PROPOSAL FOR A FAST SCANNING SYSTEM BASED ON ELECTRO-OPTICS FOR USE AT THE ILC LASER-WIRE*

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Abstract

Electro-optic devices open the possibility of ultra-fast scanning systems for use in intra-train scanning at the ILC, where scanning rates in excess of 100 kHz may be required. A first study of the possibilities is presented together with the first results from a prototype system.

INTRODUCTION

Laser based beam profile monitors and in particular the laser-wire (LW) are the key for non-invasive electron beam profile measurements. The LW works by scanning a focussed laser beam across an electron (or positron) beam. The number of Compton-scattered photons as a function of laser spot position then provides information on the bunch transverse profile.

So far, two different scanning techniques have been considered: moving the entire LW optical system [1] and deflecting the laser beam with piezo-driven mirros [2]. Both of the mentioned techniques do not solve the important issue related to a real-time LW monitor, such as the scanning speed. Piezo driven mirrors for instance preserve in fact the beam quality but their speed is limited by the load (scanning mirror) attached to the piezo driver. The result of such a scan is therefore averaged over many trains and not as rapid as it should be.

Consider the parameters of the ILC [3], with trains of about 2820 electron bunches spaced by 337 ns, giving a bunch repetition rate of ~3 MHz and a train length of approximately 1 ms. A scanner capable of running at a rate of ~100 kHz would then provide information about the particle beam size in about one hundred different positions along the train.

The first idea to improve the scanning speed was to use acousto-optic devices, whose time response could be as fast as 500 ns [4]; however their major limitations are a very low damage threshold and a low diffraction efficiency (< 40%).

In this work we studied the possibility to use electro-optic (EO) techniques for implementing a scanner device capable, in principle, to reach scanning rates in excess of 100 kHz. In particular, we produced a first prototype of an EO scanner and tested experimentally its working capabilities.

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ELECTRO-OPTIC EFFECT

The working principle of our EO scanner is based on the EO effect, where a refractive index change is induced by an applied electric field:

$$\Delta n = \frac{1}{2} n^3 \vec{r} \bullet \vec{E}, \tag{1}$$

where n is the linear refractive index, $\vec{E}$ is the E-field vector and $\vec{r}$ is the EO tensor, whose form and magnitude depends on the material. This refractive index modulation will change the refraction direction through an interface between the EO medium and the output (linear) medium.

DESIGN AND REALIZATION OF A FIRST EO SCANNER PROTOTYPE

Fig. 1 illustrates how the basic working princple described previously has been applied to realize a first prototype of an EO scanner. Basically, by modifying the refractive index accordingly to eq. (1), *i.e.* by applying a driving electric field, it is possible to change the beam propagation direction from the output face of an EO prism.

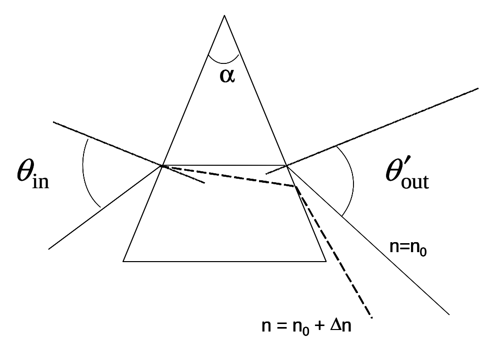

Figure 1: Electro-optic prism. The dashed line represents the beam path when the refractive index is changed.

For realizing this first prototype we chose Lithium Niobate (LNB), a standard material widely used for EO devices. Although it is not the best material available in terms of nonlinearity and optical damage threshold, it was the best choice at this stage of the research due to practical reasons such as cost and availability on the market. In fact, the experimental results presented below can be generalized to any other material (a list of other possible candidates, with their nonlinear coefficient and optical damage thresholds can be found in [5]).

A three-dimensional sketch of the EO prism is depicted in fig. 2. The triangular surfaces were coated with a gold-chromium alloy to allow the application of the electric field through the prism. The prism's thickness was chosen to be 5 mm in order to have a good compromise between the value of the applied field (which is inversely proportional to the distance through which the voltage is applied) and the optical aperture of the prism. The prism could accommodate a laser diameter up to 3 mm.

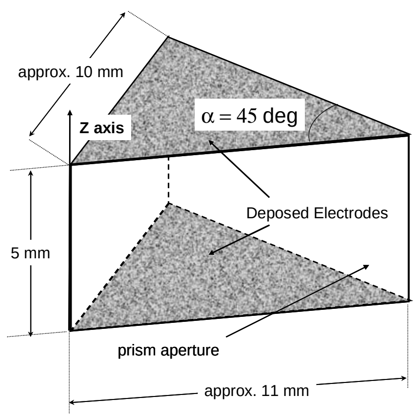

Figure 2: 3D sketch of EO prism. The grey surfaces are metallic coated.

EXPERIMENTAL STUDIES

The first stage of experimental analysis consisted of measuring the deflection of a continuous wave laser beam (provided by a green HeNe laser) by applying a static voltage through the prism of up to 2000 V. The experimental set-up is sketched in fig. 3. A variable beam expander was used to provide a collimated beam of 1, 2 and 3 mm diameter to be sent on a linear (BK7 glass) 45 degrees prism which served to introduce a previous ellipticity to the laser beam subsequently compensated by the EO prism. In this configuration it was possible to obtain a perfectly circular beam out of the device yet use it close to the critical angle where the deflection is more sensitive to refractive index changes (see [5] for more details). The obtained deflection was then visualized by a CCD camera profile (with a 10X beam expander) set up after a 300 mm focusing lens. The lens transformed the scanner deflection into a beam shift on the focal plane equal to $f\Delta\theta$.

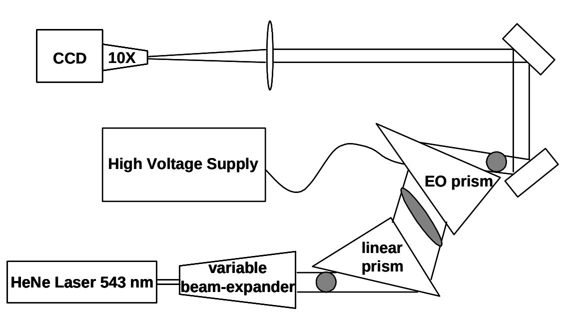

Figure 3: Experimental setup.

With the maximum applied voltage of 2 kV, giving rise to an electric field of 4 kV/cm, the refractive index change, calculated through eq. (1) with LNB r_{33} coefficient of 30 pm/V, was approximately 6×10^{-5}.

According to Snell's law, applied to the configuration shown in fig. 1, the total deflection $\Delta\theta = k\Delta n$, where the coefficient k depends on the prism angle α and increases rapidly when approaching total internal reflection. In our case, as it will be shown in the next section, it was possible to obtain a value of the coefficient k equal to approximately 4 (thus $\Delta\theta$= 0.24 mrad for 2kV applied). We would like to stress the fact that in this condition, as explained before, if only the EO prism were used, the output beam would have been strongly elliptical and totally useless for scanning. The use of a pre-induced ellipticity by the linear prism is a solution to this problem.

EXPERIMENTAL RESULTS

In fig. 4, 5 and 6 are reported beam images as taken by the CCD camera mounted with a 10X beam expander for three different voltages applied on the EO prism. Each figure is referred to a different input beam condition. On the right side of the pictures Xc is the horizontal position of the laser beam on the CCD and numbers at the bottom indicate the full width of the beam at $1/e^2$ (twice the beam waist).

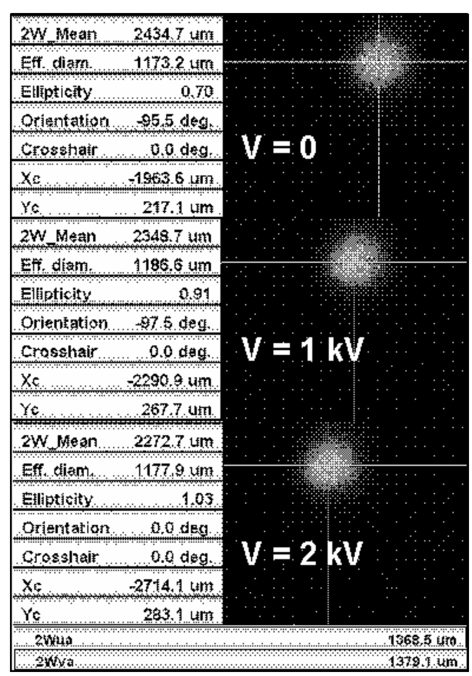

Figure 4: Beam scanning with input diameter of 2mm. Total shift was 75 μm with a waist of 68 μm.

Fig. 4 shows the highest shift of 75 µm obtained with an input beam of 2mm diameter onto the EO scanner focused by the lens down to 68 mm waist radius. Input beam diameter in fig. 5 was 3mm (limit of acceptance of our prism) and was focused down to 46 µm. In this case the output angle from the EO prism had to be slightly smaller and so was the total deflection (as explained previously the deflection become larger the closer the beam is to the critical angle): the shift obtained was 52µm.

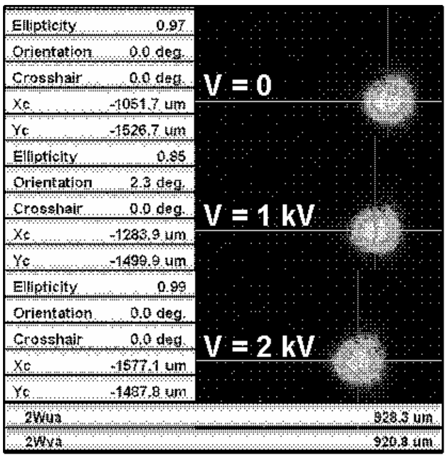

Figure 5: Beam scanning with input diameter of 3mm. Total shift was 52 µm with a waist 46 µm.

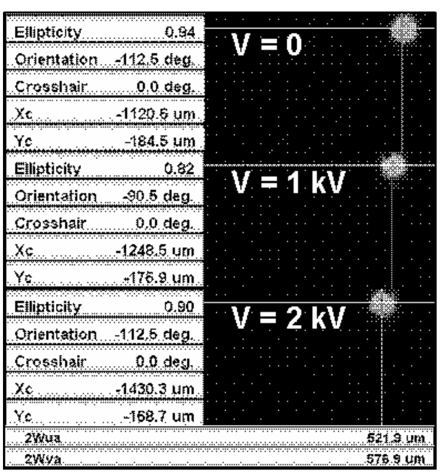

Figure 6: Beam scanning with input diameter of 2mm and beam expander after EO prism. Total shift was 31µm for 26 µm waist.

The pictures shown in fig. 6 were taken under different conditions: in fact after the EO prism (the input beam was still 2mm) a 2.5 times beam expander was set up. Increasing the beam spot size before the focusing lens made possible to obtain a much smaller focused beam (i.e. 26 µm waist). The effect of the beam expander on the other hand affected also the deflection obtained from the prism, reducing it by the same factor 2.5.

CONCLUSION

The main result of this first stage of the research is that EO prism could be actually used for a scanning device.

In particular we demonstrated that the problem of laser beam distortion is solvable by introducing a previous (opposite) distortion on the beam by means of a linear prism.

Concerning the actual deflection obtained with such prototype, it is just one order of magnitude smaller than the typical value of 1-2 mrad obtainable with piezo-driven scanner mirrors. In fact, in any of the cases shown previously the total shift was always slightly higher than the focused laser waist, while the ideal scanning range should be 5-10 times larger than the waist.

This issue might be solved in different ways. For example by using a material with higher EO coefficient (there are several available on the market [5]) it would be possible to obtain larger deflections.

Applying a higher driving voltage it is also a possible solution although not really wanted due to the practical problems of driving several kilovolts at very high frequencies. Another possible solution could be to increase the size of the prism in order to have a larger spot to be focused tighter. The latter one is also problematic because, as mentioned previously, the thicker the prism the less effective is the applied voltage.

As we can see, many issues are still open but many possible solutions are there to be investigated.

REFERENCES

[1] Y. Honda *et al.* Nucl.Instrum.Meth.**A538:**100-115,2005.

[2] J. Carter et al., "Beam Profile Measurements and Simulations of the PETRA Laser-Wire", Proc PAC05 (2005).

[3] ILC Baseline Conceptual Design (2006).: http://www.linearcollider.org/.

[4] T. Kamps et al, Proc. PAC03 (2003).

[5] A. Bosco et al, Proc. ICFA NanoBeam 2005 (2005).