

X-pinch soft x-ray source dynamics at a subnanosecond time resolution

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Abstract. The paper reports on an experimental study of the X-pinch soft x-ray source dynamics at a subnanosecond time resolution with the use of an x-ray imaging technique based on an AXIS-NX streak camera. The study was performed on a compact generator with a current amplitude of 300 kA to a short-circuit load and current rise time of 180 ns. It is shown that in the spectral range 1–1.55 keV, the X-pinch soft x-ray source in whole represents a set of sources which can be radially offset by ~ 10 microns about the X-pinch axis. Each of the sources generates a pulse of duration 0.2–0.7 ns. The interval between the formation of the sources and hence between their radiation pulses is 0.5 ns and longer.

Driving a current pulse through wires crossed as the letter X results in a bright soft x-ray source at their cross point [1]. It is generally accepted that on electrical explosion of the wires, the matter near the cross point is imploded and a neck of characteristic axial size 300–500 μm is formed at the X-pinch center (see, e.g., [2]). Next, due to neck cascading, a micro-neck develops and its pinching results in a soft x-ray source. If the time-integral size of the source is no greater than several microns and the radiation pulse is no longer than several nanoseconds, the source is termed a hot spot. A soft x-ray source arises almost in all cases, whereas the formation of a hot spot requires certain conditions: at least a rather high rate of rise of the current (~ 1 kA/ns) and fine matching of the X-pinch mass and current pulse shape.

Despite the rather long history of X-pinch research, there is no accurate procedure for measuring the source size below 10 μm . Most commonly this is done by comparing shadow images of a test object (a thin wire or a narrow slit) and shadow shape calculated with regard to diffraction effects [3, 4]. From similar comparative analysis, one can find, by trial and error, a source size, which most fully fits experimental image intensity distributions in the plane of a photographic film or another position-sensitive detector.

The main task of our experiments was to record shadow images of a test object at a high time resolution, which would allow us to trace the soft x-ray source dynamics in time. In particular, it was supposed that at a certain point in time, the radial source size is much smaller than 1 μm due to constriction and probably to radiative collapse. In the experiments, an AXIS-NX x-ray streak camera with a time resolution limit of 20ps was used. An essential shortcoming of the available equipment was a CsI cathode the maximum sensitivity of which was in the quantum energy range 1–1.5 keV and 4.5–10 keV, whereas the least sizes of X-pinch soft x-ray source are recorded in the range 3–4keV [3]. The tasks also pursued in the experiments included adjustment



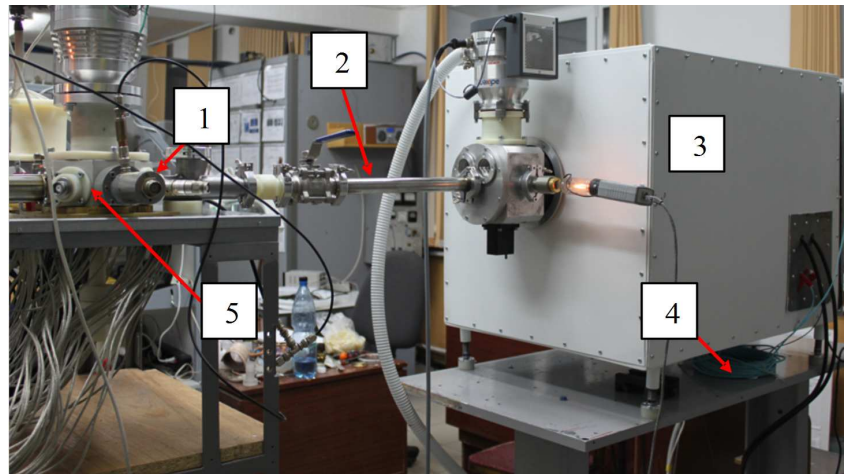


Figure 1. Photo of the experimental setup: 1—vacuum x-ray diode; 2—diagnostic vacuum line of the streak camera; 3—Faraday cage with the streak camera on the inside; 4—optical cable of remote control; 5—vacuum chamber of the pulse generator powering the X-pinch.

of the AXIS-NX streak camera and development of a noise-immune circuit for synchronizing the camera and compact pulse current generator powering the X-pinch.

The experiments were performed on a self-made compact generator [5–8] with a current amplitude of 300kA to a short-circuit load and current rise time of 180 ns. The X-pinchs used in the study comprised two or four molybdenum wires each of diameter $25\ \mu\text{m}$. The parameters of the current pulse were measured with a Rogowski coil located at the inlet of the vacuum chamber and with a magnetic probe located directly in the current return conductor. The radiation pulse was recorded with two vacuum x-ray diodes (XRD) filtered by a mylar film and aluminum foil $3\ \mu\text{m}$ and $8\ \mu\text{m}$ thick, respectively. The maximum spectral sensitivity of the diodes fell in the range 1–1.55 keV. The AXIS-NX streak camera was used to obtain shadow images of a test object with a time sweep of 500 and 100 ns to full screen. The test object was an array of several vertical tungsten wires of diameter $30\ \mu\text{m}$.

The streak camera was placed in a specially designed Faraday cage (figure 1) and controlled by a remote computer. The control computer and oscilloscopes were in a shielded cabinet. The control unit of the streak camera and computer were connected via an optical cable. The streak camera was triggered by a separate signal timed with a trigger signal of the X-pinch generator. To exclude electromagnetic noise from the camera trigger signal, the signal was transmitted into the Faraday cage through an optical cable. For optical-to-electrical conversion of the trigger signal, there was an optoelectronic converter at the inlet of the Faraday cage. All equipment inside the cage was powered by an uninterruptible power supply, which was off during the experiment.

Schematic of the time-resolved x-ray imaging is shown in figure 2. The vertical axis of the X-pinch is on the axis z . The wires of the test object are also located along the axis z . A shadow image of the test object is formed at the slit of the streak camera with a semitransparent cathode. The image of the cathode is swept in the vertical direction by the electron optics of the streak camera. A feature of streak cameras with semitransparent cathodes is the presence of a direct static image of an x-ray emitting object on the screen. The static (unswept) image is formed by x-rays passing through the photocathode and arriving at the scintillation screen, but this image can be eliminated by adjusting the streak camera at a small angle to the x-ray direction.

Figure 2b shows a static image (at the left) and swept image (at the right) on the streak

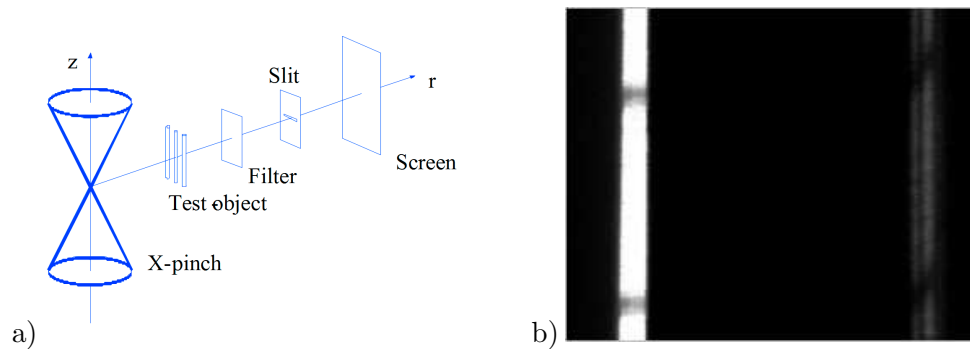


Figure 2. Schematic of the time-resolved x-ray imaging (a) and streak images for two molybdenum X-pinch wires of diameter $25\ \mu\text{m}$ (b).

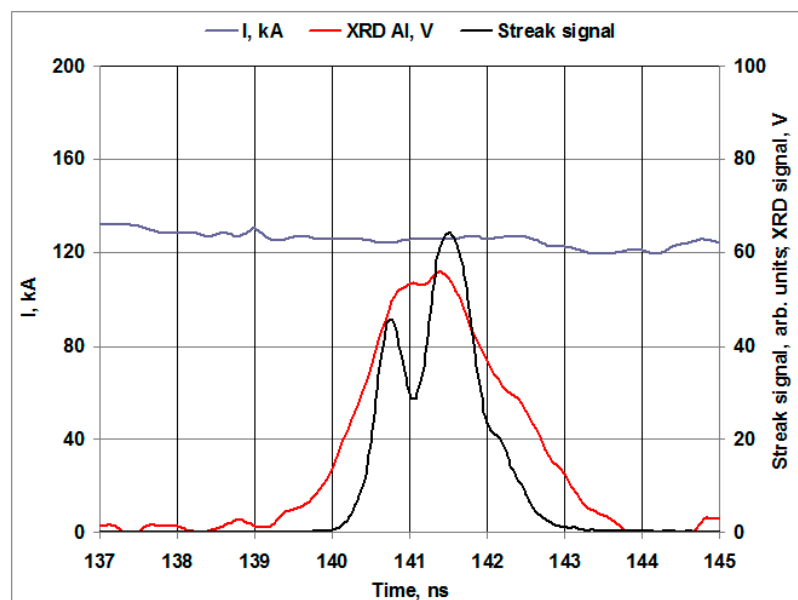


Figure 3. Streak signal (black), XRD signal (red), and current through the X-pinch (blue). The time ranges from the beginning of the current pulse.

camera screen for two molybdenum X-pinch wires of diameter $25\ \mu\text{m}$. The swept image reveals two x-ray bursts spaced in time by $0.7\ \text{ns}$. It is also seen that the image is shifted along the streak camera slit. The radiation pulses recorded by the streak camera and vacuum x-ray diode are shown in figure 3.

The shift of the swept X-pinch images can be explained by at least two processes: the motion of the X-pinch soft x-ray source and the formation of two radiation sources radially offset relative to each other [9–12]. Measurements of the shift of the test object with regard to its magnification allow the conclusion that the source shift is $12\ \mu\text{m}$. Measurements of the source size from static and dynamic images were difficult because of their too smeared edges and absence of diffraction effects, which are observed in the range $3\text{--}4\ \text{keV}$. However, the clear-cut shift of the shadow images allows us to state that the source size is at least no more than $10\text{--}12\ \mu\text{m}$. The presence of two distinct radiation pulses on the swept image favors the assumption on the formation of two radiation sources spaced apart along the radial axis. Each of the sources produces a pulse

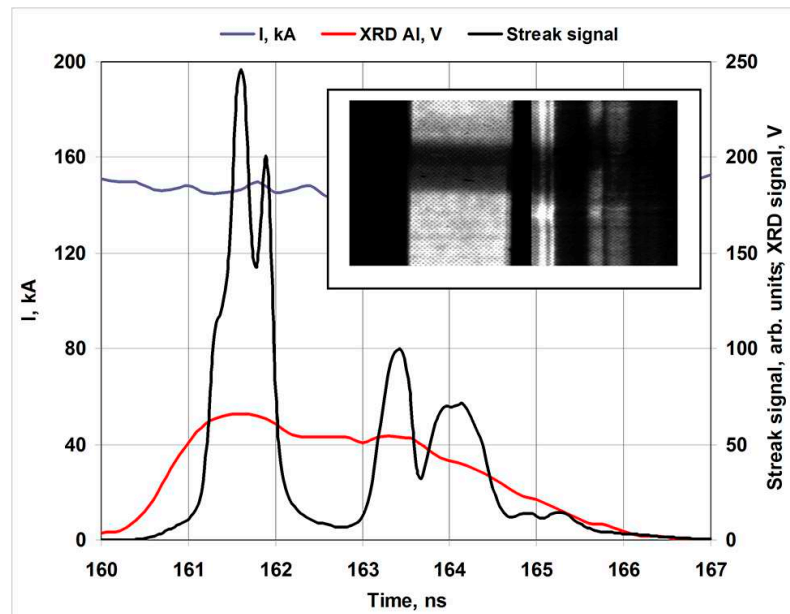


Figure 4. Streak signal (black), XRD signal (red), current through the X-pinch (blue), and shadow images (inset, static image at the left). The time ranges from the beginning of the current pulse.

of duration 0.5–0.7 ns. The radiation pulses recorded by the vacuum x-ray diode and streak camera show a rather good correlation, suggesting that the images were taken in the spectral range 1–1.55 keV.

The technique used to record shadow images does not allow us to judge the position of the sources along the axis z . It is seen from figure 2 that a vertical shift of the source will not affect the shift of its swept image.

Under certain conditions, the X-pinch radiation represents multiple bursts, the intervals between those can range to several and tens of nanoseconds. An example of radiation pulses and swept images for this case is given in figure 4.

It is seen in figure 4 that in this case, three radiation pulses of halfwidth ~ 1 ns are formed. A source shift is observed only for the second pulse and is about $15\mu\text{m}$. It should be noted that the first pulse has an internal structure: it consists of three pulses each of duration ~ 0.2 ns.

Thus, it has been shown that in the spectral range 1–1.55 keV, the X-pinch soft x-ray source represents a set of radiation sources which can be radially offset by $\sim 10\mu\text{m}$ about the X-pinch axis. Each of the sources generates a pulse of duration 0.2–0.7 ns. The interval between the formation of the sources and hence between their radiation pulses is 0.5 ns and longer. For improving the spatial and temporal resolution of the point-projection imaging technique based on X-pinchs, it is necessary to carefully search for modes with the least number of sources.

Acknowledgments

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