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X-RAY STREAK CAMERA P600 WITH OPTIMIZED SPATIAL AND TIME RESOLUTIONS

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ABSTRACT

This paper presents the latest performances of our P600 U.V. streak tube and the way followed to design a camera with a new P600 X streak tube.
This camera was defined to reach a high spatial and temporal resolution.
The first experiments with a continuous wave X-ray source have shown a spatial resolution better than 25 $\ell p.mm^{-1}$.
The extraction field on the photocathode ($45\ kV.cm^{-1}$) is high enough to let us expect a temporal resolution better than 3 ps in the the keV range.
Dynamic tests will be carried out as soon as possible with a plasma X-ray source produced by an energetic 40 ps laser pulse.

I - INTRODUCTION

During the last years, an increasing interest on X-rays has been shown, especially for the analysis of plasmas created in laser matter interaction experiments. There are two different ways to study a laser plasma with X-rays :
. by observing the X-ray self emission of the plasma ;
. by probing it (radiography, backlighting) with an external X-ray source.

In both cases we must record spatially and temporally the X-ray emissions in a large spectral range : this is possible by using an X-ray streak camera. Our purpose consists in the development of picosecond X-ray streak camera (called P600 X), which has enhanced performances compared to our previous TSN 503 X and TSN 505 X.

II - P600 U.V. PROTOTYPE

The prototype, working with a CsI photocathode has been experimented in our P600 U.V. camera /1-2/.

II-1. Electron optics design

The main features consist of :
. an accelerating grid located at 2.5 mm from the photocathode ;
. a quadrupolar lens for spatial focusing (horizontal axis) ;
. a vertical focusing lens (along time axis) ;
. a deflector combined with the vertical lens ;
. an integrated microchannel plate (M.C.P.) ;
. a P 11 screen (size 26 x 42 mm), near the M.C.P. (proximity focusing).

II-2. Experimental results

The P600 U.V. streak camera that drives this tube was designed with a miniature laser triggered spark gap which was able to deliver :
. a -5 kV, 15 ns accelerating pulse ;
. two ramp voltage ($\pm$ 2,5 kV) to deflect the image of the slit along the screen at sweep speeds up to $10^{10}\ cm.s^{-1}$.

The main performances are shown in figure 1 and 2.

- Spatial response (Fig. 1.) : When the image of a point light source, illuminating the CsI photocathode, is swept along the screen at a speed $v = 5.10^{9}\ cm.s^{-1}$ the spatial response is in the range of 100 $\pm$ 23 μm for a 25 ps laser pulse ; it is mainly limited by the quality and noise factor of the microchannel plate.

- Time response (Fig. 2) : for this test a light pulse is selected from a YAG oscillator emitting at λ = 1,06 μm. A third harmonic is then generated at λ = 355 nm and a two photon effect occurs in the CsI photocathode : all these phenomena contribute to shorten the photo-electronic response of the tube ; figure 2 shows the rise time t_r of the tube over three decades and demonstrates the capability of the image tube /2/ :

$t_r \simeq 1$ ps (from 10 % to 90 %) ; $t'_r \simeq 4$ ps (1 % to 10 %) ; $t''_r \simeq 7$ ps (1 ‰ to 1 %).

So, we had a 12 ps rise time over 3 decades in the illumination scale.

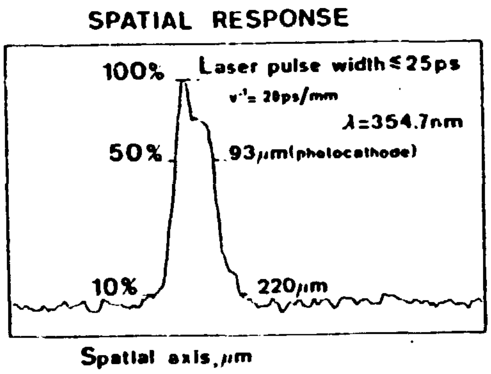

Fig. 1. Spatial response of P600 U.V.

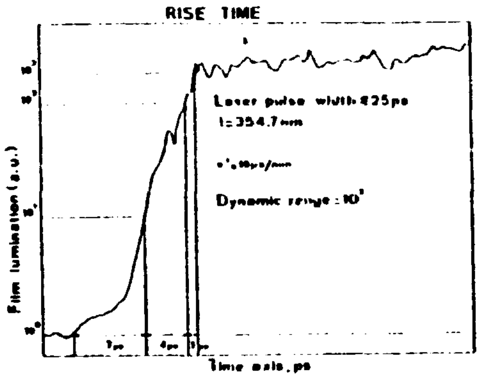

Fig. 2. Rise time of P600 U.V.

As these results were very promising, especially for rise time, we were encouraged to modify the electron optics for the new P600 X-ray tube in order to enhance the performance by :

. reduction of the electron optics magnification from 2.7 to 2 ;
. correction of the residual non isochronism along the slit ;
. enhancement of spatial resolution by suppressing the M.C.P.

III - P600 X STREAK TUBE

III-1. Electron optics design (Fig. 4)

. The CsI photocathode is replaced by a standard R.T.C. P 500 X photocathode (0.35 μm of Gold on 25 μm of Beryllium) which can be removed.
. The vertical focusing-deflecting lens is modified in order to :
  . compensate a residual effect in the spatial magnification ;
  . reduce the non isochronism effects along the spatial axis .
. The length of the tube is increased by 2 cm for reducing the magnification.
. The microchannel plate is removed and replaced directly by the P 11 screen (26 x 42 mm) in order to enhance the resolution and reduce the noise of the tube itself.

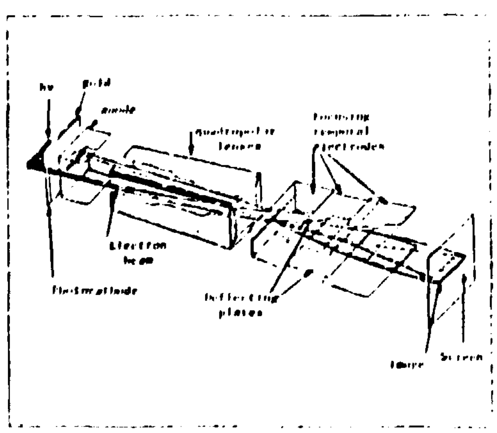

Fig. 3. P600 X electron optics

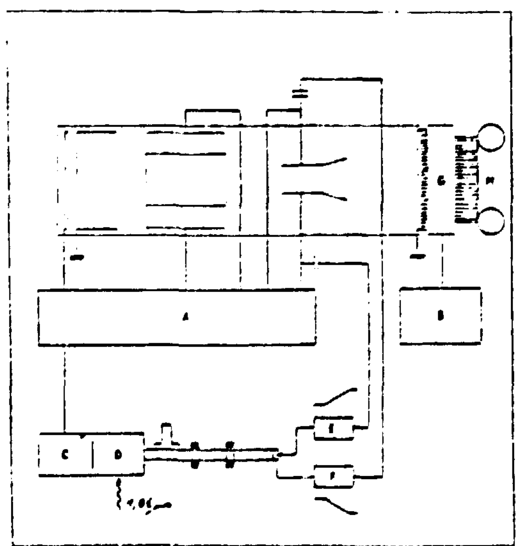

Fig. 4. P600 X camera design

III-2. Camera design

In order to get enough gain from the screen it is necessary to accelerate the photoelectrons with a −15 kV DC voltage on the photocathode and the accelerating field is then very high ($E = 45\ kV.cm^{-1}$).

Different DC voltages are generated for biasing the electrodes :

. in (A) : −15 kV on the photocathode, ± 400 V on the quadrupolar lens, −7 kV on the vertical focusing deflecting lens ;
. in (B) : low voltage for supply the image intensifier tube ;
. The laser triggered spark gap is represented in (D) with its power supply (C) ; it 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 500 µJ input pulse at $\lambda = 1{,}06\ \mu m$.
. A pulse transformer delivers two symetric pulses that are adequately shaped by the way of pulse forming networks E and F, before supplying the deflector plates of the camera.
. The screen deposited on a fiber plate is directly coupled to the intensifier (G) an and then to the film (H) using fiber optics.
. The main controls concern : accelerating voltage, spark gap voltage, spatial and temporal focusing, gain of the intensifier.

III-3. Datas of the P600 X camera

As we previously said, our main goal is to obtain simultaneously the best spatial and temporal resolutions.

III-3.1. Theoretical considerations

It is well known that this purpose may be reached by two dependant ways :

. First, by increasing the electric field E on the photocathode to reduce the dispersion effect τd in the transit time of photoelectrons emitted with different speeds $v_e = 0$ and $v_e = v_{max}$ (Δv_e F.W.H.M.). This contribution can be described by

$$\tau d = \frac{m}{e} \frac{\sqrt{\Delta v_e}}{E} \quad (1)$$

or, if $\Delta\varepsilon$ corresponds to the F.W.H.M. of the energy distribution ε with $\varepsilon = \frac{1}{2} m v_e^2$ (2), we obtain numerically $\tau d \simeq 2{,}3 \times 10^{-8} \frac{\sqrt{\Delta\varepsilon}}{E}$ (3)

. Secondly by reducing the spatial response μ along the time axis when working in the dynamic mode. The corresponding contribution τ_v due to the sweep speed v on the screen is $\tau_v = \frac{\mu}{v}$ (4).

It can also be achieved by increasing the accelerating field E : this decreases the electron beam space charge which is the main limiting factor when reducing μ. Taking into account our instrumental value $E = 45\ kV.cm^{-1}$, and Henke's figure $\Delta\varepsilon \simeq 4$ eV (1487 eV incident X-rays photons for a gold layer photocathode) /3/, we find $\tau d \simeq 1$ ps

Assuming in the dynamic mode that μ remains in the order of 100 µm, (we have measured $\mu = 75$ µm on the P600 U.V. with a laser pulse shorter than 20 ps in the unswept mode), we calculate that $\tau_v = 1$ ps for $v = 10^{10}\ cm.s^{-1}$ and $\tau_v = 2{,}5$ ps for $v = 4.10^9\ cm.s^{-1}$.

The time resolution τ of the camera can be approached, in gaussian response approximations, by $\tau = (\tau_v^2 + \tau_d^2)^{1/2}$ (5).

So that when $4.10^9\ cm.s^{-1} < v < 10^{10}\ cm.s^{-1}$, the limiting time resolution becomes : $1{,}4\ ps < \tau < 2{,}6\ ps$ for incident X-rays in the 1,5 keV range.

III-3.2. Experimental results

The experiment has been carried out with a DC C.G.R. source (DIFFRACTOMIX GC 343 X-ray tube). Electrons are accelerated with a 17 kV voltage on a tungsten anode which generates X-rays essentially in the 1,5 to 15 keV range. When illuminating the photocathode on its whole 2 x 15 mm surface (without slit) through a resolution chart consisting of parallel copper bars. We have measured :

. spatial magnification (photocathode to screen) : 2 along the spatial axis Ox
. spatial resolution ρ : better than 40 µm (25 $\rho\ell\ mm^{-1}$) (Fig. 6.).

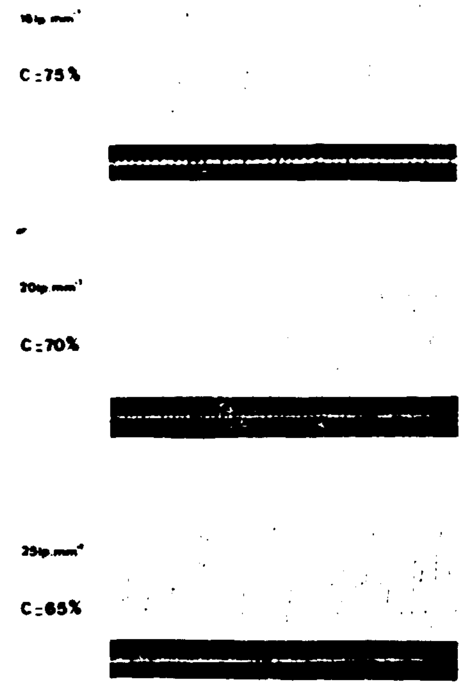

Fig. 6. Spatial resolution (x axis)

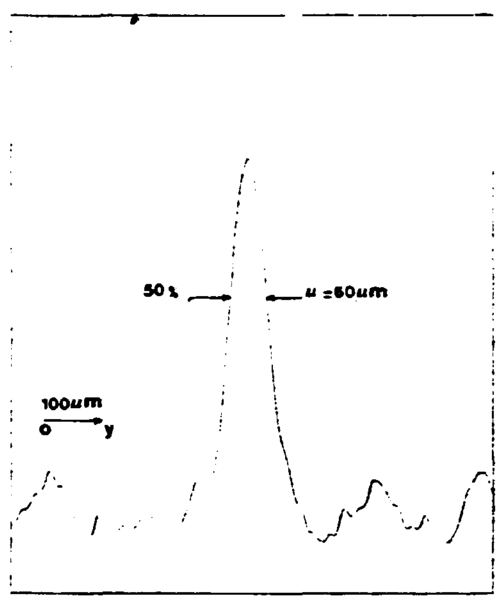

fig. 7. Spatial response (y axis) 20 ℓp.mm^{-1}

CONCLUSION

We know from the P600 U.V. results that the resolution of the tube is not seriously affected when it operates in the dynamic mode (P600 U.V. working with an extraction field three times less than with P600 X).

For this reason we expect, that the next calibration tests performed with a laser induced plasma X-ray source will prove that the P600 tube has the following caracteristics :

. spatial resolution : nearly 20 ℓp.mm^{-1}
. time resolution : better than 3 ps
. dynamic range : nearly 1000.

After that, the same tube and the camera will be adapted for operation in the sub-keV range, directly in the target chamber vacuum.

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