AN ELECTRO-OPTIC DEFLECTOR FOR A FAST LASER-WIRE SCANNER*

A. Bosco[#], G. A. Blair, S. T. Boogert, G. Boorman,
John Adams Institute at Royal Holloway University of London, Egham, UK.

Abstract

A large aperture electro-optic deflector has been designed, realized and tested for application on a laser-wire scanner for particle accelerators. Results on the important parameters such as deflection strength, speed and mode quality preservation are shown and discussed.

INTRODUCTION

Laser-based beam profile monitors, and in particular the laser-wire (LW), will be standard tools for electron beam sizes measurements in future synchrotron light sources [1] and electron–positron colliders [2].

One of the main advantages in using such technique is that the LW is inherently a non-invasive profiling system [3]. Furthermore, it allows sub-micrometric resolution [4], and fast profiling speed [1], [5].

In [5], an extensive analysis of an original design of a large aperture electro-optic (EO) scanner was presented. This work is actually the natural continuation of [5]; it presents in fact, the first experimental results from the same EO prototype. In particular, attention has been focused on the measurement of its deflection strength and on the preservation of the laser mode quality.

PRINCIPLE OF OPERATION

The principle of operation of the presented device is based upon the generation of a linear gradient of refractive index across the transversal laser beam cross-section obtained through the linear EO effect. In fact, an EO material experiences a change Δn in the refractive index n_0 that is directly proportional to an applied static electric field [6]:

$$\Delta n = \frac{1}{2} n_0^3 r_{33} E_z \, , \qquad (1)$$

where r_{33} is the EO coefficient which couples the a linearly polarized laser beam to a parallel electro-static field along the crystallographic c-axis [note that the more general coupling formula is tensorial and eq. (1) is valid only for a particular class of materials such as the one treated in the text]. Now, if the static electric field is applied through an arrangement of alternated electrodes hyperbolically shaped, as shown in Fig. 1, the component E_z (and therefore Δn according to Eq. 1) will vary along the transversal coordinate from a positive to a negative maximum amplitude, with a nil value in the centre of the crystal.

The effect of such modulation of the refractive index on a laser beam that propagates through the EO crystal will be that the right side will travel at a different speed than the left one. Thus the laser beam wave-front will deflect in a measure proportional to the refractive index difference and the propagation length [5].

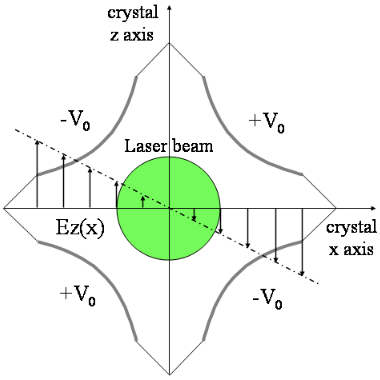

Figure 1. Schematic picture of a quadrupole EO deflector. The value of the refractive index changes from left to right by 2Δn given by Eq.1.

PROTOTYPE DETAILS

A type of EO scanner based upon the principle described in the previous section is already available on the market but there is a fundamental limitation on the optical aperture (and a consequent limit in its use with high power lasers), due to the fact that the electrodes are shaped directly on the EO crystal (the largest clear aperture available in the market is around 3 mm diameter). In fact, to obtain a device with large clear aperture, it would require growing a good (homogeneous) crystal with extremely large dimensions (16x16 mm^2 for a clear aperture of 6 mm) with obvious technical growth problems.

In [5], in order to overtake this problem, we proposed a hybrid solution in which the electrodes were shaped on a holder made of a common polymer (a picture of the device is shown in Fig. 2). A 8.6 mm hole was drilled through the holder in order to accommodate the EO medium. The chosen EO material was a 45 mm long cylinder of Lithium Niobate doped with MgO to decrease the unwanted photo-refractive effect which would otherwise be strong at the interesting wavelength of 532nm.

---

*Work supported by: STFC LC-ABD Collaboration and Commission of European Communities under the 6th Framework Programme Structuring the European Research Area, contract number RIDS-011899.

alessio.bosco@rhul.ac.uk

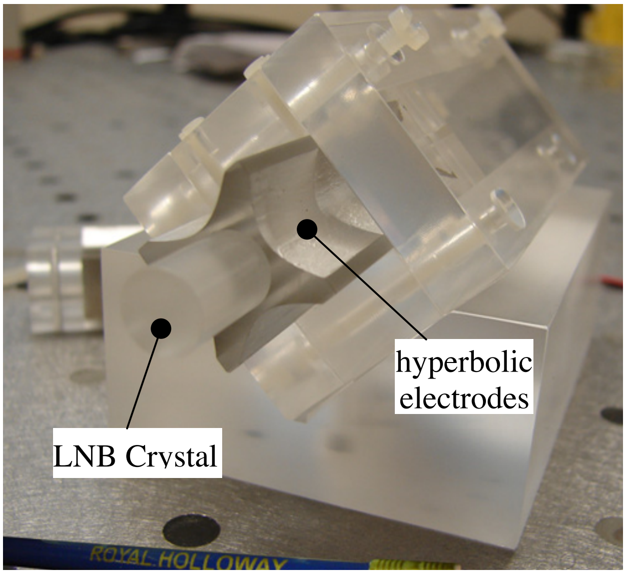

Figure 2. Picture of the realized crystal holder with hyperbolic shaped electrodes.

The obvious advantage of this configuration is that the clear aperture coincides with the diameter of the EO crystal cylinder. The realized prototype had a clear aperture of 8.6 mm, capable to accept a beam diameter up to 7 mm (within the diffraction limit 8.6 mm/1.22 [6]). On the other hand, the electric field that generates the refractive index has to propagate through an interface between two media with different dielectric properties. This might result in an actual electric field that is distorted from the ideal case of Fig. 1. This problem was treated analytically in [5] where it is shown that the distortions of the electric field at the interface are localized at the interface. Moreover, these distortions can be reduced further in two different ways: first, by choosing materials for the holder and the EO core with better dielectric matching; and second by optimizing the shape of the electrodes.

EXPERIMENTAL TESTS

The experimental setup used to test the device is sketched in Fig. 3. The laser used for these tests was a frequency doubled continuous wave Nd:YVO4 laser emitting at 532 nm. The laser was pulsed by means of a mechanical chopper to a pulse repetition rate of 2 kHz. A TTL signal from the chopper driver was then input to a National Instruments^{TM} PC card in order to generate a subharmonic signal locked to the laser for triggering the CCD camera.

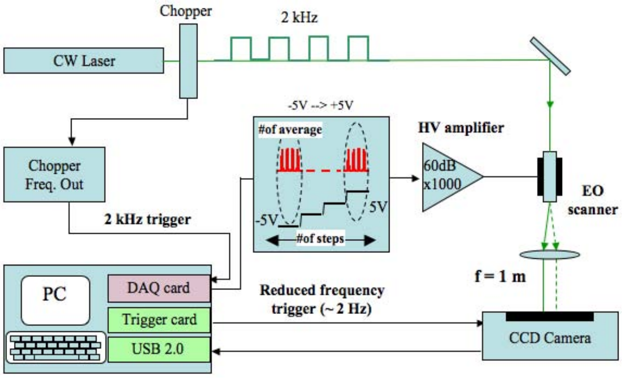

Figure 3. Diagram of the experimental setup.

The laser beam profiles were recorded using a Gentec^{TM} CCD camera (model WincamD) externally triggered. The CCD camera was placed after a plano-convex lens with a focal length of 1 m, for recording the beam deflection (actually the beam shift at the focal plane) and measuring the M^2 quality factor of the laser after propagating through the EO device (the input M^2 of the laser was 1.005).

An amplifier with a gain of 60dB (1000X) and bandwidth of 75 kHz, fed by a stepped ramp function from -5V to +5V (again synchronized with the laser pulses), was used to supply the high voltage to the EO device.

EXPERIMENTAL RESULTS

Deflection strength

In Fig. 4 is reported a series of images of the laser profile for applied voltages from -5kV and +5kV in 2kv steps and in Fig. 5 a plot of the deflection against the applied voltage. The high voltage function consisted of a

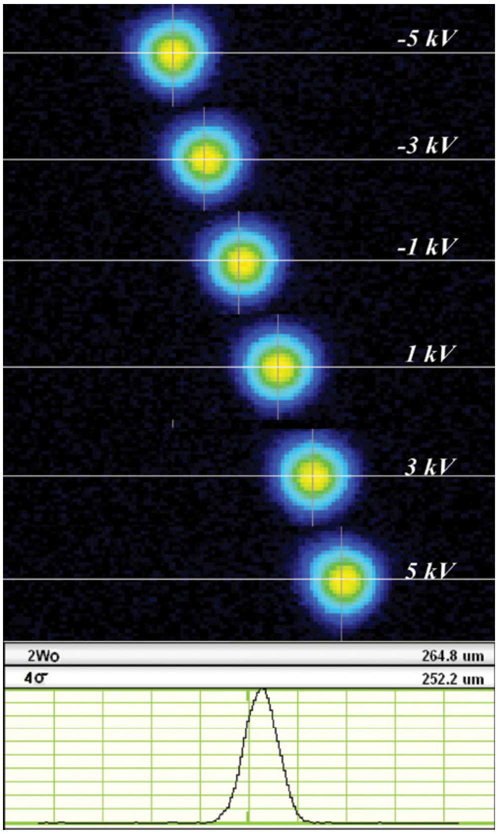

Figure 4. Images of the laser beam while scanning.

series of 61 stepped ramps of 20 steps each (from -5kV to +5kV and then back to -5kV, step 1kV). Each step contained 50 laser pulses and was 25 ms long. The CCD camera trigger was obtained by dividing the laser trigger by a factor 1050, in order to record the beam at different voltages within each cycle. The number of images for each position (i.e. applied voltage) was then 6, useful for a statistical analysis and a repeatability test. As we can see from the plot of Fig. 5, the obtained beam displacement at the focal plane is 0.583 mm, i.e. an angular scan range of 0.583 mrad. From the fit we can quantify a deflection factor of 58 μrad/kV. The laser beam is focused down to a σ = 62.5 μm (see the profile in Fig. 4), therefore the total deflection is close to 10 σ.

Beam quality preservation

From the images reported in Fig. 4 it s already possible to see that the laser beam maintains its Gaussian shape and its circularity. A better analysis of the beam quality is here reported through a measurement of M^2 reported in Fig. 6. Measurements were taken with an applied voltage of 5kV a set of CCD longitudinal positions.

As we can see, the propagation through EO deflector changes the beam quality by a relatively small amount, from 1.005 to 1.09 for the horizontal profile and 1.06 for the vertical, i.e. less than 10%.

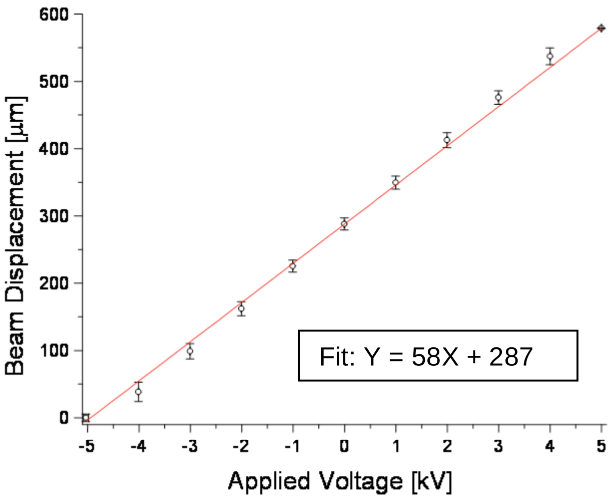

Figure 5. Plot of laser beam displacement Vs applied voltage.

CONCLUSIONS

In conclusion, we realized and tested an EO device capable of deflecting a pulsed laser beam (test were done using a repetition rate of 2 kHz). The clear aperture f the device was 8.6 mm, 3 times bigger than what is available on the market.

The obtained deflection was 10 σ and the beam quality factor M^2 was increased by less than 10% after propagation through the device.

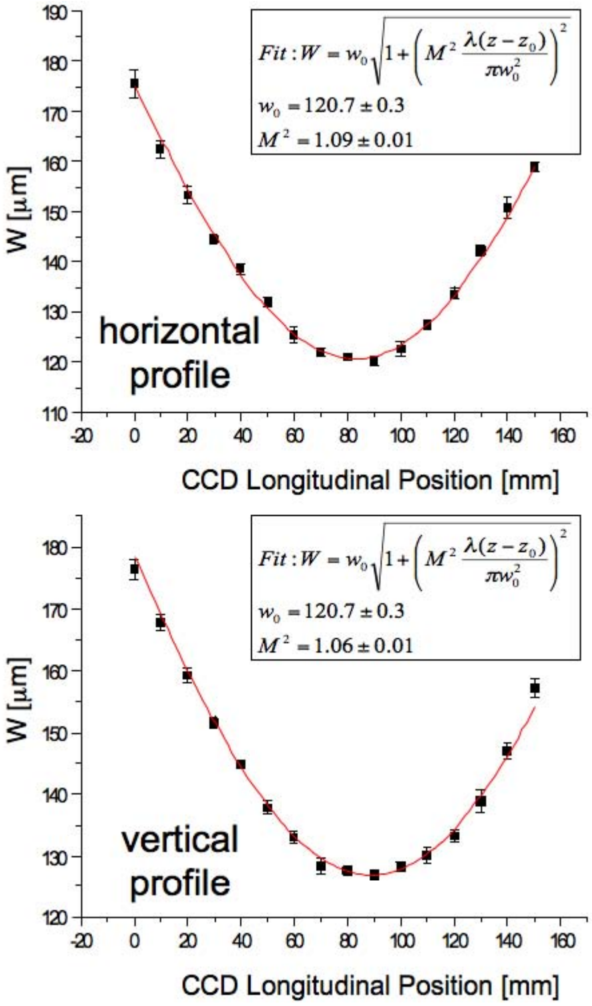

Figure 6. M^2 measurement of the beam after propagation through the EO crystal with an applied voltage of 5kV.

The presented results are basically independent from the laser repetition rate. In fact, the only limit is on the high voltage amplifier bandwidth (currently 75kHz).

The next experimental tests on the same device will be performed using a laser at 130 kHz and a high voltage ramp as short as 80μs.

REFERENCES

[1] A. Bosco, et al., Nucl. Instr. and Meth. A (2008), doi:10.1016/j.nima.2008.04.012.
[2] I. Agapov, G.A. Blair, M. Woodley, Phys. Rev. ST Accel. Beams 10 (11) (2007) 112801.
[3] A. Telnov, Nucl. Instr. And Meth. A 513 (2003)
[4] L. Deacons, et al., PAC07, THOAC01, 2007
[5] A. Bosco, et al., PAC07, MOPAN110, 2007
[6] Yariv, Pochi, Yeh, “Optical waves in crystals: propagation and control of laser radiation” John Wiley and Sons (2002).