A necessary experimental discussion concerning the X-rays' plasma focus use for radiographic images applications

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Abstract. A. Da Re et al. [1] shown one of the first preliminary studies on X-rays coming from an experimental Plasma Focus (PF) device. Using radiographic films to obtain images of different thick plexiglass filters it was possible to diagnose some aspects of the X-rays emitted by PF source of nanosecond exposition times. Beside of the scientific interest in the X-ray PF characterization, some efforts have been made to improve this emissions as a useful X-ray application technique [2] including moving objects at high rpm [3]; despite a very nice radiographies experimentally obtained, a good quality PF X-ray images must be improved when they are contrast with radiographies obtained by means conventional techniques.

Introduction. There is a permanent interest to understand the generation properties of X-rays emitted from the PF devices. But, it is still necessary more efforts to characterize the energy of the X-rays that can be use for medical and industrial applications [4]; we need to know more deeply how the PF parameters give X-rays with a “predictable” energy and intensity.

Image analysis is useful to know some characteristics of X-rays [1,5] and it give orientation about the control of this radiation. The compact PF devices have a shorter quarter period and a smaller anode radius than PF working at energies greater than 1 kJ, so the X-rays emerging are relevant because its low radiation exposure time. We have obtain "convenient" X images, but a necessary discussion is needed when it makes some looks to the conventional ones concerning the control parameters when a conventional X-ray image is obtained (acceleration voltage, intensity and exposure time) and the PF control parameters to obtain an "adequate" radiological image (charging voltage, inductance, capacitor bank, and gas pressure among others). Metallic filter arrays were used to estimate the X-ray energy [5]. Interesting scientific efforts, technical development, discussion and analysis of the methodology used in this work, and also in the interpretation of the results, are specified elsewhere [5-7]. The pulsed X-rays under investigation are principally from Bremmstrahlung, as a result of the electron collision with a target placed into the hollow anode bottom side (Fig. 1), and line emission from higher-Z ions due to impurities and/or metallic target material. The electron beam is principally generated at the PF region after plasma disruption [4].

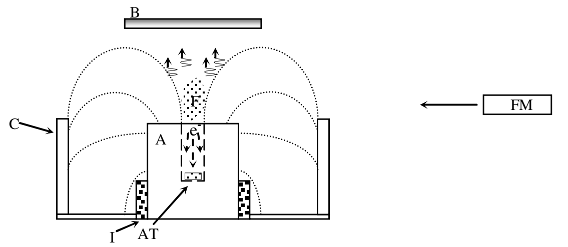

Figure 1. Scheme of the PF-400J deviceprofile: (A) cylindrical hollow anode, (C) cylindrical cathode rods, (I) alumina insulator, (AT) anode target, (B) X-ray film, (e$^-$) e-beam after plasma collapse, (F) focus region, (FM) photomultiplier watching the focus region.

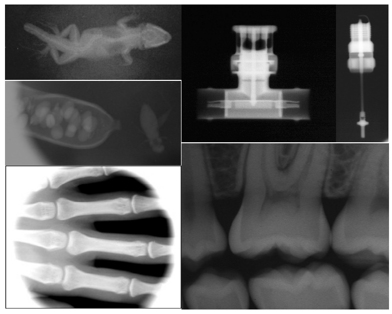

Figure 2. Radiographic images obtained with the PF-400J excepting the teeth image that was obtained in a professional radiographic centre. A Bite Wing bilateral teeth radiography is obtained when the film is exposed to an X-rays produced by a source whose typical control parameters as 80 kV, 10 mA, and 0.38 sec of exposition time, for 40 cm between the source and the film.

Experimental Setup. The experimental study was carried out on PF-400J device (Fig. 1). The control parameters are: 880 nF, 30 kV (~400 J), and 40 nH, 127 kA peak current. The filling gas was H_2 at working pressure 6.5-10 mbar. The electrodes are copper made with an alumina insulator, and they are located in a (3,7 mm thick wall) stainless steel chamber [5].

Films (Agfa Curix ST-G2) were exposed to X-rays and to improve the emission a metallic piece (Cu,Mo,Ag or Pb) was located in the hollow anode. A Photonis XP2262b photomultiplier and BC408 plastic scintillator was used to register the time resolved X-ray emission; it was placed, perpendicular to the axial axis, at 2.25 m from the chamber and watching the F zone (Fig. 1).Tthe typical feature of the X-ray signal is shown at ref. [5].

The X-ray film was installed inside of a regular chassis, placed in the axial axis, outside of the discharge chamber at different distances from the top anode level (Fig. 1); the X-rays fly towards to the diagnostic after crossing a 45 mm diameter aluminium flat window. A stepped filter array, to analyse the X-ray energy was used [5]. A detail is given in the Table 1.

Experimental results and analysis. The images (Fig. 2) are obtained after different numbers of shots, for around 30 ns (FWHM) each, using different targets (Table 1). A mixture of energy, intensity and exposure time is needed to obtain an X-ray image when a conventional X-ray generator is used, parameters that should be correlated with the corresponding PF ones (charging voltages, pinch current, inductance, and gas pressure among others).

Actually, the parameters which influence the quality of the images are principally the

Table 1. X-ray effective mean energy

Irradiated element	Charging voltaje (kV)	Gas pressure (mbar)	Target element (Z)	Film-source distance (cm)	Effective shot number	Estimated X-ray energy (keV)
Seed/Insect	29 – 30	6.5 – 8.5	Cu (29)	45.5	10	42.7 ± 3
Tiny lizard	29 – 30	8.0	Mo (42)	45.5	5	35.6 ± 5
Hand	30	10	Ag (47)	45.5	16	46.4 ± 2
T-BNC	29	6.6	Pb (82)	17	5	93.0 ± 3
Spark-plug	29	6.5	Pb (82)	23	12	93.0 ± 3

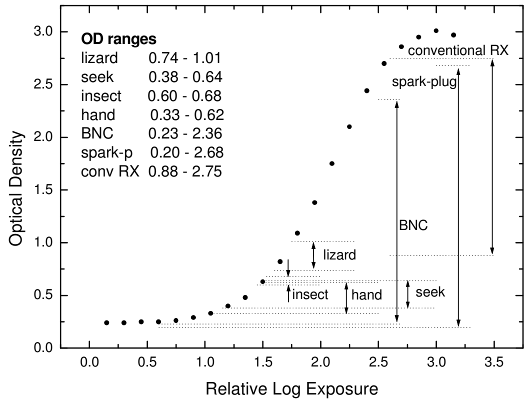

Figure 3. Sensitometric curve of the used Ortho CP-G Plus Agfa radiographic film and the corresponding optical density ranges of the radiographic images shown at the Fig. 2.

charging voltage, gas pressure, filling gas itself, number of shots and anode target [5]. Evidently, a greater number of shots bring a loss of information in the X-ray image meanwhile a low number gives a darkness level close to the base+fog level of the film (our case, images shown in Fig. 2. There is an important trouble; meanwhile a conventional source induce an emission line radiation to obtain an image (filtered, collimated and a close monoenergetic X-ray beam), in the PF we have an inhomogeneous beam with a broad energy spectre [5]. But, are we close from the adequate radiographic image?. We have measured the optical density (OD) of the images to know where they are represented against the sensitometric curve (Fig. 3). The biological images are close to the base+fog level (OD=0.26); it is desirable to have images with OD in the straight region of the sensitometric curve. To obtain images with the OD index in the straight zone it is necessary to perform consecutive shot [5] in combination with the charging voltage and gas pressure; it is necessary take care with the saturation level (OD=3.00 in our case).

For metallic elements it is necessary to produce higher X-ray energies; Fig. 3 shows also the resulting images of a stainless steel T-BNC connector and a spark plug that were located in the axial axis at 17 cm and 20.3 cm, respectively, from the upward F zone (Fig. 1). The radiographies were generated by 5 and 12 consecutive shots (around 20 ns each one) X-rays, with an effective mean energy of 93 ± 3 keV, respectively. The OD analysis shows why these radiographies are good images than the organic ones. All the PF X images shown in the figure 3 can be evaluated (in quality) with the conventional teeth image whose OD values centred in the straight zone of the sensitometric curve.

Due to the different "obstacles" (filters) for the X-rays coming from the discharge chamber, it could be expected that there were not energies smaller than ~30 keV. In fact, in a previous analysis [5], and using stepped metallic filters arrays, indicated us that it fluctuates between 30 and 100 keV. How is shown in the images illustrated in the Fig. 2, the PF-400J has a suitable range of photon energies to obtain radiographies of a reasonable quality. A deeper analyse and discussion about the calculated effective mean X-ray energy against the number of shots can be found elsewhere [5].

Conclusions. The understanding of the X-ray processes generation after pinch collapse in a plasma focus (PF) device is being increased through the years, but there are still open questions, especially in the knowledge of the driver parameters that could report reproducibility and control to this kind of ultrafast pulsed radiation emission. To study the X-ray generation processes, correlated with its driver parameters and the PF device capability to produce X-rays, it is more advisable to use low energy plasma focus devices due to their versatility and easy handle to drive.

Using a charging voltage of around 30 kV and H_2 gas at 10 mbar of working pressure in the PF-400J device, we have obtained photon energies in the range of 35.6 keV to 93 keV, a suitable range to diagnose biological or metallic elements. The X-rays which imprints the radiographic films come principally from Bremmstrahlung when electrons arrive to a metallic target during pinch phase and collapse. It was measured the optical density of radiographic images, and the combination of X-ray energy and low number of irradiation shots in the radiographic film give images close to the base+fog level of the film in the case of the organic material irradiation, and images of better quality (corresponding to inorganic materials) which are better distributed in the straight region of the sensitometric curve. In spite of the previous experimental results, it indicate the necessary complementary and future investigations to find correlations between the X-ray characteristics with the charging voltage, induced voltage during compression, pinch current intensity and absorption coefficient of the irradiated elements itself among others. It is possible to obtain radiographic images with higher OD index, "moving" the image towards the straight region of the sensitometric curve, because the versatility of the PF-400J to perform consecutive irradiation shots.

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References

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