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Preliminary study on X-ray source from Plasma Focus device for fast radiography

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Abstract Plasma derived flash X-ray sources may find potential applications in medicine and industry. Notwithstanding, as is the case of Plasma Focus (PF) devices, their characterisation in term of photon energy, temporal and spatial beam stability is far to be considered satisfactory. In this work, a radiographic approach, which avoids the effects caused by the intrinsic instability of the pinch output of a PF machine, is proposed and an attenuation curve can be attained even in presence of X-ray emission instability. Using two radiographic films for each shot exposition symmetrically positioned and collimated to the pinch region the mean energy of the photons in the X-ray beam are evaluated. The X-ray emission symmetry from the pinch region was then utilised to control the validity of the proposed methodology.

Key words plasma focus • X-ray sources

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Introduction

Fast X-ray radiography is used in many situations where the non destructive analysis of objects rapidly moving is required. In biomedical applications, for instance, its utility ranges from the traditional angiography to the most recent technique of monitoring the deformations of bones performing very rapid movements. Industrial potential applications are the on-line control of ultra fast casting or of the manufacturing of miniaturised moving apparatuses [3]. In these specific cases, the thickness and the atomic number of the materials require energies of the incidental photons up to 150 keV. Moreover, the required intensity, in order to have acceptable resolution in spite of the very short times of exposure here considered (fraction of μs), is of many orders greater than those provided by an ordinary radiological apparatus. For this reason the use of a Plasma Focus device as an X-ray source is here proposed. The PF represent a solution at low cost of management, compact and reliable, and offers performances in terms of intensity of the useful beam of X-rays (originated directly in the pinch or indirectly from relativistic beams of electrons on targets) and of the time of exposure (<100 ns). In order to test its convenience compared to other apparatuses currently available [4], the X-ray beam needs to be characterized in terms of stability, intensity and energy of the emitted photons.

The aim of the present investigation is to confirm the feasibility to exploit this new technology in the field of fast radiography of objects with low atomic number Z elemental composition. To this end the assessment of the mean energy of the X-ray beam is carried out by means of a sim-

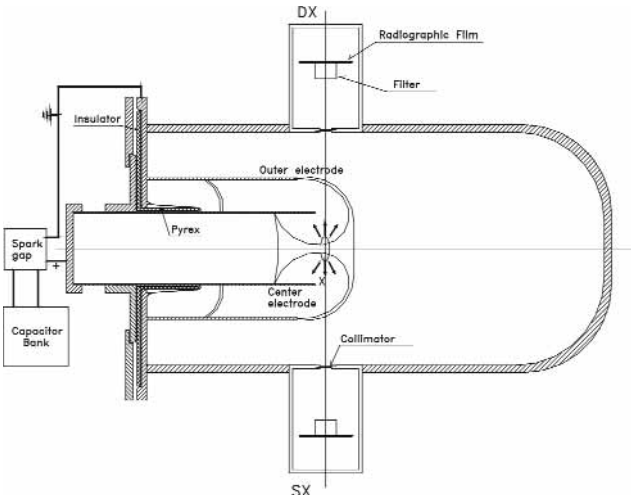

Fig. 1. Experimental set-up.

ple and inexpensive methodology, which foresee the use of two radiographic film devices symmetrically positioned and collimated to the pinch region.

Experimental set-up and results

The experimental set up is shown in Fig. 1. The Plasma Focus, Mather type, in use at the Department of Physics of the University of Ferrara (PF1) has the followings characteristics: electrodes length 130 mm, diameter of external electrode 107 mm, diameter of the internal electrode (hollow anode) 34 mm. Energy of the capacitor bank 7 kJ. Maximum peak current 0.5 MA. Working pressure 4.5 mbar of a mixture of deuterium and argon (6%) [2]. Two additional cylindrical vacuum chambers, 8 cm in diameter and 14 cm in length, are symmetrically positioned at 200 mm from the axis of the electrodes in correspondence to the "focus" (Fig. 1). The chambers are well collimated on the pinch position, in order to avoid the X-ray component from the anode. Notwithstanding, the two devices are not devised to perform exactly the same measurements. Each chamber contains a radiographic film (type: Kodak Ultra-speed D, ISO W2, 31×41 mm) on which a differential filter, achieved by 5 sheets of plexiglas, 3.5 mm thick, assembled scaling 3 mm each other (see Fig. 2), has been positioned. The filter leaves on the film surface an unshielded border and gives images, as shown in Fig. 2 which provides, at each shot, a blackening corresponding to the radiation intensity.

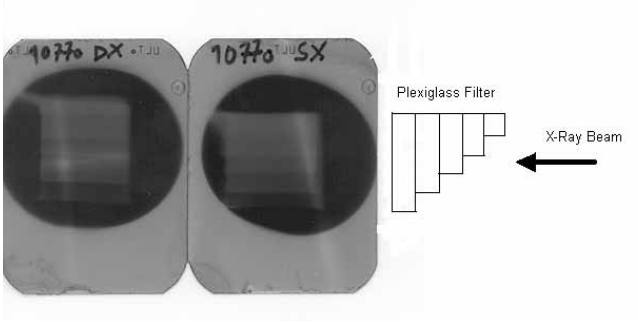

Fig. 2. Images obtained after one discharge.

After irradiation, the images of the developed films have been digitised and analysed with a dedicated program which gives the optical density of the films on the basis of an inside standard. The data, after the subtraction of the background (the degree of white of the non radiated surface depends on the quality of the film, on the developing time, etc.), have been normalised deducing the blackness of the unshielded border, in order to compare films from different discharges.

For each shot it is, therefore, possible to obtain a diagram of the optical density values against the plexiglas thickness. Fig. 3 reports results obtained for different shot irradiation and position of the radiographic films. The effect of both the intrinsic variability of the pinch X-ray emission and the different measurement device is evident.

However, by supposing a linear correlation between the optical density and the intensity I of the X-ray impinging on the film after having an absorption in the plexiglas sheet, these diagrams may be useful in assessing the mean energy of the emitted photons. As it is well known [5], the unknown broadband spectrum X-ray radiation is characterised by the effective photon energy evaluated by means of an attenuation curve. Such attenuation curves may be supplied by the usual Beer-Lambert relation:

$$(1) \qquad \frac{I}{I_0} = \exp(-\rho\mu x),$$

where: μ is the coefficient of mass absorption of the plexiglass (depending on the elemental composition of the material and on the photon energy E), ρ its density and x (in cm) the thickness being taken into account. I_0 is the incident X-ray intensity determined in the zone of the film not interested to the plexiglass attenuation. When the data of equa-

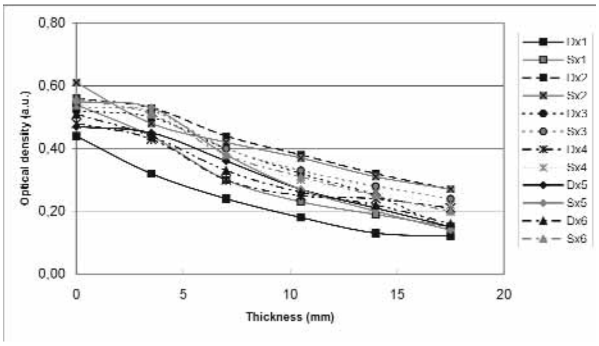

Fig. 3. Optical density in function of the thickness (in mm) of the Plexiglass filter. Dx: recorded data from the Dx radiographic apparatus; Sx: recorded data from the Sx radiographic apparatus.

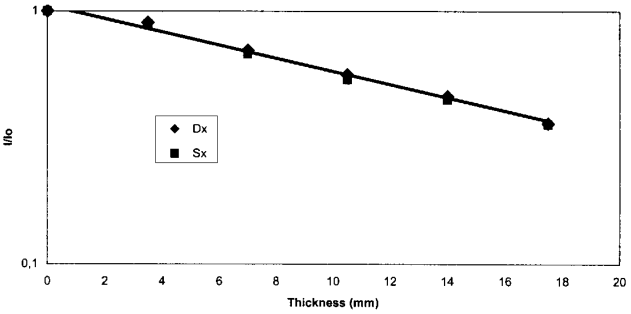

Fig. 4. Attenuation curve in semi-logaritmic scale for the Dx and Sx recorded data.

Table 1. Correlation coefficients and risks.

discharge	r	risk
10758	0.9901	0.12%
10762	0.9970	0.02%
10766	0.9856	0.21%
10770	0.9923	0.08%
10774	0.9953	0.04%
10778	0.9983	0.01%

tion (1) are plotted from the attenuation curve, in a semi-logarithmic scale as shown in Fig. 4, the value of μ and its uncertainty can be easily obtained by evaluating the angular coefficient of the reported straight line. In such a way a value of 0.50 cm^2/g is assessed, which corresponds to a mean effective photon energy of about 20 keV. This value is calculated by using the "Xcom" program [1] once the elemental composition and density of the plexiglas is known.

Since I and I_0 can be assessed within every shot registration with the same experimental condition, the effects caused by eventual beam intensity instability are cancelled out when equation (1) is considered. Moreover, the validity of such procedure is confirmed by a cross comparison of the data belonging to the different X-ray film apparatuses. In Fig. 5 the ratio of the I/I_0 obtained for every different thickness is reported. The distribution of the ratio results as well as their uncertainties are well within the experimental error, which can be devised for this kind of measurements. A further proof can be supplied by testing the correlation coefficient and the risk [6] for each pair of the corresponding values from the two apparatuses. The results reported in Table 1 have shown highly probable correlation and, therefore, confirm the expectation given in Fig. 5.

Conclusions

The measurement of the mean effective energy of photons emitted by a short intense pulse, can be employed for monitoring with X-ray emission by PF based devices. In this frame, we have pointed out the feasibility to measure the mean effective energy by means of a very simple and cheap methodology. The possible beam instability effects intrinsically removed, allowed by the techniques itself, makes us confident about its utilization in routine practice.

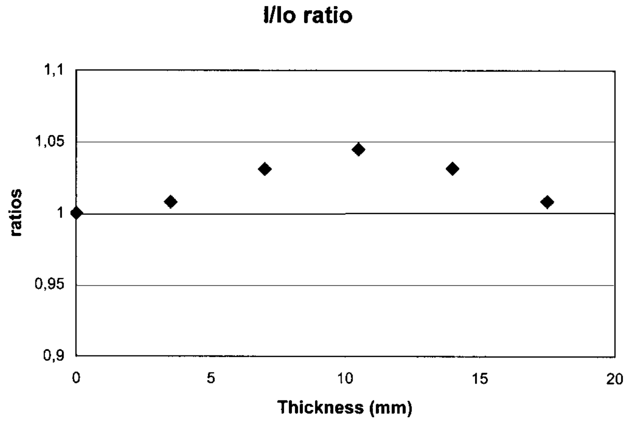

Fig. 5. Ratios between $(I/Io)_{Dx}/(I/Io)_{Sx}$ for the different Plexiglas thickness.

A future development, which foresees a linear array of PIN Diode to substitute the film device, is in progress. The results obtained at this stage of the investigation are not satisfactory to have an absolute indication of the spectral intensity of the X-ray emission from the PF sources. However, the mean effective energy here assessed agrees with the current literature [3] as representative of the emitted photon by both the hot plasma and Relativistic Electron Beam (REB) modality.

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