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Two-dimensional microtarget imaging with continuous time-base sweep

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Abstract. A technique for two-dimensional imaging of an x-ray source with a continuous time-base sweep is described. The technique is based on the use of an x-ray image converter tube in combination with a pinhole camera, which has a linear pinhole array. The basic relationships for determining the parameters of the recording system are given. Setting up the procedure is described and the results of two-dimensional microtarget imaging with a continuous time-base sweep in an experiment at the 'Iskra-4' laser facility are presented.

1. Introduction

A study of the microtarget compression dynamics in laser nuclear fusion (LNF) experiments is important both for understanding the process itself and for testing the simulation codes. Target images are recorded with a high temporal resolution (of the order of several picoseconds) using x-ray image-converter tubes (XICT) (streak cameras) in combination with systems for x-ray imaging of targets. A slit aperture stop [1], a pinhole camera [2], or an x-ray microscope [3] are usually employed as such systems. Such a combination permits us to obtain time scans of some cross sections of two-dimensional images.

Research on the subject of uniformity and stability of microtarget compression holds the greatest interest in the present-day stage of research. Investigations into instabilities of different kind, which arise at the interface between two media in their accelerated motion, make up a substantial part of contemporary LNF research [4]. To solve these problems, two-dimensional images should be recorded with a high temporal resolution. For this purpose, either the technique of pulsed x-ray backlighting [5] or recording systems with time sampling have been used [6]. However, while providing a relatively high spatial resolution, both these techniques have an inadequate temporal resolution and provide only a small number of images.

From this point of view much seems to be gained by a technique with a high temporal resolution that employs a conventional XICT to record not one but a series of one-dimensional images corresponding to different sections of a two-dimensional plasma image. This permits the two-dimensional image to be ultimately reconstructed with a nearly continuous time-base sweep and the limiting temporal resolution inherent in streak cameras. An implementation of this technique at the 'Gekko XII' laser facility was reported in Ref. [7]. Shiraga et al. [8] proposed to improve this technique further in order to attain a higher spatial resolution and to also obtain two-dimensional high-monochromaticity images with a high temporal resolution. A similar technique was also used in Ref. [9]. However, the specified papers do not highlight such a critical point as the procedure for bringing the target images into coincidence with the XICT photocathode entrance slit, while Ref. [9] is available only in the form of an abstract.

Here, we implemented the technique to record a continuously time-resolved two-dimensional image of a microtarget in an experiment at the 'Iskra-4' iodine laser facility [10].

2. Technique description and results of image recording

The essence of the technique for recording continuously time-resolved two-dimensional images is described in Ref. [7]. The recording setup is shown schematically in Fig. 1. The images are formed by a series of equally spaced pinholes arranged in a line that makes a small angle θ with the slit of the XICT photocathode. Adjacent images fall on the photocathode slit with a displacement δ:

$$\delta = (1 + M)s\sin\theta, \tag{1}$$

where s is the spacing between the pinholes and M is the magnification factor. Therefore, a two-dimensional image is

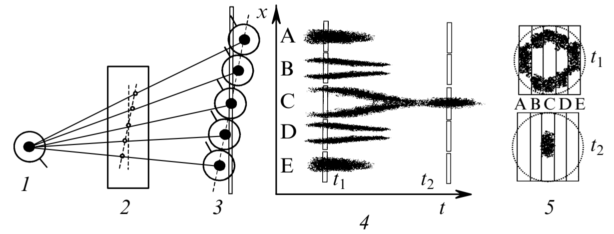

Figure 1. Schematic explaining the method of recording two-dimensional images with a continuous time-base sweep:
(*1*) microtarget; (*2*) linear pinhole array; (*3*) photocathode slit; (*4*) time-resolved image sections; (*5*) scheme of reconstructing instantaneous two-dimensional images.

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decomposed into a series of one-dimensional images shifted relative to each other. Ideally, the displacement δ should be equal to the spatial XICT resolution δ_s, with which the pinhole diameter d_{ph} should also be matched:

$$d_{ph} \geqslant \frac{\delta_s}{1+M}. \quad (2)$$

To obtain an image of the entire target with diameter D_t, the required number of sections and, accordingly, the minimum number of pinholes should be

$$N_{ph} = \frac{D_t M}{\delta}. \quad (3)$$

In this case, the length of the photocathode slit L should be long enough to accommodate N_{ph} images, i.e.,

$$L > s(1+M)\cos\theta N_{ph}. \quad (4)$$

Relations (1), (3), and (4) enable the magnitudes of s, M, and θ to be determined as functions of L, D_t, and δ_s. In practice, however, the length of the photocathode slit may prove to be inadequate to provide the required number of image cross sections. That is why a compromise is to be made in adopting a spatial resolution and width of the field of view across the photocathode slit. Clearly, the total number of spatial elements in the target whose images can be resolved in time does not exceed the total number of elements over the length of the photocathode slit. In this connection, two variants of recording in the lateral direction are possible with retention of the limiting spatial resolution along the slit.

In one of them, the limiting spatial resolution may be provided at the expense of the field of view. In the other variant, a field of view of the required width may be recorded though with a poorer spatial resolution, because, in this case, the intensity distribution in the lateral direction is to be interpolated from an incomplete set of image sections. The image of a region of size D

$$D = \Delta r (L/\delta_s)^{1/2} \quad (5)$$

can be recorded with the ultimate spatial resolution Δr, which is the same in both directions.

A two-dimensional image (frame) may be reconstructed for any point in time. The number of these frames is $\tau/\Delta\tau$ (τ is the duration of the process recorded and $\Delta\tau$ is the temporal resolution of the streak camera) and may be as high as ~ 300. In this case, it is possible to gain either the space-integrated information or the information integrated over an arbitrary time interval, which can be compared with that obtained by other methods.

The time-scanned set of sections of a two-dimensional image is read out by a scanning microdensitometer and processed by a computer taking into account the specific parameters of the recording system. The scheme of reconstructing an instantaneous two-dimensional image is shown in Fig. 1. Note that errors in the determination of s, θ, and M eventually result merely in the rotation of the reconstructed image.

The scheme of the setup for continuously time-resolved two-dimensional microtarget imaging is given in Fig. 2. A significant feature of this technique is bringing a series of microtarget images into coincidence with the XICT photocathode slit (see Fig. 1). For this purpose, the aperture stop with a pinhole array was placed in the opening at the centre of a lens (*4*). In this case, the central pinhole in the aperture stop was brought into coincidence with the lens optical centre with an accuracy of $\sim$ 10 µm. The lens (*4*) formed the image of the photocathode slit in the plane of a microtarget, so that the microtarget and the slit image could be simultaneously viewed with a microscope through an objective (*2*). The focal length of the lens (*4*) was selected so as to provide the required magnification M for the pinholes of the aperture stop located at the lens centre. The lateral shift of the lens (*4*) resulted in the shift of the slit image relative to the microtarget. Therefore, the centre of the image of the photocathode slit could be brought into coincidence with the centre of the microtarget by shifting the lens (*4*). The central pinhole in the aperture stop was therewith known to find itself in the line connecting the centres of the target and the photocathode slit. Accordingly, the centre of the target image formed by this pinhole found itself at the centre of the slit.

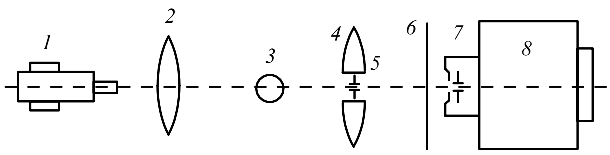

Figure 2. Schematic of the experiment setup for recording two-dimensional images with a continuous time-base sweep:
(*1*) microscope; (*2*) objective; (*3*) microtarget; (*4*) lens; (*5*) pinhole array; (*6*) light rejection filter; (*7*) photocathode slit; (*8*) 'Agat-SF5' XICT.

To align the pinhole array at a given angle θ relative to the photocathode slit, cross-hairs with a graticule were built into the eyepiece of the microscope. Initially, the microscope was set to view the photocathode slit, and in doing this, one of the lines of the cross-hairs was aligned with the axis of the slit. The microscope was then translated along the optical bench to view the image of the aperture stop with a pinhole array formed by the objective (*2*). This allowed us to set the linear pinhole array to the desired angle relative to the photocathode slit by rotating the lens (*4*) together with the aperture stop. In experiments, angle θ was set first, and later the lens (*4*) was shifted employing adjusting mechanisms to bring the centres of the microtarget and the image of the photocathode slit into coincidence.

Using the alignment technique outlined above, we, for the first time at the 'Iskra-4' facility obtained on the 'Iskra-4ɪ laser facility the time-resolved images of several microtarget sections. An 'Agat-SF5' XICT was used as the streak camera. The XICT parameters and also those of the aperture stop and the recording set-up are given below.

Number of pinholes in the aperture stop N_p	9
Pinhole diameter D_{ph}/µm	25 ± 2
Pinhole separation s/µm	290
Pinhole displacements from the nominal position /µm	< 2
Magnification factor M	1.91
Width of the photocathode slit /µm	80
Time-sweep speed /ns cm^{-1}	1.65
Intrinsic temporal resolution of the XICT /ps	27
Resultant temporal resolution /ps	30
Spatial resolution of the XICT δ_s/µm	80
Spatial resolution in the plane of the target along the slit /µm	38
Spatial resolution in the plane of the target across the slit/µm	70

To protect the photocathode of the streak camera from the target plasma radiation in the visible range, a light rejection filter (6) was placed between the lens (4) and the photocathode slit (7) immediately prior to experiment. The filter was a 3.5-μm-thick lavsan ($c_8H_{10}O_4$) film coated on both sides with ~ 0.1-μm-thick aluminium layers. Since the entrance window of the sealed-off time-resolving tube of the XICT was made of 5-μm-thick mica, the images were recorded with quanta having energies $h\nu > 2.9$ keV.

The recorded set of time-resolved sections of the two-dimensional image was read out by a scanning microdensitometer and processed by a computer using a specially written code, taking the specific parameters of the recording system into account. A target 410 μm in diameter was used in our experiment. Given this target diameter and a relatively short photocathode slit, it was possible to resolve in time only six sections of the two-dimensional image. In this case, the angle θ was set to 9° in order for the six sections to cover the entire target image in the direction orthogonal to the photocathode slit. The time-resolved section images are presented in Fig. 3. One can see that all the six sections were recorded. They are located symmetrically relative to the target centre, which demonstrates that the photocathode slit was brought into coincidence with the image of the target centre with a high accuracy. We believe that it is precisely the inadequate accuracy of the alignment procedure employed by the authors of [9] that did not allow them to reconstruct the entire target image.

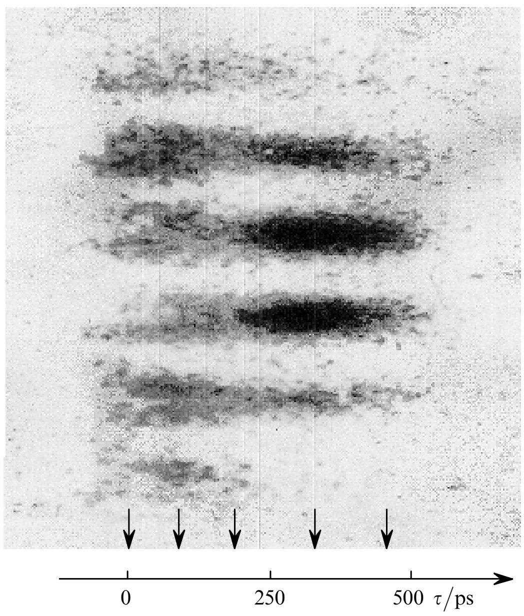

Figure 3. Time-resolved images of the one-dimensional sections.

Fig.4 shows the two-dimensional frame images reconstructed for five points in time (0, 85, 180, 320, and 455 ps), which encompass different stages of the target performance. The selected instants of time are indicated by arrows in Fig. 3. For clarity, the dashed line in Fig. 4 gives the initial target diameter and its centre is brought into coincidence with the centre of the compressed core. Referring to Fig. 3, the resultant images exhibit an appreciable noise background owing to a small number of the quanta detected. The images were therefore integrated with respect to time over 50-ps intervals to obtain a smooth picture in each of the frames.

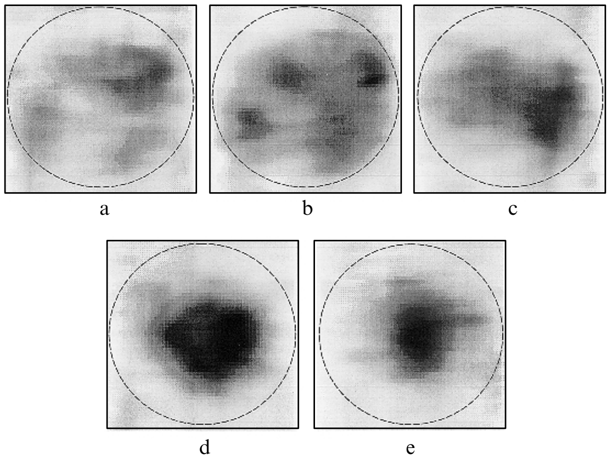

Figure 4. Two-dimensional frame images of the microtarget reconstructed for $\Delta\tau = 0$ (a), 85 (b), 180 (c), 320 (d), 455 ps (e). The dashed line shows the initial microtarget size (410 μm in diameter).

To obtain the entire target images from the sections recorded, the intensity distribution in the direction orthogonal to the photocathode slit was determined by the interpolation Lagrange formula [11]. One can see from Fig. 4 that the laser spots on the target surface are located somewhat asymmetrically in this experiment. Moreover, the laser radiation in two channels (the lower spots in Figs 4a – c) supposedly lags behind the remaining ones as regards the time of arrival at the target. It is also clear from Figs 4d and e that the radiation of the shell which compresses the DT gas is largely nonuniform, and a significant structural variation of the compressed core occurs in a time interval of 165 ps.

The technique described in this work was employed in experiments at the 'Iskra-4' laser facility the results of which were reported in Ref. [12].

3. Conclusions

Therefore, a high-precision procedure was proposed for bringing the target images on the slit of an XICT. This procedure allowed us to implement the technique of recording continuously time-resolved two-dimensional images of a microtarget in an experiment at the 'Iskra-4' laser facility. Full two-dimensional target images were obtained with a frame duration of 50 ps, which was due to an insufficient sensitivity of the 'Agat-SF5' XICT in use. Potentially, the frame duration may be 30 ps.

The images of a microtarget 410 μm in diameter were obtained with a spatial resolution of ~ 40 μm along the photocathode slit and ~ 70 μm in the orthogonal direction. For targets of smaller size, it is possible in principle to obtain an appreciably higher spatial resolution, which is actually limited only by the XICT sensitivity.

The two-dimensional frame images display the dynamics of microtarget irradiation and the structural variation of its compressed region.

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