Dense plasma focus PACO as a hard X-ray emitter: a study on the radiation source

2014 J. Phys.: Conf. Ser. 511 012024

(http://iopscience.iop.org/1742-6596/511/1/012024)

Dense plasma focus PACO as a hard X-ray emitter: a study on the radiation source

L Supán[1], S Guichón[1], M Milanese[1,3], J Niedbalski[1], R Moroso[1], H Acuña[2] and F Malamud[2]
[1]IFAS, Universidad del Centro and CONICET, Pinto 399 (7000) Tandil, Argentina.
[2]IFIMAR, Universidad Nacional de Mar del Plata and CONICET, Funes 3350 (7600) Mar del Plata, Argentina.

Abstract. The radiation in the X-ray range detected outside the vacuum chamber of the dense plasma focus (DPF) PACO, are produced on the anode zone. The zone of emission is studied in a shot-to-shot analysis, using pure deuterium as filling gas. We present a diagnostic method to determine the place and size of the hard X-ray source by image analysis of high density radiography plates.

1. Introduction

The dense plasma focus device (DPF) [1,2] produces a hot dense plasma by the rapid magnetic compression of a plasma cylinder formed at the end of a coaxial electrode system (see figure 1). When pure deuterium is used as filling gas, fusion reactions are produced in about 100 ns of the hot plasma lifetime. These reactions could be produced by two mechanisms: thermonuclear and beam-target. The thermal mechanism produces a soft X-ray emission (of some keV) [3,4] originated by bremsstrahlung of electrons on deuterons of the thermal plasma. The non-thermal mechanism produces high-energy ion beams and, in opposite direction, electron beams that collide with the anode zone originating a short pulse of hard X-ray emission [5]; both mechanisms coexist [3]. High definition radiographs have been obtained and related studies have been made in the DPF of our Lab in previous works ([7], [8]).

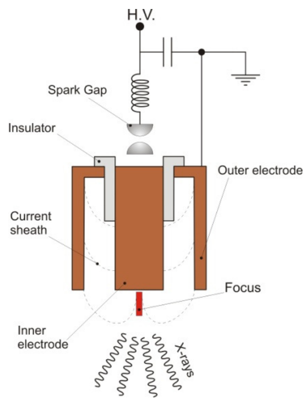

Figure 1. Basic scheme of a Plasma Focus device.

[3] Author to whom any correspondence should be addressed. E-mail: milanese@exa.unicen.edu.ar

2. The Experiment

The Dense Plasma Focus PACO (Spanish "Plasma Auto COnfinado" = auto confined plasma) is a small one: 2 kJ of energy in the capacitor bank, 4 μF, 31 kV of charging voltage, 250 kA of maximum short-circuit current. It has been designed through a bi-dimensional code [10], optimised in the sense of the neutron yield. The filling gas is deuterium (1.7 mb), in order to use neutron yield as a diagnostics. The current derivative was registered with a Rogowski coil, the voltage between anode and cathode (top side) is measured with a resistive voltage divider. The neutron yield (time integrated) was measured with a silver activation counter (SAC) and the hard X-ray and neutron pulses (time resolved) with a Bicron® scintillator-photomultiplier tube (SPMT).

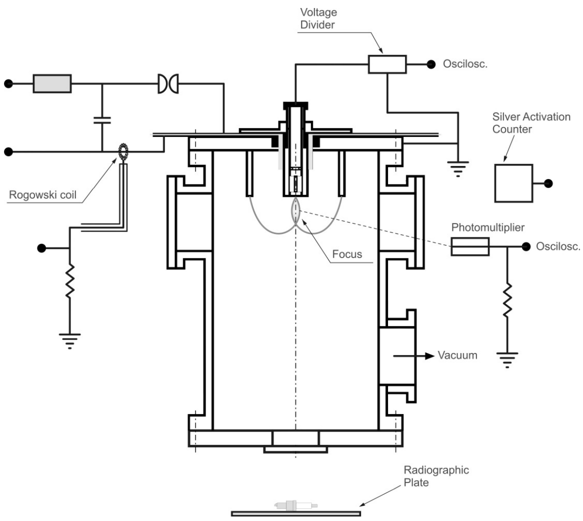

Figure 2. Diagram of the experimental setup for radiographies.

In each discharge a radiographic plate for mammography (Kodak®) was placed in the axial end-on direction to register an image of the obstacle interposed between the source and the plate. Mammographic plates were used since they have demonstrated to be more suitable to obtain a better spatial resolution than the conventional plates for thorax radiographies[6].
Due to the location of the PACO's chamber, the maximum focus–radiographic plate distance was 1.20 m. The anode of PACO, made in OFHC copper, has a tungsten disk (20 mm in diameter) in its free end.

3. Procedure and Results

The idea of the experiment was simply to put an obstacle between the source and the radiographic plate and analyze the image on the plate to infer the size of the source of radiation. The obstacle consisted in a copper plate with a thickness

$$c = (0.50 \pm 0.05) \text{ mm}$$

located at a distance a below the anode of

$$a = (380 \pm 5) \text{ mm}$$

Radiographic plates where located at a distance

$$b = (800 \pm 5) \text{ mm}$$

below the copper plate. On the other hand, it was used a pair of wires placed vertically in order to determine the position of the focus in each shot. Taking into account that the shadow projected by them points towards the source, drawing lines along these shadows and intersecting them it was possible to determine the focus position, from which distances were measured.

The system was carefully aligned and each radiography was irradiated with only one shot. Radiographic plates with sufficient exposition to radiation were used in our analysis.

4. Analysis

The obtained radiographic plate was digitalized by means of digital scanner (Canon® CanoScan LIDE 25). From the digital image (in jpg format) the curves needed for the analysis were extracted, without modifying the image.

The obtained curves are the ones corresponding to profiles in grayscale along specific lines of interest over the image. Such curves result to be proportional to the received radiation on every zone of the plate.

The following figure shows one of the obtained images after digitalization:

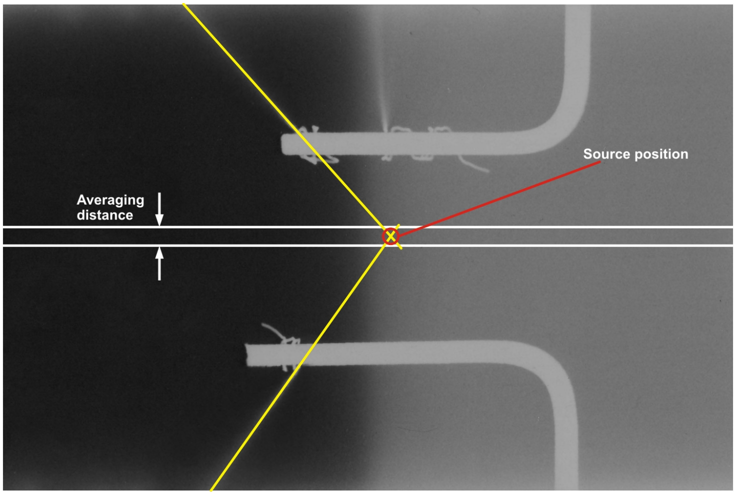

Figure 3. Digitalized image of the radiographic plate.

In order to obtain the curve corresponding to the received radiation intensity (grayscale) on every pixel on the plate along the horizontal line passing through the position of the focus (see figure 3) the values of intensity were averaged taking into account some values above and below that line. These curves were taken as a data, performing an analysis by means of a numerical procedure, described below.

4.1. Procedure

The radiation from the source arrives at the radiographic plate passing through the copper plate. Different zones will have distinct intensities which are related to the area of the source that it not obstructed by the obstacle. Below the copper plate edge the intensity reaches its mean value, which is in agreement with the fact that at this point half of the radiation coming from the source is not attenuated. See figure 4 and 5.

Therefore, the intensity of the radiation on every point of the radiographic plate is related to the integral of the source intensity profile. By modifying the limits of that integral, the different intensity values registered at every point of the radiographic plate can be obtained.

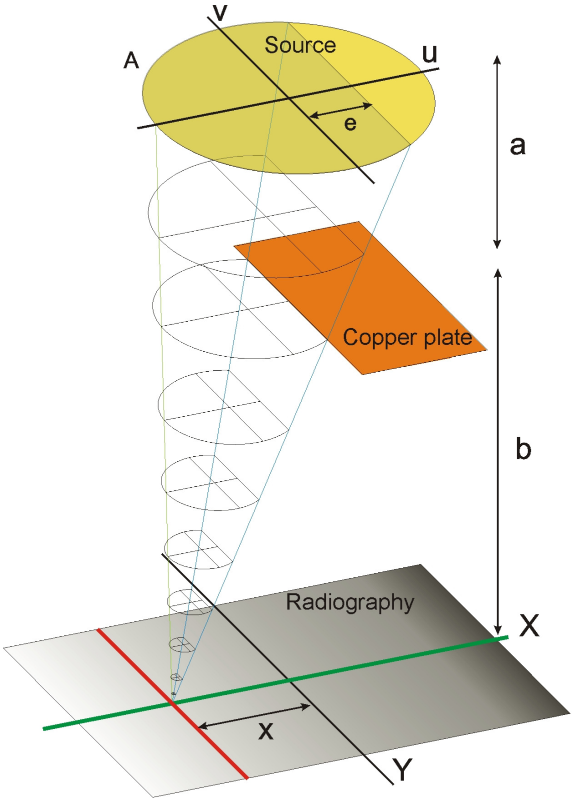

Figure 4. Scheme of the experimental configuration used to obtain the intensity profile curves.

The obtained profiles represent the intensity of radiation $I[x]$ which imprints the radiographic plate. A characteristic curve is shown in figure 5.

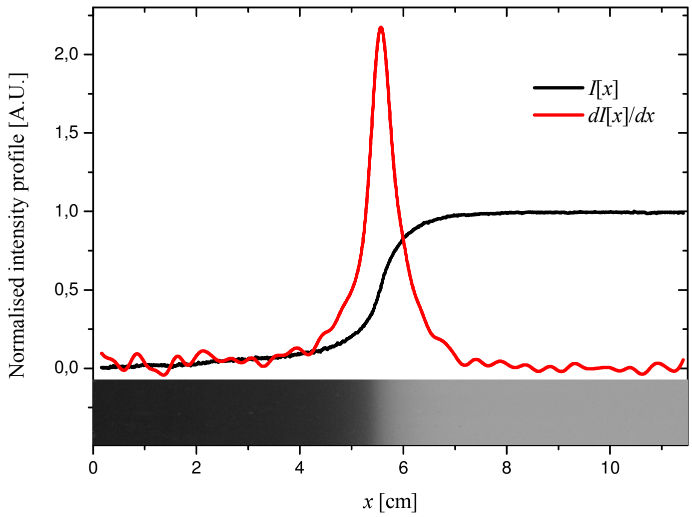

Figure 5. Intensity profile obtained $I[x]$. The derivative of $I[x]$ is also shown.

The image registered on the radiographic plate is a magnified image of the copper plate edge. The distance *x*, measured in the (*x*,*y*) coordinate system, and *e*, measured in the (*u*,*v*) system, are related by a simple expression, i.e.,

$$e = \frac{ax}{b} \tag{1}$$

The obtained curves $I[x]$ are proportional to the integral of the intensity profile of the source $S[u]$.

$$I[x] \propto \int_{s}^{\frac{ax}{b}} S[u]du = T[\frac{ax}{b}] - T[s] \tag{2}$$

The integration limits are given by a arbitrary minimum value *s* (which in principle, at most, can be equal to the anode radius) of null intensity and the position *e*. A function proportional to $S[x]$ can be obtained by deriving equation 2:

$$\frac{dI[x]}{dx} \propto S[\frac{ax}{b}] \tag{3}$$

The derivative of the intensity profile $I[x]$ is shown in figure 5. The FWHM of this curve was calculated in a series of seven radiographs and the obtained result, which is representative of the characteristic size *d* of the emitting zone. The obtained value is

$$d = (0.25 \pm 0.02)\ \text{cm}$$

5. Remarks

In this preliminary work, by means of a relatively simple procedure it could be obtained an estimation of the value of a characteristic size of the hard X-ray emitter source in the PACO Plasma Focus device. The method gave a value of a few millimeters.

So, the method has proved to be suitable for measuring a characteristic size of the source and to have quite convenient properties such as their simplicity and easiness to implement, or the advantage to be a low-cost method. But there are still some questions concerning to the reliability of the method that we expect to explore and improve in a future.

One way to explore has to do with the experimental set up, and it might consist of varying the geometry to change the obtained data in order to get, for instance, curves where some points or zones become clearer to identify, etc.

Another refinement, experimental as well as theoretical, it could be to change that configuration and implement a new one in which the approximation of parallel rays is no longer valid, so the model has to take into account even some possible effects of anisotropy of the emitted radiation which imprint the radiographic plates.

Or maybe to design a different configuration, perhaps a variation of this, with which it can be possible to explore the possibility that the source is actually slightly bigger than we could expect. If that were the case, it might mean that, although the main contribution to the X-ray hardness is due to the bremsstrahlung of electrons against the anode, the source might have another contribution that makes it bigger, as it might be the bremsstrahlung of electrons against vaporized W in this case, in general the metal of the anode.

Another fact to take into account is that the range of energy over which the mammographic plates have an appreciable response is of the order of some tens of keV. So it might be possible that in fact the zone of the source responsible for the hardest components of the radiation can be smaller than the obtained value, eventually of the order of the electron imprints on the anode surface. We expect to explore that possibility in the near future.

6. References

[1] Mather J W 1871 *Dense Plasma Focus Methods of Experimental Physics* ed R Lovberg and H Griem (New York: Academic) 9B p 187
[2] Imshennik V, Filippov N and Filippova T 1973 *Nuclear Fusion* **30** 929
[3] Castillo-Mejía F, Milanese M, Moroso R and Pouzo J 2000 *Nuclear Fusion* **30** 929
[4] Castillo-Mejía, M. Milanese, R. Moroso and J. Pouzo, *Journal of Physics* D: *Applied Physics* **33** 141-7
[5] Serban A and Lee S 1997 *Plasma Sources Sci. Technol.* **6** 78
[6] Acuña H, Milanese M, Moroso R and Pouzo J 2002 *European Physical Journal* D **21** 97
[7] Milanese M, Niedbalski J, Castillo-Mejía F, Moroso R, Supán J, Guichón S, Acuña H, Malamud F, Barbaglia M and Marcazzó J 2009 *XXIX Int. Conf. on Phenomena in Ionized Gases* (Cancún, México: July 12-17 2009)
[8] Pouzo J, Milanese M and Moroso R 2002 *AIP Conf. Proc.* 669 p 277
[9] Castillo-Mejía F, Gamboa I, Herrera J, Rangel J and Villalobos L 2008 *Applied Phys. Letters* **92**, Issue 5, Web version: 051502-1/-2.
[10] Vargas J, Gratton F, Gratton J, Bruzzone H and Kelly H 1976 *Proc. of the 6th. Int. Conf. on Plas. Phys. and Contr. Fusion Res.* (Vienna: IAEA publications) vol 3 p 289.
[11] Castillo-Mejía F, Milanese M, Moroso R, Pouzo J and Santiago M 1998 *25th EPS Conf. on Contr. Fusion and Plasma Phys.* vol. 22C p 2686-9.