Cherenkov Detector For Measurements Of Fast Electrons In CASTOR-Tokamak

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Abstract. The paper reports on capabilities of an improved version of the Cherenkov detector designed for measurements of fast electrons. The described technique enables the identification of electron beams, the measurements of their temporal characteristics, as well as the estimation of their spatial properties to be performed. Results obtained in the last experimental campaign with the CASTOR facility show good measuring capabilities of such a detection system. The radial distributions of fast-electron streams at different plasma densities, as well as the electron fluency dependences on discharge currents and toroidal magnetic fields are also presented.

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INTRODUCTION

Investigations of fast electron beams within experimental facilities generating high-temperature plasma are of importance not only for basic studies, but also for a verification of theoretical models which describe complicated motions and a transport of charged particles. To study the fast electrons generated inside tokamak-type devices, the SINS team proposed and developed a novel diagnostic technique based on the Cherenkov effect [1-3]. The aim of this paper is to describe measuring capabilities of an improved version of the Cherenkov detector system and to present results of measurements of the radial distribution of fast electron beams within the CASTOR at different values of the plasma density, discharge current and magnetic field.

EXPERIMENTAL SET-UP AND DIAGNOSTIC METHODS

Experimental studies of the generated electron beams have been performed within the CASTOR facility (major radius - 40 cm, limiter radius - 8.5 cm, minor chamber radius - 10 cm). Experimental data were collected from about 500 shots performed with the ohmic heating (so-called OH mode). Each discharge lasted about 25-27 ms, the discharge current varied from 5 kA to 15 kA, and the toroidal magnetic field (B_T) ranged from 0.8 T to 1.4 T. The described measurements were carried out at a relatively low plasma density (amounting to 0.5-1.5 x 10^{19} m^{-3}), but at a high accelerating voltage (V_{LOOP} reaching value from 2.0 V to 4.0 V per loop) [4].

The detection head contained a Cherenkov-type radiator made of an aluminium nitride (AlN) crystal, which was coated with a 10-μm Ti-layer used as the detector protection from the visible light. The AlN crystal radiator was chosen due to its relatively low energy threshold (about 50 keV), a moderate price and relatively good thermal conductivity. That radiator with the Ti-coating enabled electrons of energy higher than 80 keV to be recorded. The detector was equipped with an inlet opening window of the 5 mm in diameter, which was oriented at an angle of 45^0 in relation to the chamber axis. The view and the scheme of the primary version of the measuring head were presented in [3]. The only difference for the improved version of the experimental set-up was the elimination of coupling quartz rods in the measuring head, and the photomultiplier placement far (about 8 m) from the tokamak chamber. The radiator and light-pipe was optically coupled by means of a metal tube with polished inner walls. The described improved Cherenkov measuring head was connected with a fast photomultiplier of the HP2020-type through an optical cable of 10 m in length. The photomultiplier, recording Cherenkov signals, was placed inside a lead shielding (pill-box) with walls of about 15 cm in thickness.

The Cherenkov head enabled the measurements in different positions along the CASTOR minor radius to be performed. In the most outer position, the detector was well hidden inside the diagnostic port, then it could be moved to the shadow of the limiter, and finally after a deeper insertion, it could reach a plasma region. The simplified scheme of the experimental set-up is shown in Fig.1.

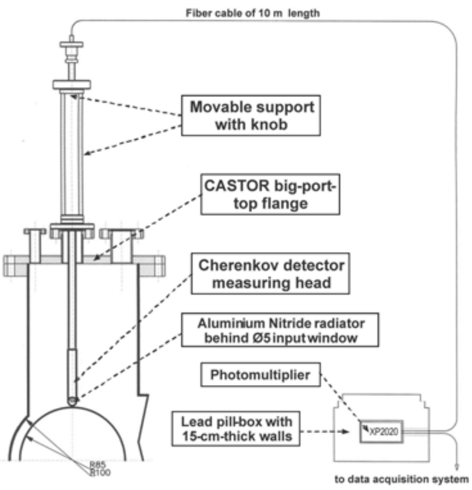

FIGURE 1. The simplified scheme of the experimental arrangement within CASTOR tokamak (R85 - limiter radius, R100 - minor chamber radius).

In order to estimate correlations between Cherenkov signals, hard X-rays signals (HXR_{tot}), which originated from the CASTOR tokamak chamber (routine diagnostics) and HXR_{loc} signals from a narrow solid angle near the Cherenkov measuring head - we also performed measurements of the hard X-rays of energy from 20 keV to 200 keV at a close vicinity of the detector. Those results were partially commented in [5].

EXPERIMENTAL RESULTS

The fast electron beams inside the CASTOR vacuum chamber were recorded by means of the Cherenkov detector described above. The distribution of the fast electron fluency was measured near the tokamak scrape-off-layer (SOL) as a function of the minor radius (r), changing a position of the Cherenkov radiator within the region close to the limiter. The results, which were obtained at the discharge current equal to about 10.5 kA, and two different values of the plasma density, are shown in Fig. 2.

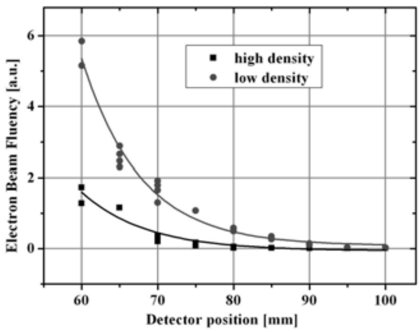

FIGURE 2. Dependence of the electron fluency on the position of the Cherenkov detector measuring head along the CASTOR minor radius, as recorded for the different values of the electron density $n_e \sim 6.5 \times 10^{18}\ m^{-3}$ (circle) and $1.2 \times 10^{19}\ m^{-3}$ (square).

The presented diagram shows the time-integrated values of the recorded electron signals proportional to the fast electron streams, which reached the Cherenkov radiator during the investigated discharges. We assumed that Cherenkov radiation signals follow the electron beams flux intensity signals for electron energy range from 80 keV to several hundreds keV. The measurements were performed as a function of the detector position along the minor radius from R = 60 mm (below the limiter located at r = 85 mm) up to r = 100 mm (near the chamber wall). Such measurements were not carried out for r < 60 mm because the detector might be destroyed.

The experimental data, obtained for plasma of a relatively low-density, show that in this case the fast electron flux rises up strongly for the deeper insertion of the detector into a plasma region (r < 80 mm). For plasma of a higher density (above $10^{19}\ m^{-3}$) the electron flux is considerably lower, in particular for r = 60-80 mm.

Some examples of the time-resolved Cherenkov signals, which were recorded in

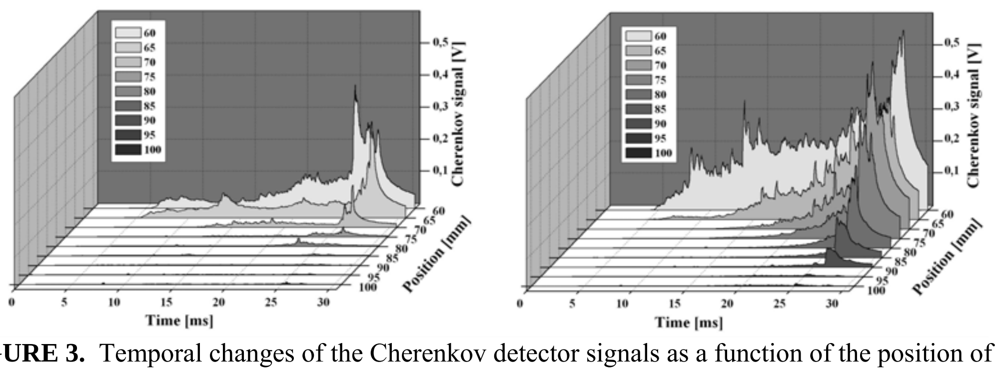

FIGURE 3. Temporal changes of the Cherenkov detector signals as a function of the position of the measuring head along the CASTOR minor radius, as observed for high-density discharges (on the left) and low-density discharges (on the right).

CASTOR discharges with high- and low-density plasma, are presented in Fig. 3. With an increase in the distance from that axis the electron signals decreased and they appeared later. Deeper in a plasma, at positions r = 60 mm, the electron signals appeared 5 ms after the discharge beginning, and they lasted almost until its end. At the instant t = 25 ms there was observed a strong increase in the signal intensity, which might be explained as a result of the destruction of the toroidal plasma column. The amplitude of this electron peak decreased with an increase of the distance from the plasma center.

It should be noted that for high-density CASTOR discharges the plasma column was confined within the region of the minor radius smaller than that given by the limiter (placed at r = 85 mm). In such cases the dense plasma column kept fast electrons close to the plasma core. With an increase in the plasma electron density (n_e) one could observe a fast decrease in the integrated electron flux intensity [5].

It should also be noted that the electron beam signal depended considerably on the plasma current. That dependence, which was obtained from the detector placed at the position r = 70 mm, at the magnetic field B_T = 1.32 T, is presented in Fig. 4. One can observe that the electron beam fluency increased almost linearly with an increase in the discharge current, in spite of a big jitter of the experimental points, which might be explained by some differences in plasma densities in successive discharges.

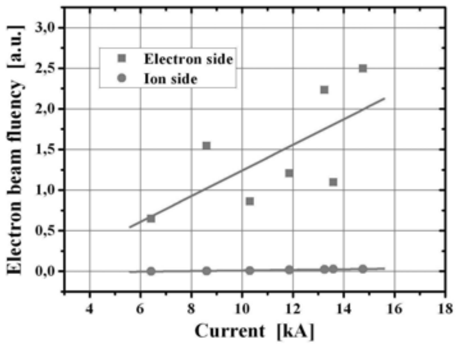

FIGURE 4. Dependence of the electron fluency on the CASTOR discharge current, as measured by means of the Cherenkov detector oriented in the electron- or ion-detection direction.

During an analysis of the experimental results particular attention was paid to the observation performed when the Cherenkov detector head was turned around its axis by 180^0, i.e. when the inlet opening was oriented in the so-called ion side (see Fig. 4). In that case the recorded signals were very low (practically negligible). It proved that the photomultiplier was well protected against hard X-rays, the fiber cable was insensitive to electromagnetic interferences, and secondary X-rays (e.g. Bremsstrahlung from the measuring head shielding) did not influence on Cherenkov radiator significantly.

A distinct influence of the toroidal magnetic field on particle confinement and consequently on the plasma density in CASTOR was observed. From data shown in Fig.5 one can deduce that the fast electron generation is influenced by changes of the toroidal magnetic field differently in the confined plasma region (r < 70 mm), in the region with a long connection length to the limiter (70 mm < r < 85 mm) and in the limiter shadow (r > 85 mm). A deeper analysis of the combined radial and magnetic field dependencies might indicate a possible connection of those effects with plasma profile changes at different toroidal magnetic fields.

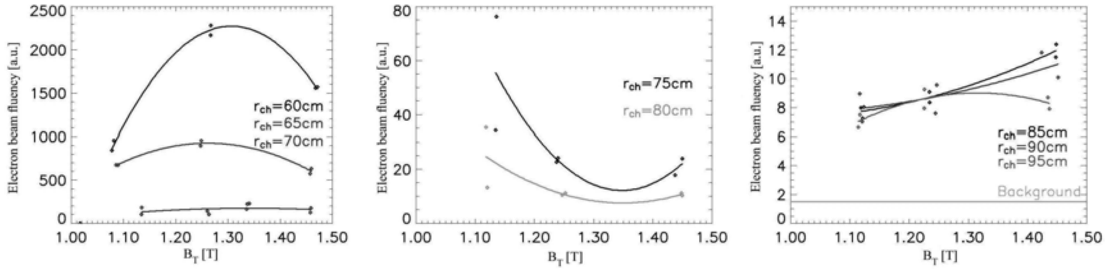

FIGURE 5. Combined dependence of the integrated Cherenkov signals (electron beams fluency) on the toroidal magnetic field B_T and the detector position r_{ch}.

SUMMARY

The modifications of the Cherenkov detection system enabled different electromagnetic interferences to be reduced significantly. Especially the direct hard X-ray radiation influence on the photomultiplier photocathode and dynodes was diminished to a very low level by means of a photomultiplier lead pill-box and its location far from the tokamak chamber. It was confirmed that the recorded Cherenkov signals were induced just by fast electrons (> 80 keV). Within the CASTOR tokamak, the dependences of the fast electron signals on the radial position of the Cherenkov detector, as well as on the plasma density, plasma current and toroidal magnetic field value, were investigated and commented. It can be concluded that appropriate Cherenkov detectors might be applied for investigation of fast electrons in other tokamak-type facilities.

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