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P 600/650 X-ray streak camera with optimized spatio-temporal resolution

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Abstract

This paper presents the latest performances of the P 600 X-ray streak camera designed for laser fusion experiments. It reaches very high performances in the 1.5 to 10 keV range : 16 to 20 pl.mm^{-1} for the maximum sweep speed which corresponds to a 2 ps theoretical time resolution. We discuss its adaptation to the soft X-ray spectral range down to 100 eV.

Introduction

During the last ten years, an increasing interest on X-rays has been shown, especially for the analysis of plasmas created in laser-matter interaction experiments.

We began the development of such high speed streak cameras by modifying standard image converter tubes structures (RTC P 500).*

Their time resolution, in the spectral range extending from 10 keV down to 100 eV, is in the 25 ps range but the spatial performance is limited (Figure 1) by the image converter tube electron optics which is now 40 years old.

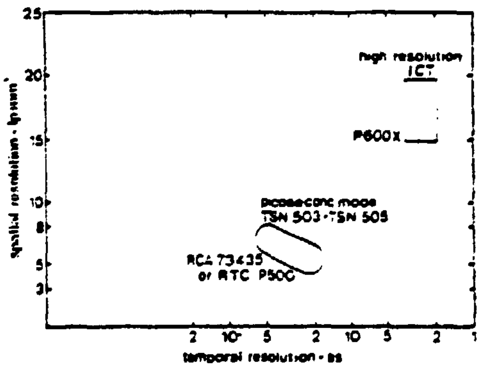

Figure 1. Spatial resolution versus temporal resolution of standard ICT

Two main goals had to be achieved in order to reach the performances required for the X-ray diagnostic :
- spatio-temporal resolution enhancement
- X-ray spectral range extension down to 100 eV.

The first one was reached with the development of the P 600 X-ray image converter tube and camera by L.E.P.** and C.E.L. (see Figure 1). The second one is to be reached with the adaptation of this P 600 I.C.T. into the P 650 soft X-ray version.

P 600 X image converter tube

Electron optics design

The concept of this electron optics (see Figure 2) is mainly based on :

- an intense accelerating field applied on the photocathode in order to overcome both space charge effects[1] in the electron beam and dispersion of transit time between photocathode and screen[2],

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- and, then, two focusing lenses designed to work independently in the spatial and temporal axis, to get a high quality resolved element[3].

The prototype built by L.E.P. consists of the following elements :

- a gold photocathode (0.35 μm deposited on a 25 μm beryllium window) working in the transmission mode in the 1.5 - 10 keV spectral range
- an accelerating electrode located at 2.5 mm from the photocathode and developing a mean accelerating 45 $kV.cm^{-1}$ electrical field
- a quadrupolar lens for spatial focusing and a separate vertical focusing lens (along the time axis) combined with the deflectors
- a P 11 phosphor screen (size 26 mm × 42 mm) deposited on a fiber optic plate.

The tube is fiber optically coupled with an image intensifier (ITT BENDIX F 4113, useful diameter 40 mm).

Camera design

To drive this tube a special camera was designed at C.E.L. (see Figure 3) with an optically triggered miniature spark gap[2], which produces the deflecting voltage.

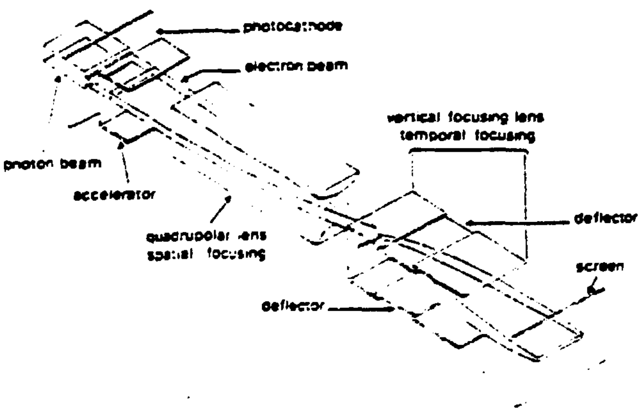

Figure 2. P 600 image converter tube with lamellar optics

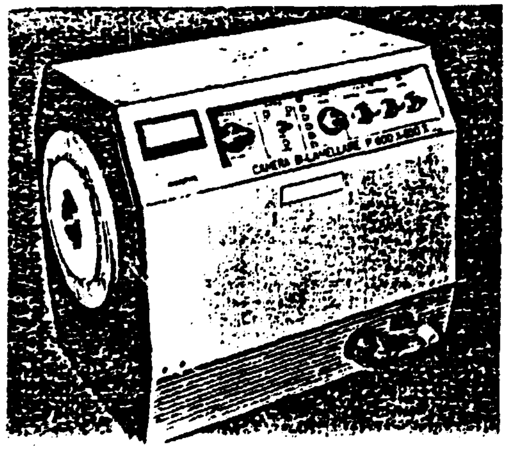

Figure 3. P 600 X streak camera

This laser triggered spark gap generates a 15 kV pulse (15 ns F.W.H.M., 250 ps rise time); its delay and jitter are respectively 3 ns and 0.2 ns for 1 mJ input pulse at $\lambda = 1.06$ μm.

A pulse transformer delivers two symmetric voltage pulses which are adequately shaped by the way of pulse forming networks before supplying the deflectors plates of the camera.

Static results

The source consists of a C.G.R. DIFFRACTOMIX G.C. 343 d.c. X-ray source which illuminates the 2 mm × 15 mm useful photocathode's area through a resolution chart made of gold bars ; we have measured the following performances :

- magnification along spatial axis (photocathode to screen) : 2
- resolution along spatial axis : . 80 μm on the screen (12.5 $\ell p.mm^{-1}$)
  . 40 μm on the photocathode (25 $\ell p.mm^{-1}$)
- resolution along time axis on the screen : 60 μm.

This has to be compared (see Figure 4) to the results obtained with R.T.C. P 500 FX or R.C.A. 73435 image converter tubes working in the same picosecond mode :

- magnification along spatial axis (photocathode to screen) : 1.5

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- resolution along time axis : . 180 um on the screen (5,5 ℓp.mm^{-1})
  . 165 um on the photocathode (6 ℓp.mm^{-1})

- resolution along time axis : 1500 um.

The image quality as well as the resolution improvement clearly appear in Figure 4.

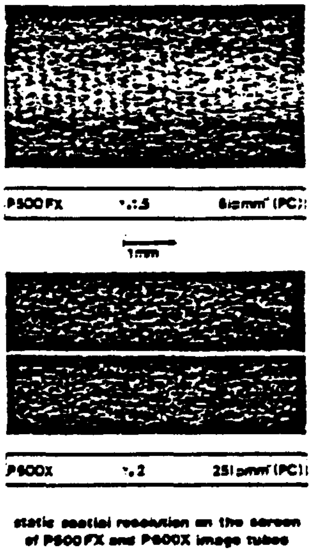

Figure 4. Static spatial resolution on screens of P 500 and P 600 X-ray I.C.T.

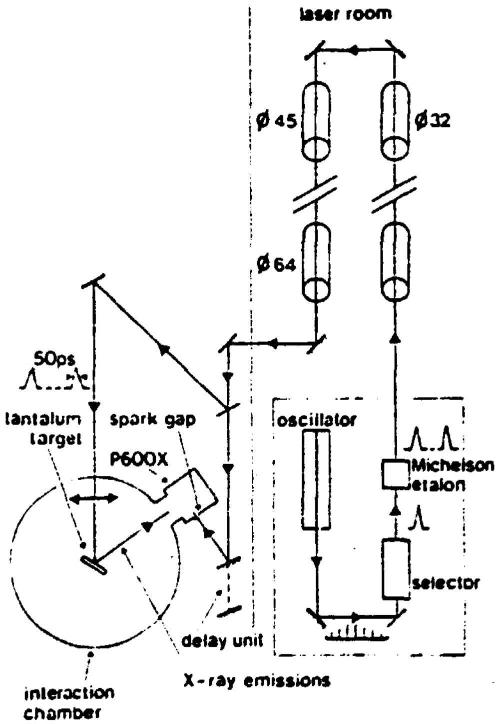

Figure 5. Diagram of experimental set up

Dynamic performances

The camera is then operated as shown in Figure 5 on the KETJAK experiment. A mode locked Y.A.G. laser delivers a train of pulses. The switched out pulse (50 ps F.W.H.M.) is divided in two pulses in a MICHELSON interferometer used as a delay line. This etalon is ajusted to provide the optimum temporal separation between the two generated pulses. Each of them can be amplified up to 5 J. A few mJ are splitted from the laser's output directly to the camera's spark gap while the two main pulses are focused onto the metallic target.

Under these conditions the laser induced plasma delivers two X-ray pulses (≈ 50 ps) separated by a known temporal delay.

Let us now comment some experimental results :

Spatial response. In this case, the two X-ray pulses separated by 150 ps illuminate the gold photocathode through four resolution charts allowing so the measurement of contrast modulation for 20, 16, 12.5 and 10 ℓp.mm^{-1} from the image recorded on the photographic film. The streak speed $v = 4 \times 10^{9}$ cm.s^{-1} nearly corresponds to 1.6 ns for sweep duration on the screen (figure 6).

The microdensitometer analysis along the spatial axis allows to plot the modulation transfer function (See Figure 7). The resolution on the photocathode is limited in the 16 to 20 ℓp.mm^{-1} range (62 to 50 um) with respective contrasts of 35 and 5 %.

It is to be noticed that the degradation between the static and dynamic mode is mainly due to the limited quality and noise factor of the micro-channel plate intensifier rather than to the deflector tube itself.

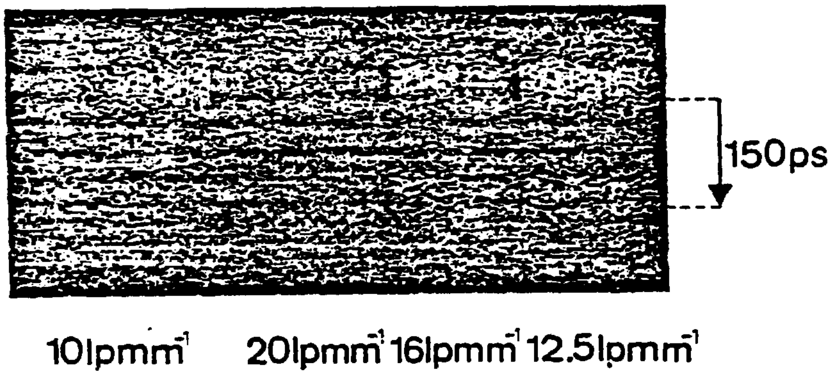

Figure 6. Spatial resolution (P.C.) sweep speed v^{-1} = 25 ps.mm^{-1}

This result is obtained for a high sweep speed (4×10^{9} cm.s^{-1}) which enables the optimum time résolution.

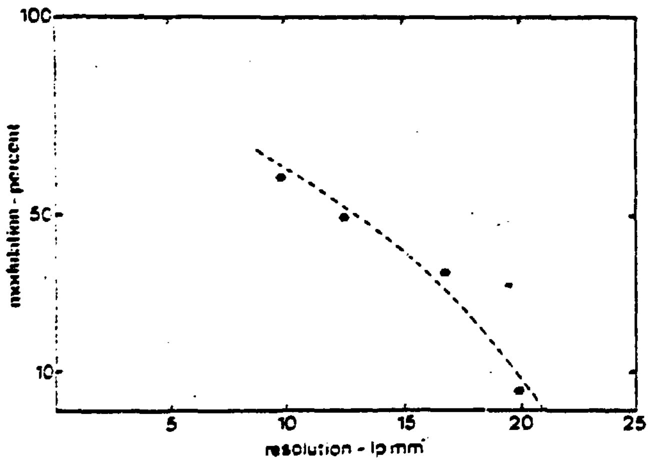

Figure 7. P 500 X I.C.T.'s modulation transfer function

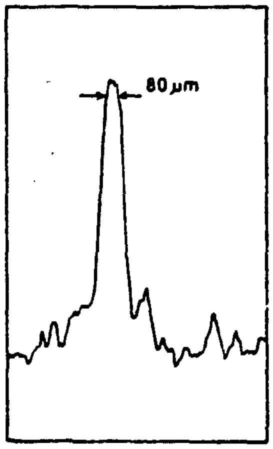

Figure 8. Spatial response along time axis

Time resolution. It is well known that two factors mainly limit the time response of such a tube. This has been yet discussed previously[2] :

- the transit time dispersion t_d resulting from the photoelectron's energy spread $\Delta\varepsilon$ (eV) and field E (V.cm^{-1}) on the photocathode is given by

$$t_d = 2.34\times10^{-8}\ \frac{\sqrt{\Delta\varepsilon}}{E} \qquad (1)$$

which gives $t_d \simeq 1$ ps, taking into account the data from Henke[3] for 1487 eV X-ray incident photons on gold

- the minimum time-equivalent resolved element on the screen t_v for a given sweep speed v and the experimental resolution µ (picosecond duration illumination for an unswept beam) is :

$$t_v = \frac{\mu}{v} \qquad (2)$$

For nearly gaussian pulses and energy distributions, one can approximate that the overall instrumental time response is $\tau = (t_v^2 + t_d^2)^{1/2}$. (3)

Since we have experimentally determined μ = 80 um by measuring the recorded response along time axis for a 50 ps X-ray pulse (See Figure 8) without triggering the camera ("unswept mode"), (2) becomes t_v = 2 ps with v = 4×10^9 $cm.s^{-1}$

and $\boxed{\tau = 2.2 \text{ ps}}$ IS THE THEORETICAL INSTRUMENTAL TIME RESOLUTION THAT CAN BE EXPECTED FROM THE P 600 CAMERA UNDER SUCH OPERATING CONDITIONS.

In fact, and since the F.W.H.M. incident laser pulse lasts some tens of picosecond, we have measured 50 ps F.W.H.M. X-ray pulses (See Figure 6) which only represent the duration of the X-ray pulses recorded by the camera, but obviously not the temporal response of the camera itself (τ = 2.2 ps).

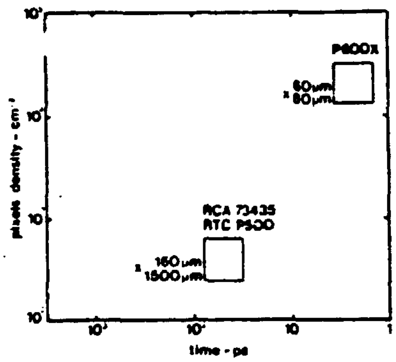

Figure 9. Density of informations avalaible on different I.C.T.

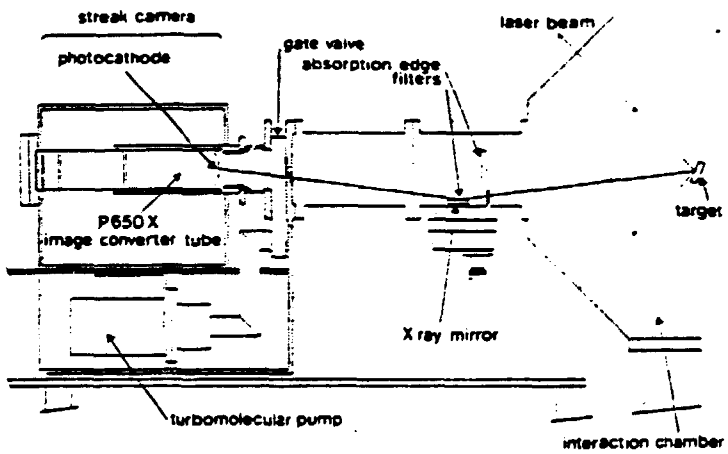

Figure 10. Diagram of P 650 X system

Non-isocnronism effect. This effect has been greatly reduced by appropriately shapping the tube's electrodes.

The difference of transit time between the center and the edges is now less than 10 ps on 80 % of the photocathode useful length.

P 650 X Image Converter Tube

The adaptation of P 600 X prototype into a P 650 Soft X-ray version (100 eV - a few keV) has been built by L.E.P.

This tube (Figure 10) will work directly in the chamber's vacuum in the transmission mode with a 500 Å gold photocathode deposited on a 8000 Å polystyrene substrate.

The front end of the I.C.T. is isolated by a pneumatic gate valve which includes the pumping pipe linked to the turbomolecular pump, thus providing vacuum down to 10^{-6} torr.

A few minutes before the shot the gate valve is opened, setting then the photocathode in the target chamber vacuum. A photograph of P 650 image converter tube is shown on Figure 11.

Conclusion

As a conclusion, it is possible to say that our main goals have been reached since a 2 ps theoretical time resolution is available simultaneously with a 16 to 20 $\ell p.mm^{-1}$ spatial resolution (or enhancement of a factor 50 in the density of resolved elements as compared to the standard R.C.A./R.T.C. image converter tubes operated in the picosecond static mode).

Furthermore, the spectral extension down to 100 eV is to be very helpful for laser induced plasma diagnostic.

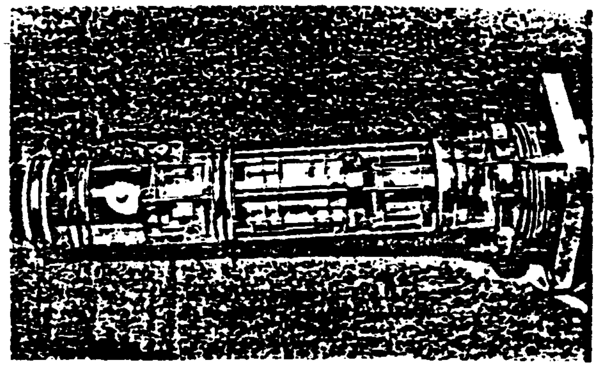

Figure 11. P 650 X Image Converter Tube

Acknowoledgments

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