STUDY OF HYBRID X PINCHES IN DIFFERENT CONDITIONS

A.R. Mingaleev[1], T.A. Shelkovenko[1], S.A. Pikuz[1], I.N. Tilikin[1], S.N. Mishin[1], V.M. Romanova[1], A.E. Ter-Oganesyan[1], C.L. Hoyt[2], A.D. Cahill[2] and D.A. Hammer[2]

[1]P.N. Lebedev Physical Institute, Moscow, Russia;
[2]Cornell University, Ithaca, NY, 14853 USA

A standard X-pinch consists of two or more fine wires that cross at a single point as the load of a pulsed power generator. To simplify the X-pinch load, a hybrid configuration consisting of solid conical electrodes connected by a wire, has been suggested and tested on four generators ranging in current from 200 kA to 1 MA and risetimes varying from 45 to 170 ns. The experiments have shown that for each generator, a wire material, diameter and length can be found for which the X-pinches generate a single intense burst of soft x-rays and develop a single hot spot. Also they generated less hard x-ray intensity than that measured in comparable standard X-pinches.

PACS: 52.38Ph, 52.58Lq, 52.59Px, 52.70La

INTRODUCTION

Previous research on standard X-pinches has shown that the most important processes leading to x-ray emission occur in a region <1 mm in length in the vicinity of the wire cross point [1]. In the early stages of X-pinch development, a minidiode is formed in this region from the dense wire core material, but then the dynamics that follow are unpredictable, especially for multiwire X-pinches. To simplify X-pinch loading and make X-pinches more predictable, it is attractive to make an artificial mini-diode from solid material connected by a single wire with appropriate linear mass. As such, a hybrid X-pinch configuration was proposed that both simplifies wire loading and avoids formation of the complicated, uncontrolled spatial structure of a multi-wire X pinch in the region where the X-pinch wires cross. Such a structure breaks the symmetry, destabilizes the process of plasma column formation at the wire cross point, and degrades x-ray generation [2]. The hybrid X-pinch configuration consists of solid conical electrodes connected by a wire (Fig. 1). It was first tested as the main load on XP, a 45 ns risetime, 500 kA peak current pulsed power generator at Cornell University. At these conditions most of the hybrid X-pinches tested generated a single intense burst of soft x-rays and developed a single hot spot that was of micron-scale size [3]. It was shown also that the hybrid X-pinches generated less hard x-ray intensity than standard X-pinches [3, 4]. Absence of x-rays with photon energies > 20 keV associated with long-lived electron beams in explained by fast closure of the diode by expanding dense plasma from the electrodes. At the same time short-lived electron beam produces bright small-size x-ray source in 8…15 keV spectral band usable for point-projection radiography [4].

The hybrid X-pinch have been successfully used as a source of pure continuum radiation with flat spectrum for imaging absorption x-ray spectroscopy of relatively cold plasma of exploded Al wires and wire arrays [5]. This configuration has the potential to be reloaded easily under vacuum for use as an X-ray source for point-projection backlighting of different plasma and biological objects.

EXPERIMENTAL RESULTS

To test the hybrid X-pinch configuration further, experiments have been carried out on generators with longer risetimes and current up to 1 MA at Cornell on COBRA (100 ns, 1 MA), and on BIN (100 ns, 0.27 MA) and MINI (170 ns, 0.25 MA) at P.N. Lebedev Institute. On each generator the same 60° conical electrodes with flat ends made of tungsten with 5 % copper, with a wire connecting them, were used, as shown in Fig. 1. The wire material, diameter and length must be varied to make the best use of the different generator rise times and currents. The wires were loaded through 1 mm holes in the cones. Al, Ti, Ni, NiCr, Cu, Mo, Pd, Ag, W and Au wires having lengths ranging from 0.6 to 2.5 mm were tested in the experiments. The wire diameters were varied from 12 to 200 μm for different experimental conditions. To study the hybrid X-pinch quality we used all standard diagnostics on the generators.

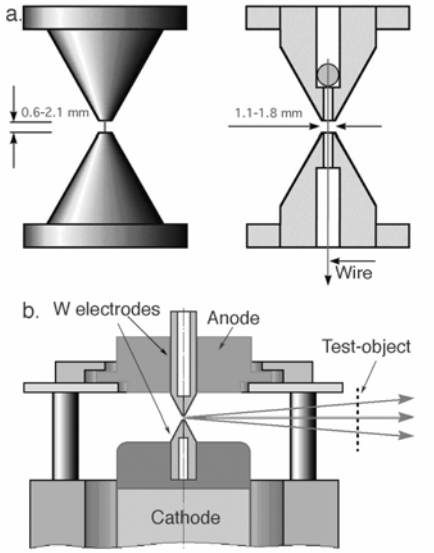

Fig. 1. The hybrid X-pinch experimental arrangement shows that the X-pinch wires have been replaced with solid conical electrodes connected by a wire. Both external and cross-sectional views are shown (a); experimental setup with hybrid X pinch as the main load (b)

Here we present results obtained only with a single X-pinch as the main load of the generator (see Fig. 1,b). Results from other configurations will be described elsewhere. The simplification that the hybrid configuration provides is clear even in the case of small generators. Compare, for example, columns 2 and 3 in Table where for the standard X-pinch, 2…7 wires with lengths, l = 8…20 mm, are needed, while only one wire with length, Δl = 1.7…2.2 mm, is needed for the hybrid X-pinch. For generators with MA current level this is especially important since, instead of 12…64 wires, only one wire is used.

The structure of the X-pinch radiating area has been studied and hot spot size and energy yield have been measured in every shot using radiographs of test objects and calibrated PCDs [1–5]. In the experiments on the COBRA generator, laser shadow (laser pulse – 180 ps) and XUV pinhole (frame – 5 ns) imaging have also been used. Measurement of the x-ray yield on the four different generators shows that the energy yield and x-ray hardness are comparable for standard and hybrid X-pinches except for the longest rise time generator, MINI.

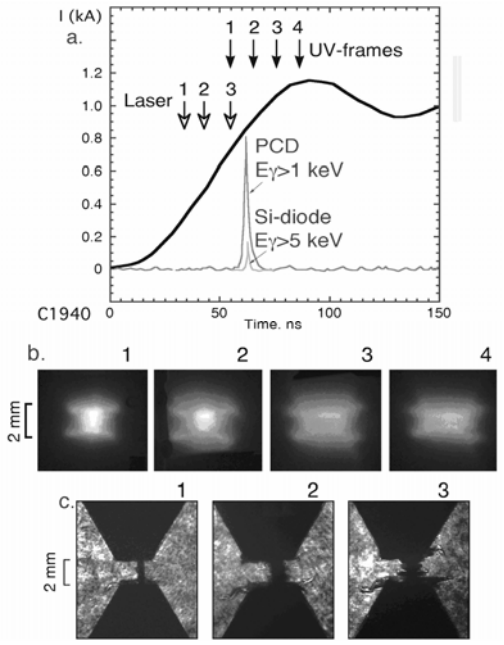

Fig. 2. Signals of PCD and Si-diode together with the current pulse for a hybrid X pinch on COBRA with a 102 μm diameter and 2 mm long Mo wire (a); pinhole images of the X pinch recorded by framing camera with 5 ns frame (b); laser shadow images (c)

In Fig. 2, results obtained on the COBRA generator from a hybrid X-pinch with a 2 mm long, 102 μm diameter Mo wire are presented. In Fig. 2,a, PCD and Si-diode signals show a single x-ray burst. Since these signals were recorded at the same time, and the signal from Si-diode has very small intensity we conclude that the hybrid X-pinches radiated much less hard x-ray compare with standard X-pinches.

The signal recorded by Si-diode could be the high energy tail of the hot spot thermal radiation. From Fig. 2,a, one can see that the soft x-ray burst was radiated between the first and second frames of XUV framing camera (see Fig. 2,b) and 4 ns later than the last laser frame (see Fig. 2,c). From these images, we can say that the X-pinch minidiode lasts about 30 ns after the soft x-ray radiation burst, but with a decreasing gap. Measurements of the hard x-ray radiation in hybrid X-pinches on all generators used show very low intensity of radiation from energetic electrons in comparison of standard X-pinches.

Source size (wire numbers) on pulsers with different output parameters

X-pinches / Pulsers	**Standard**	**Hybrid**
COBRA 1 MA,100 ns	1.4 μm (12…64)	0.9 μm (1)
XP 0.4 MA, 45 ns	0.9 μm (2…7)	0.7 μm (1)
BIN 0.27 MA, 100 ns	1.1 μm (2…4)	1.2 μm (1)

Hollow and filled tubes from Al, Ni and polyethylene were tested as a load on COBRA pulser, that expands possibilities of hybrid X pinch applications, for example in studying of the matter under extreme conditions.

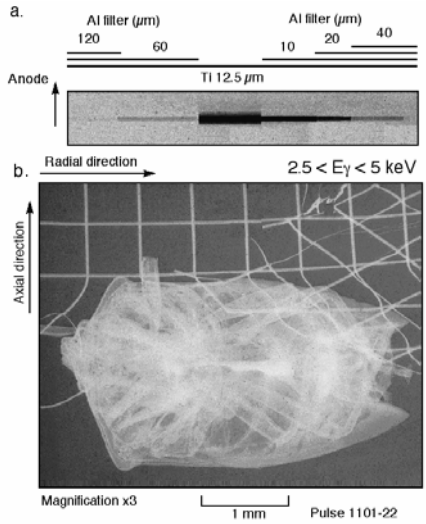

Fig. 3. Image of the slit of the SSW-camera (a); radiograph of a biological object obtained in radiation of a hybrid X pinch with a 25 μm diameter Mo wire on the BIN generator (b)

The image of a slit of the SSW-camera shown in Fig. 3,a, obtained in radiation of a hybrid X pinch made with a 25 μm diameter Mo wire on the BIN generator showed that the X-pinch has a single hot spot with x-ray energies up to 5 keV. Radiographs of different test-objects show that the hot spot size is comparable with that of the standard X pinch for experiments on all generators (see Table). An example radiograph of a biological test object and a mesh (the mesh and the biological object were at the same distance from the source and the film) is shown in Fig. 3,b. The figure demonstrates that radiograph was obtained with high spatial resolution and that the x-ray radiation was sufficiently hard to show the inner structure of the few mm size biological object.

CONCLUSIONS

We can conclude that hybrid X-pinches reliably generate an intense single burst of soft x-rays and develop a single hot spot that is about 1…5 μm diameter. The hybrid X-pinches had energy yield comparable with that of standard X-pinches for ≤ 110 ns rise time generators and generated less hard x-ray energy on all four generators. The new configuration enables us to simplify the X-pinch configuration and can be used to design a system for reloading X pinches under vacuum for application as a source of x-ray radiation for point-projection backlighting and x-ray absorption spectroscopy of different plasma objects.

ACKNOWLEDGEMENTS

This work was supported by the SSAA program of the NNSA under DOE Cooperative Agreement DE-FC03-02NA00057 and the Russian Foundation for Basic Research (project nos. 11-02-01210-a).

REFERENCES

1. T.A. Shelkovenko, D.B. Sinars, S.A. Pikuz, D.A. Hammer. Radiographic and spectroscopic studies of X-pinch plasma implosion dynamics and x-ray burst emission characteristics // *Phys. of Plasmas*. 2001, v. 8, p. 1305.
2. T.A. Shelkovenko, S.A. Pikuz, R.D. McBride, et al. Symmetric Multilayer Megampere X-pinch// *Plasma Physics Reports*. 2010, v. 36, p. 50.
3. T.A. Shelkovenko, S.A. Pikuz, A.D. Cahill, et al. Hybrid X-pinch with conical electrodes // *Phys. of Plasmas*. 2010, v. 17, p. 112-707.
4. T.A. Shelkovenko, S.A. Pikuz, A.R. Mingaleev, et al. Accelerated Electrons and Hard X-Ray Emission from X-Pinches // *Plasma Physics Reports*. 2008, v. 34, p. 754.
5. P.F. Knapp, S.A. Pikuz, T.A. Shelkovenko, et al. High resolution absorption spectroscopy of exploding wire plasmas using an x-pinch x-ray source and spherically bent crystal // *Review of Scientific Instruments*. 2011, v. 82, p. 063501.

Article received 20.09.12

ИЗУЧЕНИЕ ГИБРИДНЫХ Х-ПИНЧЕЙ ПРИ РАЗЛИЧНЫХ УСЛОВИЯХ

А.Р. Мингалеев, Т.А. Шелковенко, С.А. Пикуз, И.Н. Тиликин, С.Н. Мишин, В.М. Романова, А.Е. Тер-Оганесьян, С.Л. Хойт, А.Д. Кахилл, Д.А. Хаммер

Стандартные Х-пинчи состоят из двух или более проволочек, перекрещенных в диоде сильноточного генератора. Чтобы упростить конфигурацию Х-пинчей, была предложена и протестирована на четырех сильноточных генераторах с токами от 200 кА до 1 МА и временем нарастания импульса от 45 до 170 нс нагрузка в виде гибридного Х-пинча. Гибридные Х-пинчи состоят из двух твердотельных тугоплавких электродов, соединенных проволочкой. Проведенные эксперименты показали, что для каждого генератора можно подобрать материал проволочки, диаметр и длину, при которых гибридные Х-пинчи образуют единичную горячую точку и излучают интенсивную вспышку мягкого рентгеновского излучения. При этом зарегистрированный уровень жесткого рентгеновского излучения был значительно ниже, чем в стандартных Х-пинчах.

ВИВЧЕННЯ ГІБРИДНИХ Х-ПІНЧІВ ПРИ РІЗНИХ УМОВАХ

А.Р. Мінгалєєв, Т.А. Шелковенко, С.А. Пікуз, І.М. Тілікін, С.Н. Мішин, В.М. Романова, А.Є. Тер-Оганесьян, С.Л. Хойт, А.Д. Кахілл, Д.А. Хаммер

Стандартні Х-пінчі складаються з двох або більше дротиків, перехрещених у діоді потужнострумового генератора. Щоб спростити конфігурацію Х-пінча, була запропонована і протестована на чотирьох потужнострумових генераторах із струмами від 200 кА до 1 МА та часом наростання імпульсу від 45 до 170 нс навантаження у вигляді гібридного Х-пінча. Гібридні Х-пінчі складаються з двох твердотільних тугоплавких електродів, з'єднаних дротиком. Проведені експерименти показали, що для кожного генератора можна підібрати матеріал дротика, діаметр і довжину, при яких гібридні Х-пінчі утворюють одиничну гарячу краплю та випромінюють інтенсивний спалах м'якого рентгенівського випромінювання. При цьому зареєстрований рівень жорсткого рентгенівського випромінювання був значно нижче, ніж у стандартних Х-пінчах.