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DPF device application in the material characterization

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Abstract The ability of a dense plasma focus (DPF) installation, to serve as a unique powerful hard X-ray and neutron pulse generator, is discussed. A principle of the dynamic detection of defects, based on a small-scale DPF device, is described. The results of a dynamic defect detection experiment are presented. Different aspects of the application and adaptation of a small DPF chamber for the material science, are discussed.

Key words dense plasma focus • material sciences • small DPF chamber • X-rays

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Introduction

A dense plasma focus installation, explored mostly within the fusion program, is known as a powerful neutron and very broad X-ray spectrum generator. At the same time the DPF is able to operate with some gases or gas mixtures, becoming a generator of a pure X-ray radiation, not accompanied by the neutrons.

As an X-ray radiation generator the DPF has two principal distinctive features. The first one is the X-ray pulse shortness, and the second one is an extremely great power of the X-ray pulse. These features accompanied by DPF X-ray spectrum peculiarity give an opportunity to apply a DPF installation (even of a small dimension class) into a number of branches of science and technology, where other X-ray sources cannot be used.

DPF X-ray radiation features

The hard X-ray DPF radiation is a result of a strong relativistic electron beam (REB) interaction with the anode surface, generating the bremsstrahlung. Namely, estimations of such a type, based on a hard X-ray dose measurement, give evidence of the presence of the strong REB, which appear inside a DPF device. Such estimations indicate that up to 75% of the discharge current can be transported by REB, during a very short time interval, approximately equal to the X-ray pulse duration. The place of the REB generation is located near the DPF chamber axis and its interaction region is situated at the center of the anode surface. So, in the case of a flat anode the effectiveness of the energy transformation

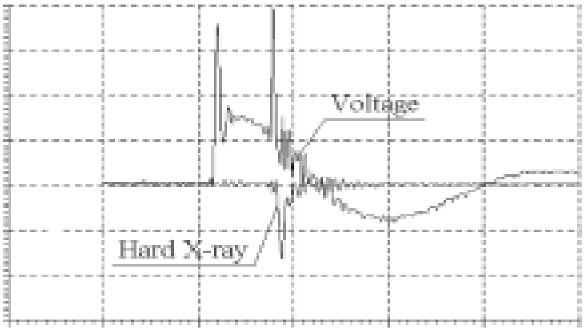

Fig. 1. Typical DPF waveforms.

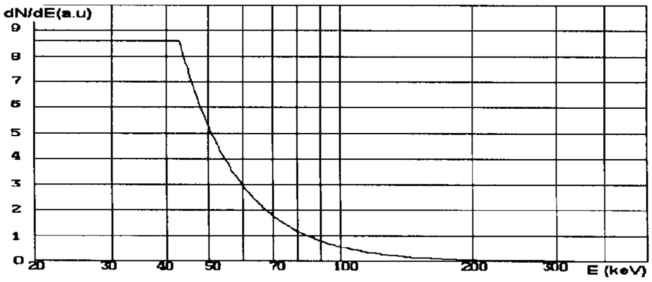

Fig. 2. Hard X-ray spectrum from the DPF.

from REBs, to hard X-rays is very high. As an experiment demonstrates, by means of a DPF installation about 0.02–0.03% of the stored energy can be emitted as the hard X-ray radiation. Generally speaking, the installation energy storing is the only limitation of an achievable hard X-ray pulse power.

In fact, the high current REB generation in the plasma surroundings constitutes substantial distinction of a DPF from other known X-ray generators based on vacuum X-ray roentgen tubes. It is well known that the maximal accessible REB current value, to be transported through a vacuum environment, is limited by the Alfven-Lawson restriction. As an example, the value of the restricting threshold for electrons of energy 100 keV is ~10 kA. For this reason, the generation of a short hard X-ray radiation pulse, strong enough to X-ray any object, is impossible to be performed by means of a standard roentgen tube in a single mode operation.

A strong REB appears inside a DPF chamber at the moment when the total discharge current reaches its maximal value, as a result of the sharp current breakdown leading to the charged particles acceleration by a short-time electrical field of an extra-high value (up to 1 MeV). The oscillogram of voltage accompanied by a hard X-ray pulse, which has been registered at the PF-0.2 installation [1], is presented in Fig. 1. The picture presents the traces typical for a DPF device, but time characteristics of the discharge process and the duration of the radiation pulse depend on the energy store of the installation and the quality of the assembled parts. For example, the hard X-ray radiation pulse from the PF-0.2 installation is equal to $\tau \sim 4$ ns, while that from the PF-3 installation amounts to $\tau \sim 10$ ns. A typical hard X-ray spectrum from the DPF is presented in Fig. 2. Its principal distinction, in comparison with the X-ray tube radiation spectrum, is that it has a power-like character. At the same time, high-energy quanta (up to $E_\gamma \sim 1$ MeV) are always present in the DPF radiation spectrum, although in a small quantity. A DPF hard X-ray source size is ~100 mm in the case of a flat anode end surface.

Installation for the dynamic defect detection

The dynamic defect detection (DDD) is based on taking X-ray photographs (roentgenograms) of an object moving with a high speed or on making momentary roentgenographs of a fast non-stationary process. The space resolution of such type roentgenograms is determined by the radiation source size, the X-ray diffraction and also by the velocity of the moving object. Both, estimations and experiments show that for movement speeds, typical for the modern industry the space resolution has to amount to ~10 mm.

The DDD installation has been produced and tested at the P. N. Lebedev Institute on the basis of the PF-3 installation [1].

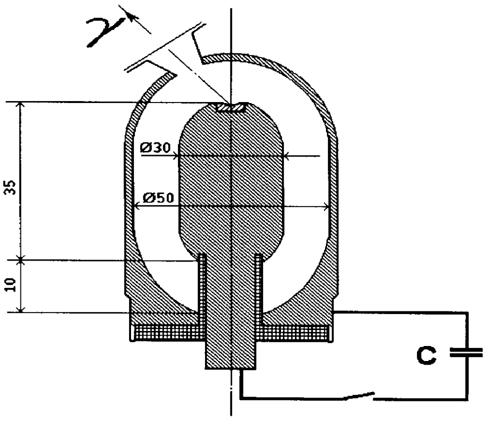

Fig. 3. DPF chamber for hard X-ray production.

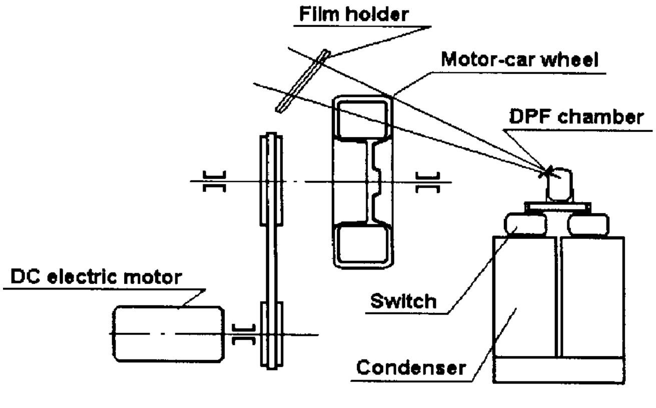

Fig. 4. Scheme of the DDD installation.

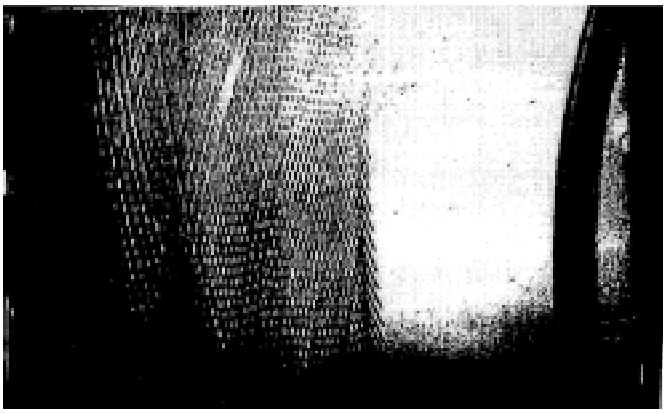

Fig. 5. Roentgenogram of a cord part of the rotating motor-car wheel.

The DPF chamber, designed especially for the hard X-ray pulse generation has been used in the DDD installation (Fig. 3). The device was able to emit 0.5–0.7 J of energy, within the spectral region of 20–500 keV, with the maximal radiation intensity of $E_\gamma \sim 30$–60 keV. A number of X-ray pictures of some resting objects have been taken. An X-ray film of the PM-1 type with the luminescent screen (pure space resolution conditions), and the PT-5 film without any screen (high space resolution conditions), were used to take the object images. The film-holder was located at a distance of 60–250 cm from the DPF chamber window, which was blocked by a copper foil of 90 μm in thickness.

By means of the described DDD installation, the demonstrative experiments have been undertaken [2]. The test-bench, showing an opportunity of roentgenography of the rotation of a motor-car wheel, has been assembled (Fig. 4). The speed of the wheel rotation was under control and it has the possibility to increase it up to 30 turns/s, which corresponds to the car velocity of about 200 km/h. An X-ray photo of the cord protector segment of the rotating motor-car wheel has been taken with a good resolution at the maximal wheel speed (as show in Fig. 5). It is important to note that parameters of the hard X-ray pulse make it possible to take a roentgen photo of an object, moving with a velocity, which can be more than an order of magnitude higher than the velocity achieved on the described test-bench. For example, with the X-ray detection it is possible to visualize rotating aircraft turbine blades, in order to detect a special class of micro-splits which can be seen only under the action of the centrifugal force, appearing during the high speed rotation. The mentioned above DPF hard X-ray spectrum is enriched by low energy quanta, which give the opportunity to record details of an object of a relatively low optical density. This feature is of great importance, when an object (to be X-rayed) is under elastic-tensed conditions.

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References

1. Dubrovsky AV, Gribkov VA (2000) Installations based on high efficiency high repetition rate miniature DPF chambers for material science. Nukleonika 45;3:159–162
2. Dubrowsky AV, Gribkov VA, Nikulin VYa, Silin PV (1998) A powerful pulse X-ray source for high-speed X-ray photography and other applications. In: ICHSPP'98 23rd International Congress on High-Speed Photography and Photonics, Moscow: 20–25