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Investigation of corpuscular emission from the Prague Capillary Pinch

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Abstract The paper presents results of preliminary measurements of the corpuscular radiation from fast z-pinch discharges, which were performed at the Prague Capillary Pinch facility within a frame of the Czech-Polish scientific collaboration programme. Time-integrated measurements were performed by means of a pinhole camera, equipped with nuclear track detectors of the CR-39 type. In order to perform time-resolved measurements the use was made of a single Faraday-type collector and a double-cup system. It was demonstrated that the fast capillary discharges can emit not only pulses of intense visible radiation and soft X-rays, but also pulses of the corpuscular radiation. An optical analysis of the particle tracks was performed. The particle flux at a distance of 20 cm from the collimator outlet was estimated to be 3.5×10^7 particles/cm^2.

Key words capillary pinch • corpuscular flux • track detectors • X-radiation

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Introduction

Capillary Z-pinch discharges are known as sources of intense X-ray pulses [4–6]. Such discharges can also emit some corpuscular radiation. The main aim of this work was to perform preliminary measurements of the corpuscular radiation from the Prague Capillary Pinch experiment [4]. The device consisted of an 8-stage Marx generator, a coupling section, a pulse forming line, the main spark gap, and a capillary made of alkaline polyamide. The capillary was 6 mm in diameter and 200 mm in length, and it was placed inside a metallic cylinder of 60 mm in diameter. The working gas (argon) was injected along the outer surface of the grounded electrode of the capillary. The details of the construction were described in the previous papers [3, 4].

Measuring set-up

For time-integrated measurements the use was made of a pinhole camera placed on the z-axis of the main discharge, at a distance of 20 cm from the outlet collimator of the capillary tube. A scheme of the measuring set-up is shown in Fig. 1.

The input diaphragm of the pinhole camera was exchangeable. During the described preliminary measurements it was 3 mm in diameter, and after those it was replaced by 0.2-mm pinhole. In order to register the particle radiation within the pinhole camera the use was made of nuclear track detectors of the CR-39 type. After the irradiation those detectors were etched under standard conditions (within a 6.25-N solution of NaOH, at a temperature of 70°C) for a period ranging from one hour to several hours. In order to perform time-resolved measurements there

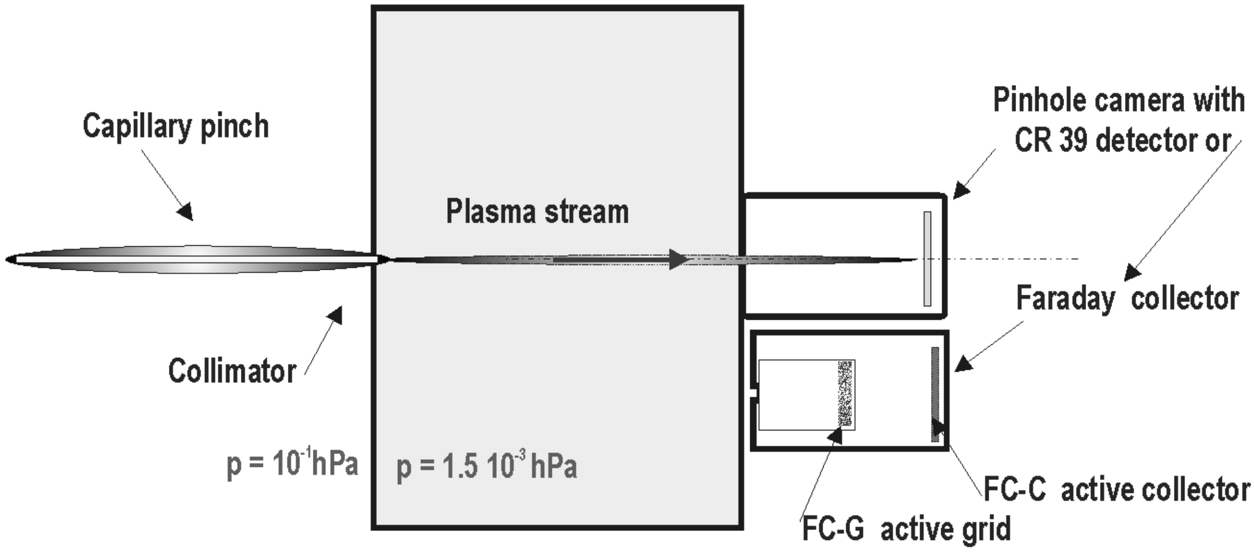

Fig. 1. Schematic drawing of the Prague Capillary Pinch system equipped with a pinhole camera and Faraday-type collectors, which were applied for measurements of the corpuscular emission.

were used Faraday-type collectors: a single cup (FC) and a so-called double-cup system (DFC), which used two ring-shaped collectors placed at a given distance (time-of-flight basis), but adjusted along the common z-axis [1].

Experimental results of time-resolved measurements

When the Faraday-type collectors were applied for time-resolved measurements of the corpuscular emission, there appeared some difficulties connected with an intense visible radiation. In fact, during the previous studies of the capillary discharges [4] particular attention was paid to the visible and X-ray emission. The optical spectra, which were registered with relatively long exposition times (about 30 ms), showed the emission of very intense H_α and H_β spectral lines. Intensity of those lines was several orders of magnitude higher than that of the argon-ion lines, although the working gas was pure argon. Also the emission time of those lines (equal to about 30 μs) was considerably longer than the main discharge period (about 1 μs).

During measurements carried out by means of the Faraday cups, the intense pulses of the ultraviolet radiation could interact with a surface of the entrance grids or collectors themselves and induce an intense photo-effect. In turn, that effect could cause some false signals. As a result, the obtained signals were caused by the photo-emission as well as and the ion- and electron-components. In the described experiments the Faraday detector was placed at a distance of 28 cm from the capillary outlet. Some examples of the registered traces of the main discharge current and the collector signals are shown in Fig. 2.

In Fig. 2 the upper waveforms represent the signals obtained when the negative polarisation of the entrance grid (FC-G) was -50 V, and that of the collector plate (FC-C) was -100 V. In that case the sensitivity of the oscilloscope channels was equal to 0.25 V/div. The lower traces in Fig. 2 represent the signals obtained when the positive polarisation was applied: for FC-G equal to +50 V, and for FC-C equal to +100 V, respectively. In the considered case the oscilloscope sensitivity was 0.20 V/div. From traces presented in Fig. 2 one can easily see that, at the negative polarisation of the grid and collector, the registered signals had three distinct peaks, which corresponded to subsequent peaks of the main discharge current.

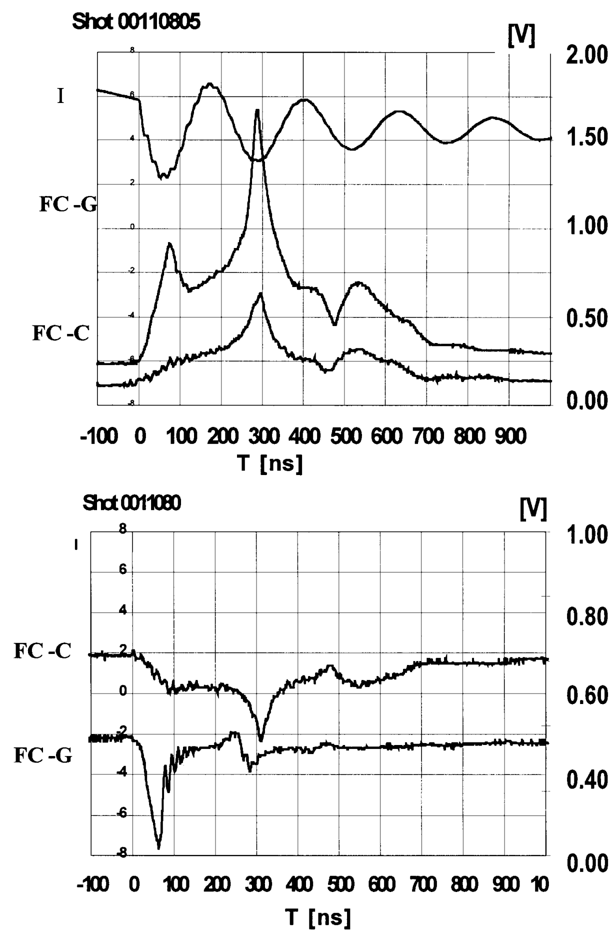

Fig. 2. Typical waveforms of the main discharge current and signals from the Faraday-type collectors, which were obtained at the negative polarization of the entrance grid and the collector plate (the upper diagram), in comparison with the signals obtained at the positive polarization (the lower diagram). Notations: FC-G – a signal from the grid, FC-C – a signal from the collector.

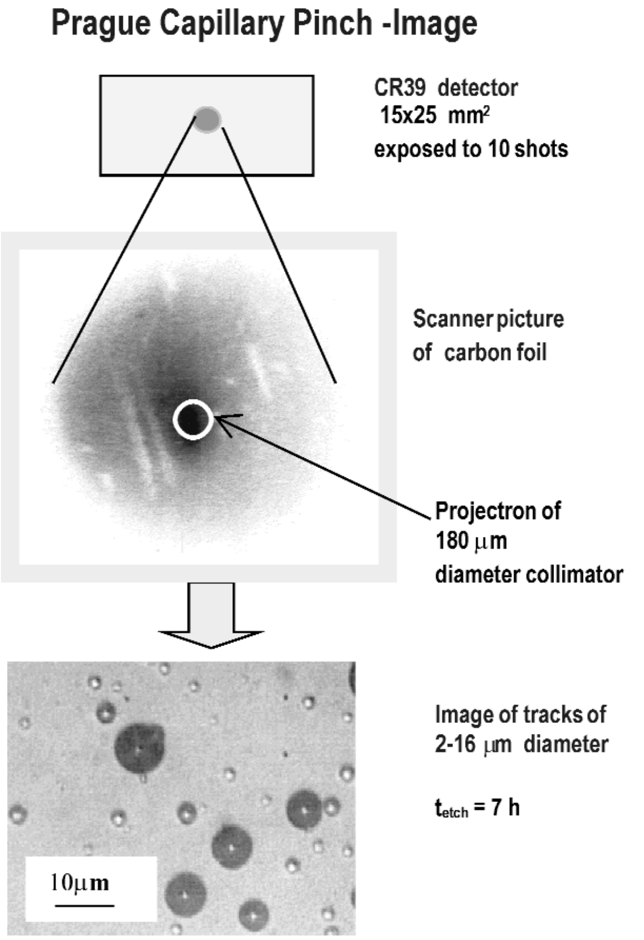

Fig. 3. Images obtained by means of a solid-state nuclear track detector of the CR-39 type, which was irradiated during 10 successive shots. The upper picture shows the whole detector surface after its irradiation, the middle picture – a scanner image of the detector surface with a thin carbon layer, and the bottom picture – an enlarged image of the central part of the detector after 7-hour etching.

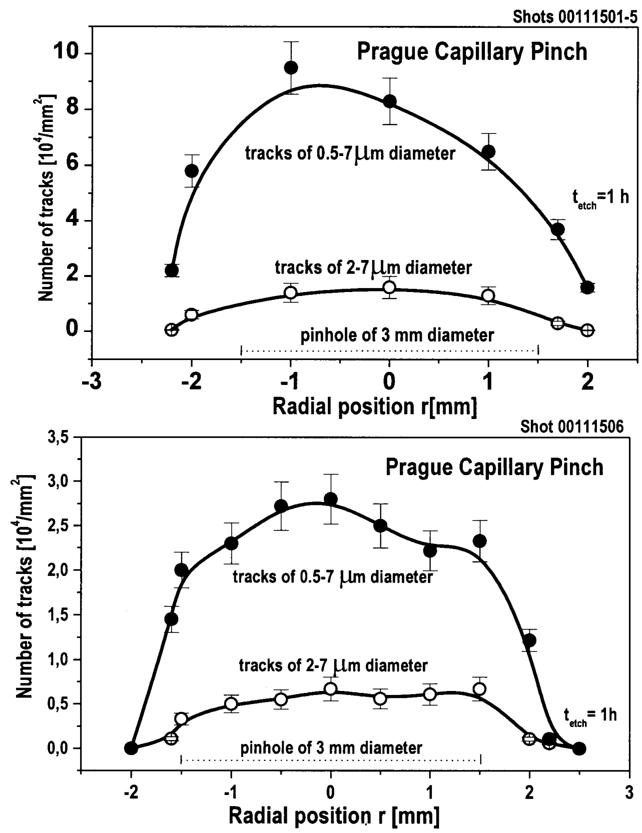

Fig. 4. Distribution of tracks as a function of the radial distance, as registered behind a diaphragm of 3 mm in diameter by means of the detector irradiated during 5 successive shots (the upper diagram), and by means of that irradiated during a single shot (the lower diagram). In both cases the detectors were etched for 1 hour.

Although in addition to the single FC there was also applied the double Faraday collector set-up (with a long measuring basis), during the described experiments it was impossible to separate signal components induced by different corpuscular radiation (ions and electrons) from that induced by UV and X-rays. When the entrance grid (FC-G) and collector plate (FC-C) were highly positive (the lower oscillogram in Fig. 2) the registered signals were evidently dominated by the electron component. It should also be noted that in that case the maximum of the FC-G signal corresponded to the peak of the soft X-ray emission, which was registered by means of an additional PIN diode [3]. Hence, one can conclude that the pulsed X-ray emission was connected with intense electron beams.

Experimental results of time-integrated measurements

The time-integrated measurements of the corpuscular emission were performed along the z-axis. Some exemplary images, which were registered upon the irradiated nuclear track detectors, are shown in Fig. 3.

The distinct blackening, visible on the picture of the irradiated CR-39 detector, was caused by the fact that during the exposition the detector surface was partially covered with a thin carbon foil. That foil could easily be separated during the etching process, and carbon could be identified by a chemical analysis. It possibly originated from the dissociation of oil vapours coming from the vacuum pump stand. It should be noted that the central (most intensively exposed) part of the irradiated and etched CR-39 detector was about 180 μm in diameter. It corresponded to the diameter of the collimator placed at the capillary outlet.

The bottom picture in Fig. 3 represents a part of the irradiated CR-39 detector etched for 7 hours and analysed with an optical microscope, which was operated at a large (1200×) magnification. In this picture, one can easily discern two types of the particle tracks: small (brighter) micro-craters of 2–5 μm in diameter, and larger (darker) ones of 5–15 μm in diameter. During the analysis of these micro-craters, one should take into consideration that in the experiment described the integral visible radiation (dominated by the H_α and H_β spectral lines) was very intense [3]. Such pulse radiation could ionize the working gas and admixtures (impurities). Hence, one might suspect that the small micro-craters could be produced by hydrogen ions, and the larger (darker) ones could be generated by heavier ions of argon, carbon, and oxygen. Diagrams, representing radial distributions of the registered tracks, which were obtained from 5 successive shots and from a single shot, are shown in Fig. 4.

Since in both the cases the pinhole camera was placed in the same position (i.e. 20 cm from the capillary outlet), and the etching times of the irradiated detectors were identical (1 hour), the registered tracks could easily be compared. For a single shot the obtained track distribution has had some peak structure, which suggests that a source of the corpuscular emission had relatively small dimensions. It should, however, be noted that the capillary collimator outlet was also small (0.5 mm in diameter). The results, as obtained for 5 integrated shots, have demonstrated a smoother track-distribution, which could be explained as a result of a stochastic jitter in the corpuscular emission (from shot to shot) and a statistical smoothing. It should also be noted that the track densities, as registered for one and five shots, were evidently different. It was possibly caused by the absorption of some particles (ions) by the carbon foil (described above), which was deposited during the successive shots. Nevertheless, the obtained results (presented in Fig. 4) suggest that the registered tracks were produced by the ions coming from the collimator region, and not by those originating from the region situated between the capillary outlet and the detecting system.

Conclusions

The most important results of the studies described can be summarized as follows:

1. The preliminary corpuscular measurements described above have demonstrated that the Prague Capillary Pinch device can emit not only pulses of the soft X-rays, but also pulses of the corpuscular radiation.
2. Taking into account the lower energy threshold of the CR-39 nuclear-track detector [2], one can conclude that energy of the registered ions was higher than 80 keV. A flux density of the investigated radiation at a distance of 20 cm from the collimator outlet was estimated to be about 3.5×10^7 particles/cm^2.
3. In order to discern different ion species, it is necessary to perform more detailed measurements, e.g. by means of a Thomson-type mass-spectrometer [2] calibrated for the required mass- and energy-range.

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