USING OF X-PINCH AS A SOURCE IN X-RAY RADIOGRAPHY STUDYING OF INITIAL STAGE OF WIRE EXPLOSION

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A wire explosion in a gaseous and condensed media extends possibilities of study of phase transitions of the wire material. We studied the influence of the external media (air, water and oil) on the explosion of Cu, Ni and W wires of diameter 10…50 μm. Wires were exploded by the current pulse with the rise time from 200 to 300 ns and the amplitude up to 10 kA. The pulse was produced by a generator based on a low-inductance capacitor, the discharge voltage being 20 kV. Experimental results are discussed on obtaining the wire explosion images in gaseous and liquid media with the help of hard X-ray radiation of an X-pinch in the BIN facility. Exploded wires were placed outside the BIN vacuum chamber and images were registered on the film without magnification. Spatial resolution was limited by film grain structure, and reached 20…30 μm. Spectral range of the imaging radiation (15…30 keV) was determined by vacuum chamber window material, film sensitivity and thickness of the media where wire was exploded. Temporal resolution was about 10…20 ns and depended on X-pinch wire material and thickness.

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Fast explosion (dI/dt ~ 50 A/ns) of thin conductors was carried out in a setup based on a capacitor with a storage capacitance of: C = 0.1 μF, L_c = 10 nH, U_{max} = 35 kV. The working voltage was 20 kV. Total inductivity of the discharge circle is L = 340 nH; the length of discharge gap is 12 mm. For the radiography of the exploding wire in media, we used hard radiation from an electron beam generated in an X-pinch minidiode of BIN generator with peak current of 270 kA and of 150 ns FWHM.

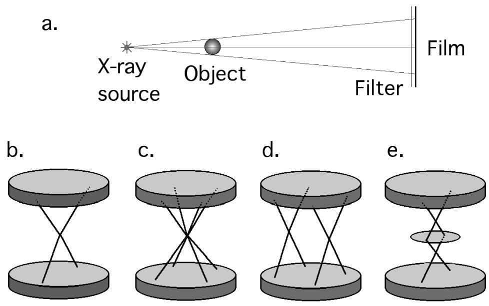

Fig.1. (a) Schematic diagram of point-projection imaging. (b) X pinch configurations used in the experiments when the two (b) or multiwire (c) X pinches were placed between the output electrodes of the high current diode alone (b, c) or with two in parallel (d) or in series (e)

An X-pinch plasma is generated using two (or more) fine wires arranged so that they cross and touch at a single point, forming an "X" shape, as the load of a high current pulsed power generator (pulser). In the crossing area, a micropinch develops that emits in a wavelength range of 1…10 keV, which depends on the material and diameter of the wire, as well as on the parameters of the current pulse [1]. In specific cases, the X pinch provides a very small size (~1 μm), short duration (<100 ps), bright X-ray burst of thermal radiation (~1 keV). The high brightness of the radiation from a tiny volume and a predictable location offer the possibility of using the X-pinch micropinches as sources of X-ray radiation for different applications, — above all as an X-ray backlighter for point-projection radiography (Fig.1).

Such scheme does not need any optical elements; its space and temporal resolution depend on a size and duration of radiation flash. In this connection an optimization of the hot spot parameters plays an important part, i.e. the increasing of the energy input at minimal size of the source, as well as developing of schemata of multi-frame radiography [2–4]. At present, X-pinch is successfully applied for the radiography of multiwire loads in the experiments on the high-current facilities such as MAGPIE [5] and Angara [6].

Immediately after the X-ray burst, the plasma neck in the X-pinch breaks [2], which is accompanied by the generation of high-energy (10…100 keV) electrons. The size of this electron source is 0.1…1 mm [7]. The long components of the harder x-ray radiation began 5…20 ns after the short component and had a 20…40 ns pulse durations. Bremsstrahlung and characteristic radiation caused by the electron beam can also be used for the radiography of dense plasma objects, − particularly for contact radiography of the objects with sizes more than 50 μm and opaque for the softer radiation [8]. Since this radiation is rather rough, it can be used outside the vacuum chamber and take images in condensed media.

In our experiments, a relatively large object was placed at a distance of 30…150 cm from the radiation source and its image was recorded on an X-ray film without magnification (the so-called contact image). We used a lucite filter with a thickness of 10…12 mm and

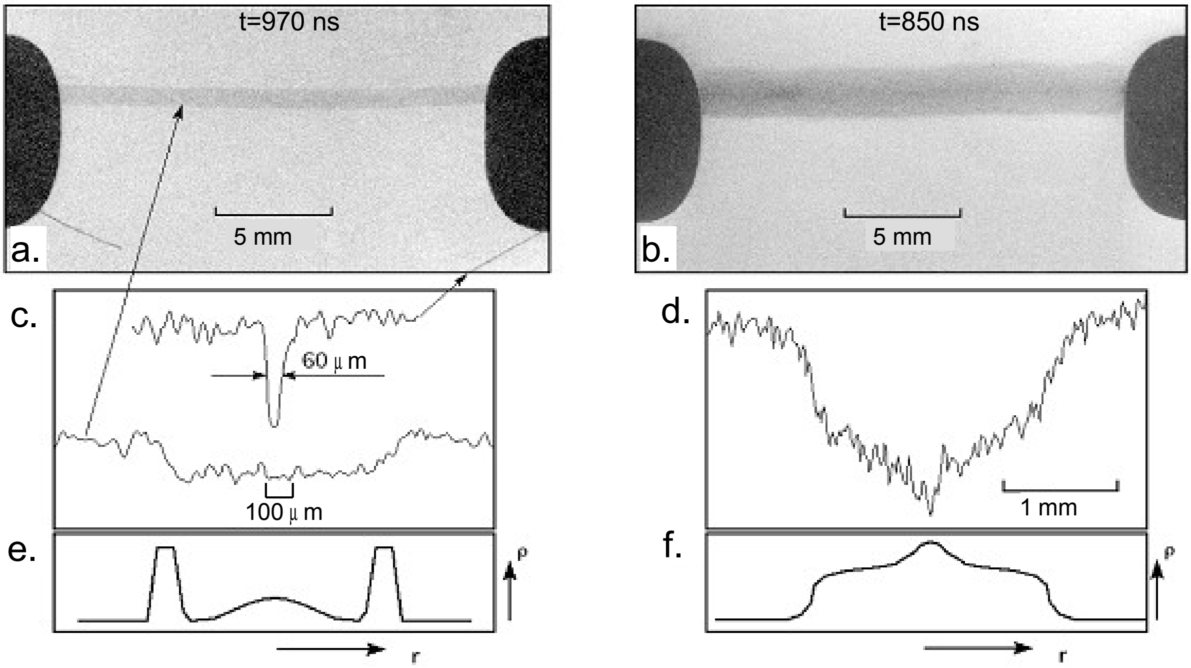

Fig.3. Radiographs of a 50-μm tungsten wire exploding in (a) water (at t = 960 ns) and (b) air (at t = 850 ns). The radiographs were obtained using an X-pinch radiation source with a photon energy of higher than 12 keV. (c, e) Densitograms of the exploding wires and (d, f) reconstructed density profiles (in arbitrary units). In plot (c), a densitogram of a segment of the wire before its explosion is also shown to illustrate spatial resolution

cutoff energy of 10 keV. At a large distance from the radiation source, the spatial resolution of the method was limited only by the resolution of the photofilm. A schematic of the radiography diagnostics beyond the vacuum chamber of the BIN generator is shown in Fig.2.

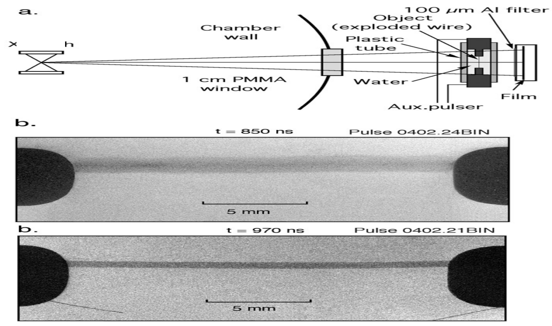

Fig. 2. Schematic diagram of X-ray radiography of the wire exploding outside the vacuum chamber using an auxiliary generator

Figs.3,a and 3,b illustrate the explosion of a 50-μm tungsten wire in water and air, respectively. The water chamber in which the wire was exploded was placed at a distance of 120 cm from the X-pinch. Since X-pinch radiation passed through a 10-mm lucite window of the vacuum chamber, 1-m air gap, 1-mm plastic wall of the water chamber, and 10 mm of water with the total cutoff energy about 12 keV, we used four-wire tungsten or molybdenum X-pinches emitting at the photon energy range of higher than 12 keV. X-ray images of both unexploded and exploded wires are shown in Figs.3,c and 3,e as an illustration of the spatial resolution and sensitivity of the diagnostics. In Fig.3,e, one can see a wire core (expanded up to 2.3 mm) with a well resolved structure. The density distributions inferred from the densitograms of the cores shown in Figs.3,a and 3,b are presented in Figs.3,d and 3,f, respectively. It can be seen from these density distributions that the core of a wire exploding in water is tubular in structure. The mean expansion velocity of the tungsten wire core is about 0.9×10^5 cm/s in water and 2.8×10^5 cm/s in air. The lower expansion velocity of the core in water (as compared to that in air) can be related to the higher specific density of water: the higher the density, the higher is the resistance to expansion. It is also seen from the X-ray images that, in air, the outer boundary of the core begins to lose its cylindrical symmetry, whereas in water, it is still cylindrically symmetric. From rough estimates of the density of the tungsten wire core shown in Fig.3,e (assuming the distribution of the matter to be uniform), it follows that the sensitivity of the method is better than 2.3×10^{-4} g/cm^2 (or 10^{18} cm^{-2}).

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ИСПОЛЬЗОВАНИЕ Х-ПИНЧА В РЕНТГЕНОВСКИХ РАДИОГРАФИЧЕСКИХ ИССЛЕДОВАНИЯХ ВЗРЫВА ПРОВОЛОЧЕК

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Исследование взрыва проволочек в газообразной и конденсированной среде позволяет получать информацию о фазовых переходах в материале проволочки. Мы исследовали влияние внешней среды (воздух, вода, масло) на взрыв проволочек диаметром 30…50 мкм из Cu, Ni и W. Взрыв проволочек осуществлялся импульсом тока с фронтом 200…300 нс и амплитудой до 10 кА, формируемым в накопителе на основе низкоиндуктивного конденсатора, заряжаемого до напряжения 20 кВ. Изображения проволочек в газообразной и жидкой средах регистрировались на пленке без увеличения по жесткому рентгеновскому излучению, генерируемому в Х-пинче установки БИН. Пространственное разрешение изображений ограничивалось структурой пленки и составляло 20…30 мкм. Спектральный состав излучения (15…30 кэВ) зависел от параметров выводного окна, чувствительности пленки и толщины среды, внутри которой находилась проволочка. Временное разрешение составляло 10…20 нс и зависело от материала и толщины излучающей нагрузки Х-пинча.

Работа выполнена при частичной поддержке РФФИ по грантам 05-02-17533, 04-02-17292, МНТЦ по проекту 2151 и субконтракту с Корнельским университетом США по проекту DE-PC03-2NA 0057.

ВИКОРИСТАННЯ Х-ПіНЧУ В РЕНТГЕНІВСЬКИХ РАДІОГРАФІЧНИХ ДОСЛІДЖЕННЯХ ВИБУХУ ДРОТИКІВ

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Дослідження вибуху дротиків у газоподібному й конденсованому середовищі дозволяє одержувати інформацію про фазові переходи в матеріалі дротика. Ми досліджували вплив зовнішнього середовища (повітря, вода, масло) на вибух дротиків діаметром 30...50 мкм із Cu, Ni і W. Вибух дротиків здійснювався імпульсом струму із фронтом 200...300 нс і амплітудою до 10 кА, сформованим у накопичувачі на основі низькоіндуктивного конденсатора, що заряджається до напруги 20 кВ. Зображення дротиків у газоподібному і рідкому середовищах реєструвалися на плівці без збільшення по твердому рентгенівському випромінюванню, генеруємому в Х-пінче установки БІН. Просторове розділення зображень обмежувалось структурою плівки і становило 20...30 мкм. Спектральний склад випромінювання (15...30 кеВ) залежав від параметрів вивідного вікна, чутливості плівки і товщини середовища, усередині якого перебував дротик. Часове розділення становило 10...20 нс і залежало від матеріалу і товщини випромінюючого навантаження Х-пінча.

Робота виконана при частковій підтримці РФФІ по грантах 05-02-17533, 04-02-17292, МНТЦ по проекту 2151 і субконтракту з Корнельським університетом США по проекту DE-PC03-2NA 0057.