Hard X-ray sources from miniature plasma focus devices

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Abstract: As first stage of a program to design a repetitive pulsed radiation generator for industrial applications two miniature plasma foci have been designed and constructed at the Comisión Chilena de Energía Nuclear. The devices operate at an energy level of the order of tens of joules (PF-50J, 160 nF capacitor bank, 20-35 kV, 32-100 J, ~150 ns time to peak current) and hundred of joules (PF-400J, 880 nF, 20-35 kV, 176-539 J, ~300 ns time to peak current). Hard X-rays are being studied in these devices operating in hydrogen. Images of metallic plates with different thickness were obtained on commercial radiographic film, Agfa Curix ST-G2, in order to characterize the energy of the hard X-ray outside of the discharge chamber of PF-400J. An effective energy of the order of 90keV was measured under those conditions. X ray images of different metallic objects also have been obtained.

Introduction

The plasma focus (PF) device is a known source of dense transient high temperature plasmas, and it has been studied since late 50`s [1] . A plasma focus is a particular pinch discharge in which a high pulsed voltage is applied to a low pressure gas between coaxial cylindrical electrodes. The central electrode is the anode which is partially covered with a coaxial insulator. In the pinch phase, beams of ions and electrons, and ultra-short (< 100ns) X-ray and neutron (using Deuterium gas) pulses are generated. Particularly the electron beam collision with the anode top side surface generates copious hard X-ray emission. The Plasma Focus device can be used as high-intensity and short duration X-ray source[2].
As first stage of a program to design a repetitive pulsed radiation generator for industrial applications the Plasma Physics and Plasma Technology Group of the Comisión Chilena de Energía Nuclear has constructed two very small plasma focus. The first has tens of joules (PF-50J, 160 nF capacitor bank, 20-35 kV, 32-100 J, ~150 ns time to peak current) [3-6] , and the second has hundred of joules (PF-400J, 880 nF, 20-35 kV, 176-539 J, ~300 ns time to peak current) [7]. The very low energy of this devices (32 to 539 J) allow repetition rate (0.1 to 1 Hz) greater than conventional devices with E> 1kJ . So, a compact (~0.5 m^3) and cheap devices are obtained, this allows easy modification in wide parameter range.
The principal aim of this work is to study the hard X-ray emission in order to obtain information of its effective energy and to use this emission to obtain radiographies of compound objects (e.i., different metals and plastics). We present the result obtained in PF-400J device.

Experimental Setup

The experiments were performed in PF-400J device, which is powered by a 880 nF capacitor bank operating up to 30 kV(~400 J). An external inductance of 40 nH is obtained. Typical current pulse at 30 kV is 141 kA peak with ~ 300 ns quarter period. The device was operated to 29 kV (370 J) with Hydrogen at pressure of 7 mbar. Voltage is measured at the base plate of the plasma focus electrodes by a voltage divider, and current by a Rogowski coil at the capacitor bank. To improve the X-ray emission a lead piece inside the hole of the anode was located. The objects to be imaged were placed outside the

stainless steel chamber, on the electrodes symmetry axis, between 10 to 50 cm away from the pinch region.
Commercial radiographic film (13x18 cm^2), Curix ST-G2 from AGFA was used together with AGFA suggested developer and fixer for this film. The film are placed inside a plastic light tight cassette, Curix from AGFA, containing intensifying plastic screen sensitive to X radiation. The cassette with film was placed as close to the object to be imaged as possible to favor the image quality. The object is placed between the plasma focus device and the cassette.The images are scanned with high resolution using a HP ScanJet 5530.
A photomultiplier tube Photonis XP2262b (5 cm diameter) with, 5 cm long BC400 plastic scintillator is used to monitor the x-ray emission in each shot. This diagnostic is placed perpendicularly to the symmetry axis at anode top level.

Results and discussion

X-ray effective energy

The method to determine the effective energy of the radiation is based on the well-known relation for radiation decay through the matter: $I(x) = I_o\, e^{-kx}$, where x is the penetration depth and k is the linear attenuation coefficient. Knowing the thickness of the material, the experimental estimation of the I(x)/Io quotient, it allows to calculate a effective linear attenuation coefficient k *, which can be interpreted like the attenuation coefficient that would have a monochrome beam to reproduce the same quotient of intensities. From k* and knowing the relation k(E) is possible to obtain the effective energy E* so that k(E*)=k*. This method, developed by Raspa (8) in her thesis, allows to obtain a correlation between linear attenuation coefficient , k, and the X-ray energy.
Several metals with different thickness were used like stepped filters. The different materials used are showed in the table 1. The Lead is used to verify the threshold of "non-irradiation" level. Figure 1 shows the typical digital computer image of a radiographic film obtained after an effective shot.

Material	Thickness [mm]						
Cooper	1.0	2.0	3.0	4.0	5.0	6.0	7.0
Molybdenum			0.25	0.50	0.75	1.00	1.25
Silver			0.25	0.5	0.75	1.00	1.25
Lead						2.5	5.0

Table 1: Metals used like stepped filters and its respective thickness.

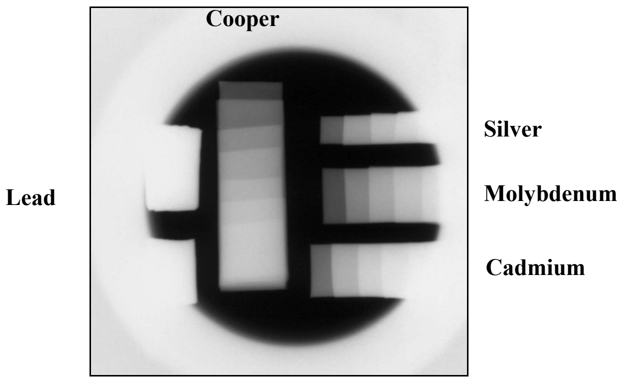

Fig. 1: Typical digital computer image of a radiographic film obtained after an effective shot.

Table 2 show effective energy obtained to the figure 2 for each metal.

Material	Effective Energy [keV]
Cooper (Z=28)	90 ± 3
Molybdenum (Z = 42)	91 ± 3
Silver (Z = 47)	95± 3

Table 2: Hard X-ray effective energy for the different materials.

X-ray images

Single images of different metallic objects were taken. Figure 2 shows a stainless steel BNC "T" where the internal structure made of metal is easily identified. This image was obtained with multiple shots to 17 cm of the pinch.
Figure 3 shows a spark plug which was taken with multiple shots to 20.3 cm of the pinch. The central conductor is cover with ceramic which was totally crossed by the radiation. The hidden central rod inside the metal piece and the spirals superior and inferior of the same one with clarity is distinguished.

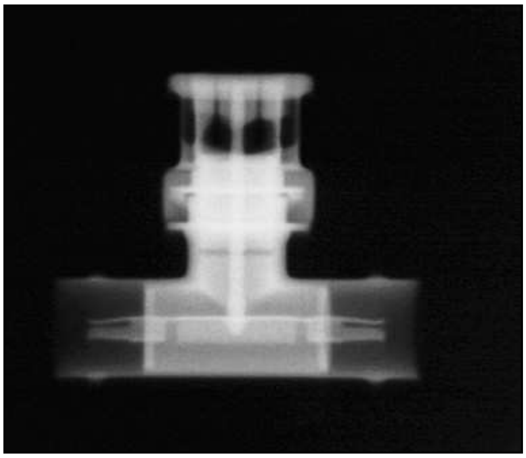

Fig. 2: Single X-ray image of a stainless steel BNC T connector .

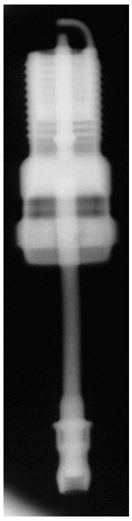

Fig. 3: Single X-ray of an spark plug.

Conclusion

The intensity and energy of the X-ray emission is increased when lead is used as target of electron beams. The spatial resolution of the images obtained with the radiographic method, has global character. In other words, it is own of the complete process of revealed, fixed and digitalization of the radiographic plate used, obtaining (10,2 ± 0,5) pixel in the digitized image, by millimeter measured on the object. Of table 2 it is possible to observe that the results obtained after analyzing different x-rays from samples of different materials are consistent; which suggests the method implemented is robust. The effective energy of emission is (92 ± 5) keV when all the results exposed in table 2 are considered . The radiographies are generated by ultra-short pulses of hard X-rays, less of 50 ns, by the impact of electron beams on the anode. This characteristic could extend its range of applications to x-rays of objects in motion. Particularly, the images (fig 2 and 3) show a high resolution of contours and allow to appreciate the inner of the piece with detail. A technique of this type would allow the detection of faults in pieces of some assembly and equipment PF could be used directly in the production chain of a factory.

Dealing with the PF-400J, we will continue with the characterization and optimization of the equipment and with the development of radiographic applications, such as the tomographic reconstruction of metallic and/or biological objects. Additionally it will be tried to repeat the study developed for the PF-400J, in the PF-50J.

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