ALUMINIUM X-PINCH DRIVEN BY A LOW INDUCTANCE PULSED POWER GENERATOR: EXPERIMENTAL OBSERVATIONS OF ITS DYNAMICS

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Abstract

A series of X-pinch experiments were performed on GEPOPU, a low inductance pulsed power generator. This generator consists of a Marx Bank and a 1.5Ω pulse forming line. The Generator was charged at 35 kV, providing a pulse of 120 ns and up to 180 kA to the load. A set of Aluminium crossed fibres of 10 and 15 μm was used as load. The diagnostics applied allowed the study of the x-ray emission from the cross point and the dynamics of the initial coronal plasma axial jet. This paper reports recent experiments carried out at Optics and Plasma Physics Lab., Physics Dept., P. Universidad Católica de Chile

1. Introduction

An X-pinch–like plasma discharge is established when a large current from a pulsed power generator drives a load of crossed metallic wires, held in the vacuum gap between two electrodes. This work explores the dynamics and properties of its soft X-ray emission. There has been renewed interest on this type of discharge in view of its possible applications in different fields of physics as a soft X-ray point radiation source (e.g.: Microlithography, medical and biological research, among others). Although radiation from hotspots has been investigated in different experiments [1] (e.g.: Vacuum Spark, Plasma Focus), the physical mechanism involved in their generation and time evolution is not well understood. In this work we report measurements of the dynamics, density and temperature of the X-pinch.

2. Experimental and Diagnostic Arrangements

The experiments described here were performed using GEPOPU, a low inductance pulsed power generator. The generator delivered up to 180 kA in a 120 ns pulse. The X-pinch load was constructed from two crossed Aluminium fibres of 10 and 15 μm diameter. To study both the x-rays emissions from the crossing point and the dynamics of the initial coronal plasma axial jet, a series of optical and X-radiation diagnostics techniques were used. A four frame x-ray framing camera with a 5 ns exposure gives spatial and temporal information in spectral regions determined by filters, including Ti, Al, Be, and aluminised Mylar. A series of filtered Si-PIN diodes were also used to record the X-ray yield. For optical probing, a Nd- YAG laser (532 nm) was used for schlieren photography and interferometry system. In the case of the interferograms a short pulse of 600 ps was used, allowing the fine scale structure to be frozen. The laser pulse was split to obtain two frames separated by 20 ns.

3. Results

The main stages of X-pinching dynamics are shown with schlieren images in Fig. 1. As current starts, a coronal plasma surrounds the wires. This plasma expands rapidly and a plasma column becomes visible along the electrode axis through the crossing point. The schlieren photography also allowed to estimate the axial jet expansion velocity as $\cong 1\ 10^7$ cm/s, which is consistent with a coronal plasma free expansion at a temperature of 0.06 eV. Furthermore, this external surrounding plasma masks the radiation from the core, in early stages. Later in time, as current reaches maximum value, the dense core plasma at the crossing point pinches at the time of the X-ray emission. The burst of X-ray emission is observed at 70 ± 20 ns with respect to the start of the current pulse, with a high degree of reproducibility. The pulse is usually observed to be single, within the time resolution of the system, but on occasions a series of pulses occupying up to 5 ns were observed.

Interferometric measurements have been done in the axial plasma column. Fig. 2 shows an interferogram while the jet stems from the cross point towards the electrodes during pinching phase. An estimate of the electron density between the limbs gives $\approx 10^{20}$ cm^{-3}. Simultaneously, an axially located Al-Mylar Filtered IRD randomly detects an early beam emission, which is probably due to fast electron acceleration at the cross point, in agreement with a slight anode asymmetry of the initial axial jet which has been previously observed [2]. A sample of emission signals, plus current and voltage monitoring are shown in Fig. 3. The results from the X-ray framing camera show a coronal plasma around the wires at early times. This plasma is cold being visible in 1.5 μm Al, but invisible in 1μm Ti and 8μm Be. We infer that the image captured is in XUV light. However at the time of the hot spot formation at the crossing point, we observe an intense point like source which is visible in Be and Ti filters, for this we infer a hotter plasma, whose temperature is less than 150 eV. These results are to be contrasted with the X-ray PiN results, where on a significant number of shots an X-ray pulse from a rather hotter plasma is observed at the time of hot spot emission. From the ratio of the signals observed with 50 and 21 μm Be, and with 5 μm Al Filters, we obtain a temperature of approximately 250 eV. The axial plasma jet may be seen on the softest Al filters only. Future work will show if this emission is from a plasma of lower density, but from a larger volume, or if some hot spots form with significantly higher temperature. The CRE code used to obtain these temperatures only considers H to Li-like emission, which is a disadvantage at lower temperatures in an Al plasma, where lower shell emission dominates. Considerable care must be taken in the choice of the filter thickness and materials to avoid confusion from XUV filter transmission, as is the case for an Al filter.

4. Discussions and Conclusions

An axial plasma column expanding from cross point with filamentary structure has been observed, so there is an important axial mass transport on the time scale of the cross point collapse and this expanding plasma has coronal plasma characteristics. The development of the cross point into collapse manifests itself by mainly K-shell line emission from H- an He–like ionisation stages of the wire material. Measurement detected that in our case the spots at the Aluminium X-pinch emission have a temperature lower than scaling from higher current generators suggests [3]. The highly reproducible burst of X-ray emission, as previous works describe [3,4,5], could be used as a soft x-ray point source. To summarize, we find that the most important characteristic of cross point hot spot formation has good correlation with current theoretical description [6]. A physical model based on the radiative collapse could be applied successfully to explain the soft X-ray emission process in X-pinch plasmas.

Acknowledgements

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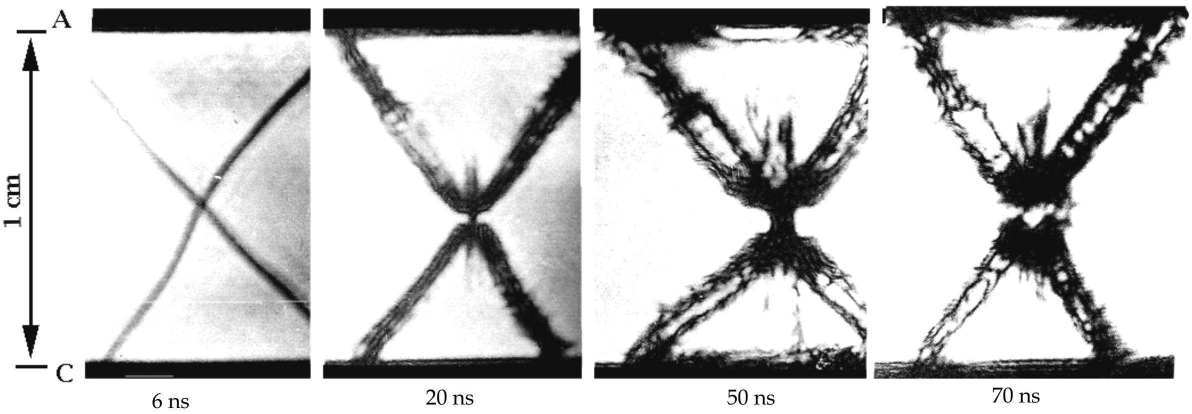

Fig. 1. The main stages of X-pinching dynamics are shown with schlieren images.

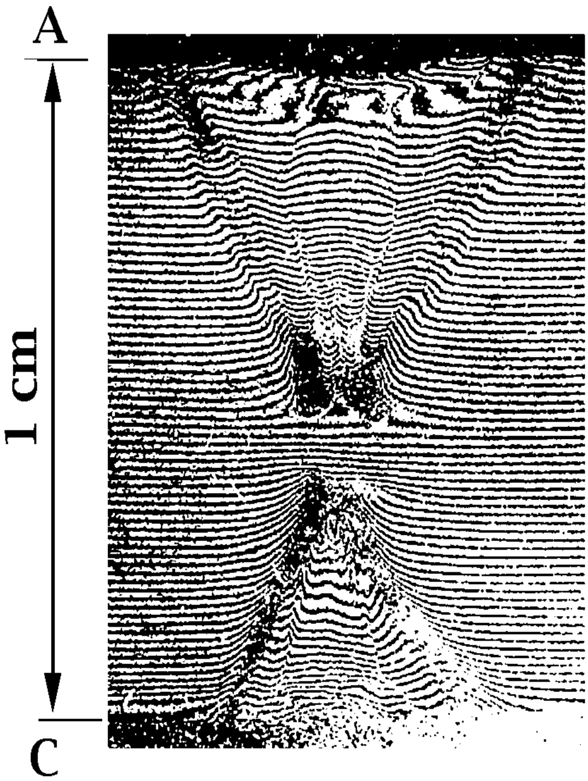

Fig. 2. Interferogram, while the jet stems from the cross point towards the electrodes during pinching phase. (t = 83 ns)

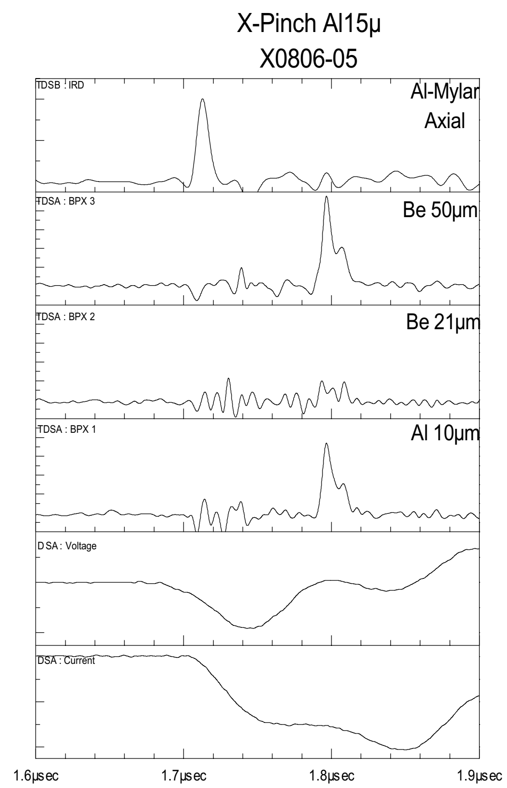

Fig. 3. Sample of emission signals, plus current and voltage monitoring.