um Pixel I = 44707 (68.2%)
View = 0 : Tilt = -45
Relative Power: 0.00 Full Range = 2
(Trigger off) delay = 0.061 ms
Imager Gain = 1.0
Exposure time = 3.185 ms
2Wua @ 13.5 % 320.7 um
2Wub @ 4Sigma 342.6 um
2Wva @ 13.5 % 297.5 um
2Wvb @ 4Sigma 321.2 um
Scale = 350.0 um/div Peak = 68.2 %, B = 0.2 %
Scale = 350.0 um/div Peak = 69.1 %, B = 0.2 %

Figure 6: Picture of the laser at the focal plane.

CONCLUSION

The laser transport via optical fiber has been successfully developed. The coupling efficiency has been optimized to a value of 65% and the transversal mode quality of the laser beam has been preserved or even slightly improved.

The final optical assembly has been developed to ensure the widest flexibility of system for use with a range of H- beam parameters.

The next planned set of measurements will include the analysis of the temporal laser profiles in order to ensure that the fibre transport does not affect the pulse shape significantly during transport.

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