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DESIGN AND TEST OF A TIME-OF-FLIGHT ANALYZER

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Abstract

A diagnostic technique for the measurement of the energy of fast charge-exchange atoms from magnetically confined plasma is presented. The constructive details and its preliminary test on the stand of the time-of-flight analyzer (TOFAN) are described. The analyzer is proposed for the determination of the ion temperature on the CASTOR tokamak and for the ions energy specturm resolution at the scrape-off layer of the T-15 tokamak.

INTRODUCTION

The energy analysis of fast charge exchange atoms from plasma represents a widespread method for determination of the distribition function of plasma ions in tokamaks /1/. However, a commonly used method (i.e. a conversion of the neutral flux to the ion one in a stripping cell and subsequent energy analysis of the ions /2/) is generally suitable for energies of atoms greater than 1 keV. In the lower energy range, the sensitivity of the standard analyzers rapidly drops with energy and moreover, a large uncertainity in absolute calibration appears, espectially below 100 eV. Therefore, such analyzers are less suitable for small devices with the central ion temperature in the range of hundreds electronvolts, where a direct time-of-flight analysis of neutral fluxes in the energy range from 20 to 1000 eV seems to be more convenient.

Basic idea is rather straitforward: a neutral flux from plasma is at first mechanically chopped to short bunches and after a sufficiently long flight path through a drift tube is registered by a secondary-emission-type detector. The form of the detector output signal can be simply linked to the energy spectrum of neutrals. The shutter opening time (microseconds) should be sufficiently shorter than the flight time of the particles through the drift tube (tens of microseconds) to get reasonable energy resolution of the analyzer.

The described time-of-flight analyzer (TOFAN) is proposed for determination of the central ion temperature on the CASTOR tokamak /3/ and for the monitoring of energy resolved particle fluxes from the plasma edge in T-15 tokamak. The similar analyzers have already been installed on PLT /4/, ASDEX /5/ and TORTUR /6/ tokamaks for the same reasons.

We report here some construction details of the TOFAN (described also in /7/) and its preliminary test on the stand by an auxiliary ion gun.

CONSTRUCTION DETAILS OF TOFAN

The two basic parts of the time-of-flight analyzer, i.e. the chopper system and detector, are seen in Fig. 1, showing an experimental arrangement for preliminary test as well.

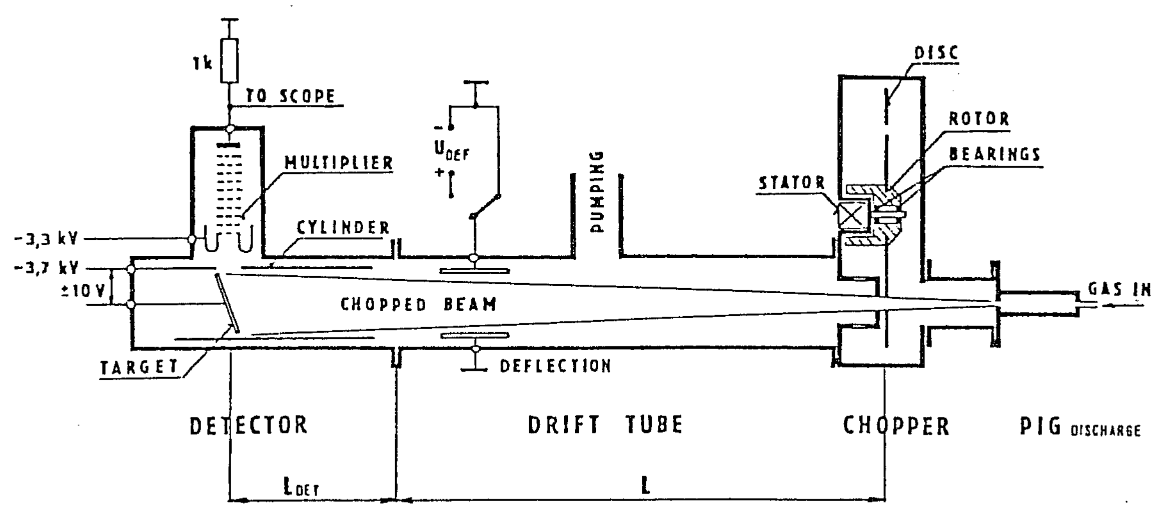

Fig. 1 Schematic arrangement for the test of the TOFAN by a particle beam. The ion gun is shown in Fig. 5 in more details, L = 1 m; L_{DET} = 0.36 m.

+ CHOPPER SYSTEM +

The energetic particles from an ion source (or tokamak plasma) pass at first to a rotating chopper disc. The chopper (the stainless steel disc of thickness 0.3 mm) has 60 equally spaced slits of 22 mm length and 0.4 mm width, mechanically cutted at a 80 mm radius. The chopper disc is driven by an asynchronous motor of a gyroscope, modified for operation under high vacuum conditions. Its short-circuited rotor turns inside the vacuum chamber on the two standard bearings, coated by a molybdenum power before installation. The stator winding is at the atmospheric pressure, separated from the rotating part by a thin (0.3 mm) stainless steel wall. The stator winding is supplied by a three phase generator, which frequency can be controlled in the range of 300 - 400 Hz. There is another slit 0.25x20 mm directly behind the disc, which acts as a vacuum break between the source of analyzed particles and drift tube. Moreover, the width of the fixed slit defines the form of the instrumental (shutter) function of the copper system. The vacuum chamber of the chopper system can be differentially pumped, if necessary.

Such arrangement, however, doesn´t allow a continuous operation of the motor due to the overheating of the stator winding. Therefore, a cyclic operating scenario is proposed for operation under tokamak discharge conditions, see Fig. 2. The chopper disc can reach the operation speed (20 000 rpm) in about 3 min. The temperature of the stator winding starts to increase at that time up to 60 ^{o} due to the power losses in the stator winding. After a tokamak shot, the power supply is switched off and the speed of the disc starts to decrease with the rate of about 1000 rpm

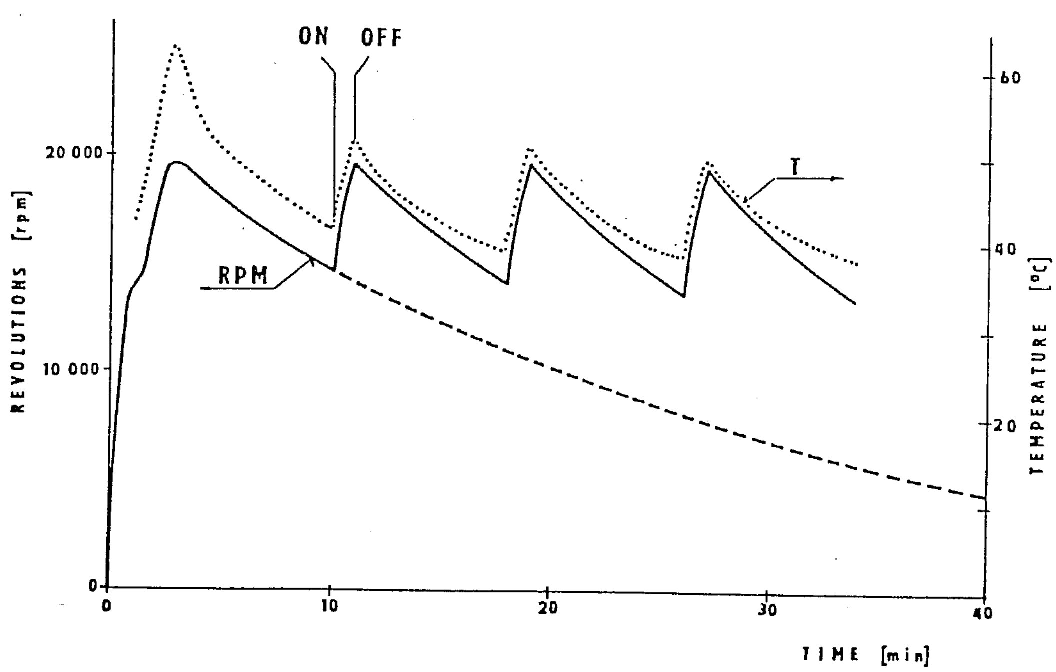

Fig. 2 The cyclic scenario of the chopper system operation

per minute. Under high vacuum conditions, the rate of decrease of rotations is determined namely by the quality of bearings and it can be used as a measure to controll them. However, another switching on of the power supply leads to a rapid increase of the speed of rotations. In principle, the time interval between the subsequent power on regimes can be shortened by an air cooling of the stator windings.

+ DETECTOR+

The particle detector arrangement is similar to that used in /4/. The particle flux impacts an aluminium disc. approx. 90 mm o.d., emitting secondary electrons (or may be negative ions /5/, which are accelerated through an extraction hole in the shielding cylinder up to energy 400 eV. The secondary particles are registered by an off-axis electron multiplier. The local electric field shaping near the target surface, which is necessary for an efficient collection of secondary particles is reached by titling of the Al-target (15 ^{o} with respect to the axis of the multiplier) and by possibility to apply a low voltage between the target and shielding cylinder. The typical potentials of the various detector elements are indicated in Fig. 1.

Preliminary test of the TOFAN

The TOFAN assembly was tested by the ion beam from PIG-discharge /8/. The ion beam with an energy E travels at first through the chopper system, see Fig. 1. Than after the flight path L, the ions are accelerated by the potential of the detector cylinder eU + E and hit the target.

The typical mass-composition of the ion beam, using the air as a working gas, is presented in Fig. 3. Some characteristic mass-numbers of the PIG-discharge as H_1^+, OH^+, N_2^+, O_2^+, CO_2^+ can be simply identified. The similar mass spectrum is shown in Fig. 4 for another discharge conditions and hydrogen as the filling gas. Beside of OH^+ and N^+ ions, one can resolve three hydrogen components H_1^+, H_2^+, H_3^+.

However, thre are at least two peaks (at t = 3,5 and 16 us), which can not be simply identified. The flight times and amplitudes of this two peaks remain unchanged after application of the potential on the deflection plates (also shown in Fig. 1) and their position is independent on the extraction voltage of the

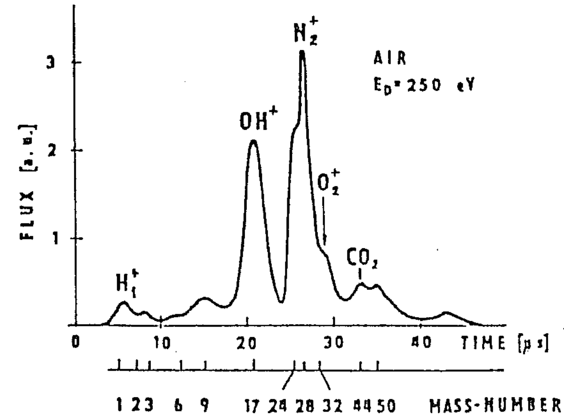

Fig. 3 The mass spectrum of the beam from PIG-discharge, using air as a working gas.

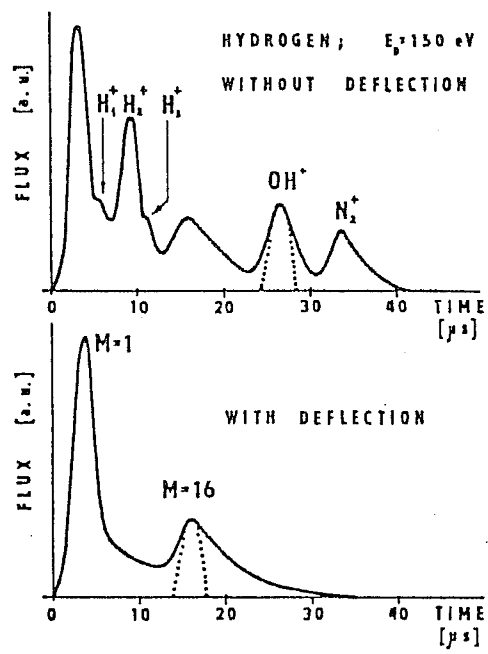

Fig. 4 The mass spectrum of the beam from PIG-discharge, using hydrogen as a working gas,
a) without the deflection voltage
b) the deflection voltage is applied.

ion source. Consequently, this peaks are identified as neutral particles created just inside the ion gun. Taking into account the total flight path $L_{det} + L$, the E/M ratio of the first peak gives for energy of neutrals an unreasonable high value with respect to the anode-cathode voltage of the ion source, when $M = 2$ is assumed. Therefore, the first peak is supposed to be the atomic hydrogen. Assuming now that the neutrals from the second peak have the same energy, we can estimate their mass-number in the range of $M = 16 - 20$. However, more precise identification of the neutral peaks needs the longer flight path.

Note that the width of an individual ion peak well corresponds to the form of the shutter function (shown by dotted line in Fig. 5), whereas the width of the neutral peaks is noticeably broader. It indicates that the ion component can be assumed as monoenergetic, while the neutrals should have substantially broader energy distribution.

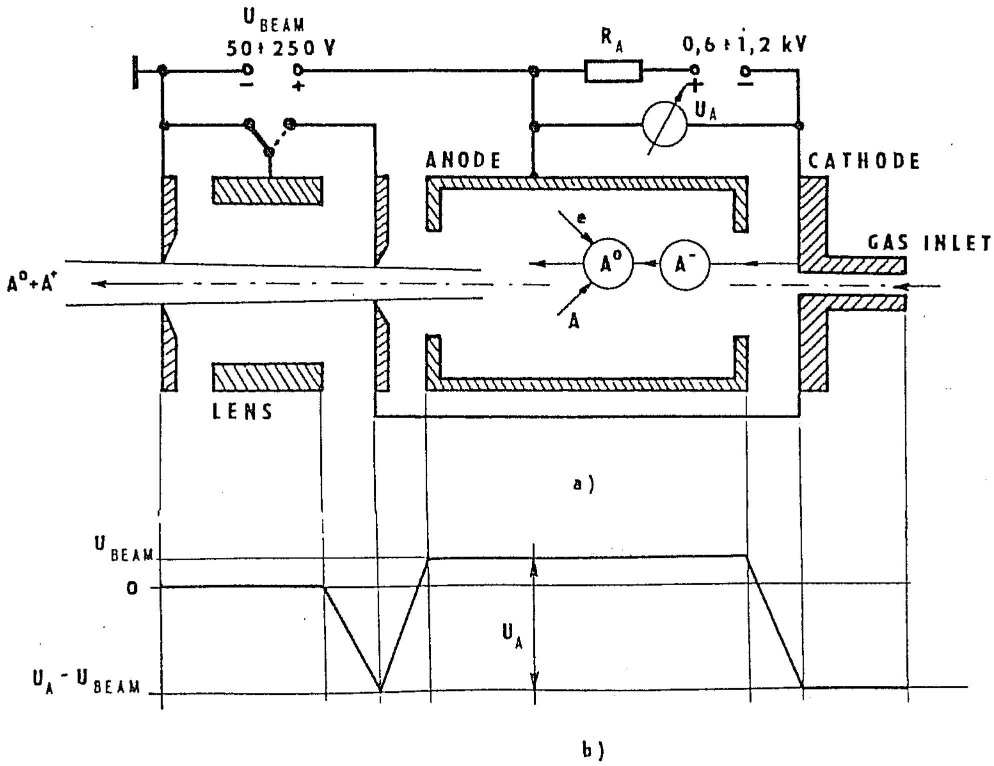

Fig. 5 a) Schematic arrangement of the PIG-discharge. Formation of the neutral beam with energy $e.U_A$ is indicated.
b) Distribution of the potential along the axis of the PIG-discharge (schematically).

The proposed mechanism of the fast neutral generation inside the PIG-discharge is schematically shown in Fig. 5. The positive ions from the anode plasma column strike the gas-covered cathode surface. Some secondary negative ions are produced and accelerated back towards the anode up to the energy eU_A. There, due to collisions they can loss the electron and travel through the extraction hole out from the discharge region as fast neutrals. Such mechanism requires for neutrals to be particles with an affinity to electron, i.e. they should exist as negative ions. Earlier /8/, we have identified the negative ions H_1^-, O_1^- and OH^- in the beam extracted from PIG-discharge, which were produced by this mechanism.

SUMMARY

The described preliminary test demonstrates that the developed time-of-flight analyzer works approprietly. From the construction point of view, the open question is still the life-time of the copper system bearings. Up to now, the bearings were in operation more than one hunderd hours without any noticeable drop of their quality. Such time interval is sufficient for managing of the preliminary measurements of energy resolved neutral flux from the CASTOR tokamak plasma, which are planned to start in the near future. However, before the instalation of TOFAN on the tokamak, the absolute calibration of the detector should be performed. Namely, the secondary emission coefficient for the Al-target has to be determined for correct evaluation of the energy spectrum. Such calibration procedure is now underway.

ACKNOWLEDGEMENT

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