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NEW DIAGNOSTIC EQUIPMENT FOR TIME-RESOLVED STUDIES OF IONS FROM STELLARATOR- AND TOKAMAK-MACHINES

M. Sadowski and A. Szydlowski
The Andrzej Soltan Institute for Nuclear Studies, 05-400 Swierk by Warsaw, Poland
e-mail: msadowski@ipj.gov.pl

The paper reports on the new equipment designed for time-resolved measurements of protons, deuterons, and heavier ions, escaping from toroidal magnetic traps. The equipment makes use of solid-state nuclear track detectors (SSNTDs), which can also be used for the registration of fusion neutrons through recoil protons, produced in an additional converter plate or in the detectors themselves. To take time-resolved ion-pictures, there is applied a rotating drum with SSNTDs placed within an auxiliary vacuum chamber. To eliminate thermal shocks a special cooling system has been designed. Laboratory tests have been performed to determine admissible temperature limits for the CR-39 and PM-355 detectors.

1. Introduction

Advantages of the SSNTDs have been known for many years [1-2]. Such detectors are characterized by very high (almost 100%) efficiency of the registration of different ions (from fast protons to heavy ion species), provided that their energy is higher than a lower threshold value (different for various ions and detectors). For protons in the CN-type detectors this threshold is about 40 keV, and in the modern CR-39 or PM-355 plastics it amounts to about 80 keV. For deuterons and heavier ions threshold values can be found in literature, e.g. [3-4]. The second advantage of the SSNTDs is that such detectors can register relatively intense ion fluxes without saturation effects up to 10^5-10^7 ions/cm^2, depending on ion mass and energy. Dependence of track diameters on mass and energy of the detected ions have been investigated for different SSNTDs and various etching conditions, i.e. for different temperatures and etching times [5-6]. Another important advantage is that the SSNTDs are insensitive to electromagnetic radiation pulses and electron fluxes up to very high doses. Due to these advantages, the SSNTDs have been used for time-integrating measurements of ion fluxes emitted from many Plasma-Focus (PF) facilities [7-8].

The SSNTDs have not been applied widely in Stellarators and Tokamaks, because such detectors have time-integrating character. They also require a long etching procedure lasting up to several hours, and a time-consumable optical analysis of the registered tracks. Taking into consideration the advantages of the SSNTDs and the fact that high-temperature plasma can be confined within Stellarators or Tokamaks for a long time (seconds), the authors of this paper proposed to perform time-resolved ion measurements by exposing different SSNTDs samples during short periods, e.g., dozen milliseconds or so. The main aim of this paper is to describe the new equipment, which was designed especially to expose several SSNTDs samples under controlled temporal- and thermal-conditions, during a single plasma discharge within a Stellarator or Tokamak.

2. Apparatus

To investigate fast protons or deuterons from Stellarator or Tokamak, the SSNTDs have to be placed outside the main experimental chamber, but under good vacuum. Such detectors can of course be used also for measurements of alphas or heavier impurity ions, but in such a case the SSNTDs should be located closer to the plasma surface. On contrary, if the equipment is to be used for the registration of fast fusion-produced neutrons (through the detection of recoil protons) the SSNTDs may be situated at a larger distance from the plasma surface. To improve their detection efficiency, they can be equipped with appropriate converters in a form of plates made of a hydrogen-reach material, e.g. polyethylene. The diagnostic equipment must also fulfil other requirements resulting from geometric, magnetic, and thermal limitations. To make use of a standard diagnostic port of the Stellarator or Tokamak facility, a diagnostic channel should be equipped with a appropriate vacuum valve. To limit the observation field one can apply a special collimator. For fast ions one can use a diaphragm made of metal of several millimeters in thickness, but for fast fusion neutrons it is necessary to apply collimators analogous to those used in nuclear physics.

In order to expose the SSNTDs samples at different phases of a plasma discharge, these detectors can be fixed upon a rotating support, which should be placed in an additional vacuum chamber. Such a support can be manufactured in a form of a rotating drum with an axis perpendicular to the diagnostic port, which is used as a viewing channel. The drum can be rotated by an external drive, e.g. electric stop-motor, provided that the driving shaft is led through appropriate vacuum seals. A simplified scheme of the proposed equipment has been presented in Fig.1.

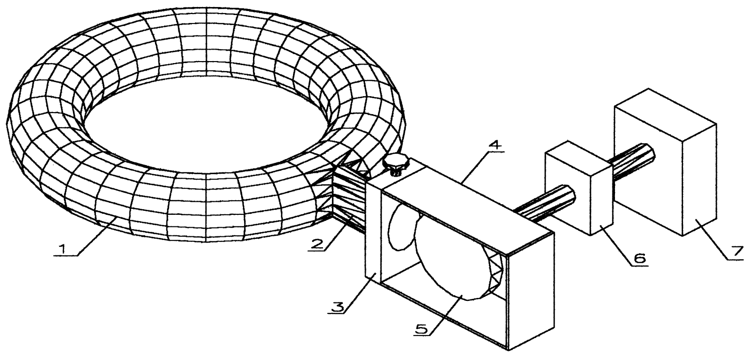

Fig.1. Block diagram of the equipment designed for time-resolved measurements of the ion or neutron emission from a Stellarator or Tokamak device. Notations: 1 – Experimental vacuum chamber, 2 – Diagnostic port, 3 – Vacuum valve, 4 – Auxiliary vacuum chamber, 5 – Rotating drum with SSNTDs, 6 – Electrical drive, 7 – Cooling system. The scheme is not to scale.

All mechanical parts and vacuum seals must be made of materials stable to heat during conditioning processes which are performed within the main experimental chamber. In order to reduce the overheating of the equipment one can apply a rotating drum equipped with a special cooling system, as shown in Fig.2.

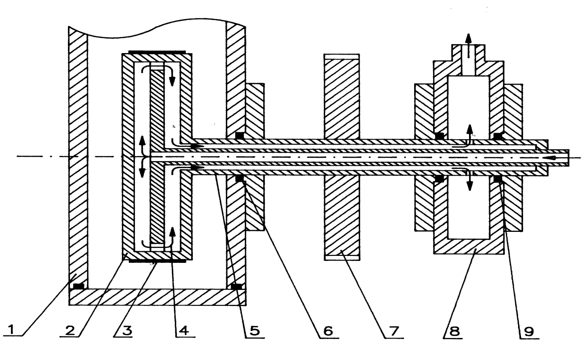

Fig.2. Schematic of the rotating drum with a cooling system. Notations: 1 – Vacuum chamer, 2 – Rotating drum, 3 – SSNTDs, 4 – Cooling flow, 5 – Driving shaft, 6 - Vacuum seal, 7 – Driven gear, 8 – Cooling block, 9 – Sliding contact packing.

The cooling system requires a sophisticated manufacturing, but it reduces a thermal hazard for the vacuum seals and the applied SSNTDs. This is of importance if the SSNTDs are installed inside the equipment before the conditioning of the main vacuum chamber.

3. Preliminary test of SSNTDs within TEXTOR facility

Responses of the modern SSNTDs (e.g. CR-39, PM-355, and PM-600 plastics) to protons, deuterons, and helium ions, have been investigated in many laboratories, and particularly at IPJ in Swierk, Poland [3-4, 8-10]. The application of such detectors within toroidal facilities may induce some special problems, which should be investigated experimentally. To test usability of the CR-39 and PM-355 plastics within the TEXTOR, several samples of such detectors were prepared for a Belgian team operating in Juelich. That team performed computations of ion trajectories within the TEXTOR chamber, and in particular it computed trajectories of 3.1-MeV protons, 14.6-MeV protons, and 0.8-MeV He^3 ions, which can reach a plasma boundary surface. At the same time there was designed and manufactured a special holder [11], which might be inserted into TEXTOR through a chosen diagnostic port, in order to reach the plasma surface. That holder was shielded and equipped with an input collimator and an additional cooling system. The collimator constituted a 5-mm-thick metal plate with 0.5-mm-diameter holes. It was oriented in such a way that only protons moving tangentially to the plasma surface could penetrate through the collimator and reach the detector [11]. An investigated detector sample was fixed inside the holder shielding and placed at a determined radial position within the TEXTOR chamber. After a test discharge the holder was taken out and the detector sample was replaced. During those studies the total neutron yield from TEXTOR varied from 3.1×10^{14} to 3.4×10^{15}, and the fusion neutrons produced a background ranging from 6.3×10^4 to 2.7×10^5 tracks/cm^2 on the detector surface.

The detector samples, irradiated with fast protons, were etched under the standard conditions [3, 9], and after that they were analyzed with an optical microscope equipped with a CCD camera coupled with a TV monitor. The analysis revealed some regions of the detector surface with distinct concentrations of ion tracks (micro-craters), as shown in Fig.3.

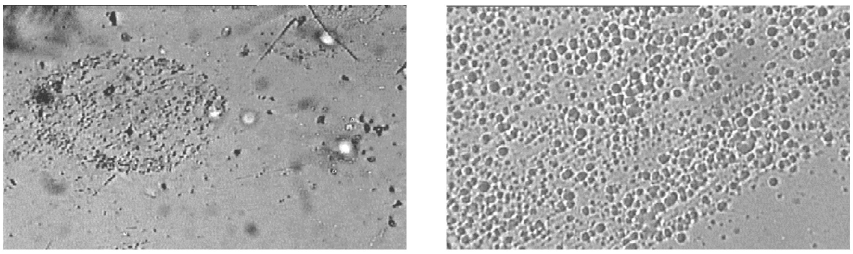

Fig.3. Proton track images observed with a small (x20) magnification (on the left) and those observed with a large (x1200) magnification (on the right). An elliptic shape of the field with tracks results from experiment geometry. The right picture shows a proton stream boundary.

The fast protons produced above 10^6 tracks/cm^2, and the total numbers of fusion protons, as determined by the integrating of those registered with the CR-39 detectors, were close to those obtained from other measurements performed with a semiconductor detector.

4. Study of a heat resistance of SSNTDs

During plasma experiments the SSNTDs can be exposed to thermal shocks and they suffer a temperature rise even to few hundreds ^oC. Therefore, there was necessary to study a heat resistance of the chosen CR-39 and PM-355 plastics [9-10]. Samples of those detectors were irradiated with mono-energetic alphas of energy 0.5, 1.0, and 1.5 MeV. After that they were heated up within an oven at temperatures varied from 80 to 200 ^{o}C for 10 to 30 minutes. After the heating the samples were etched (under the standard conditions) and analyzed.

From the performed tests it was found that in the samples heated up to 110 ^{o}C, even for 30 minutes, the etched tracks were unaltered (in a comparison with the reference ones). The tracks remained unaffected even if the samples are heated for 10 minutes at 150 ^{o}C. When the samples were heated at 150 ^{o}C for 30 minutes the tracks did not appear. In the samples heated at 200 ^{o}C for 10 minutes, there were found no tracks at all. It means that in experimental facilities, in which the detection system can be heated above 150 ^{o}C, it is necessary to use a cooling system, e.g. that described above.

5. Summary and conclusions

The main results of this study can be summarized as follows:

- The new diagnostic equipment with SSNTDs has been elaborated for the time-resolved measurements of fast ions and neutrons, emitted from Stellarators or Tokamaks.
- Preliminary tests of the CR-39 and PM-355 plastics demonstrated usability of theses SSNTDs for fast proton and neutron measurements in the TEXTOR facilty.
- Experimental study of the heat resistance of the chosen SSNTDs showed that these detectors could be used at temperatures below 150 ^{o}C. Above this temperature one must apply an appropriate cooling system.

The described measuring technique can be improved by the use of a chopper system (instead of the collimator). In such a case the exposition time of the whole detector surface could be identical. The time-consuming analysis of the registered tracks can also be facilitated by an automatic scanning system consisting of an optical microscope, a CCD camera, a PC unit with a frame-grabber module, and appropriate software (e.g. Image-Pro Plus).

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