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POLOIDAL ROTATION VELOCITY MEASUREMENT IN TOROIDAL PLASMAS VIA MICROWAVE REFLECTOMETRY

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Results of experiment modeling backscattering of microwaves from rotating plasma layer perturbed by fluctuations are presented. It was shown that auto- and crosscorelation of reflected power have a periodicity equal to rotation period. Such periodicity was observed by microwave reflectometry in experiments on RF plasma production on U-3M torsatron and was used for measurement of plasma poloidal rotation velocity.

1.INTRODUCTION

One of key issues of confinement studies in stellarators now is an understanding of role of the radial electric field. Heavy ion beam probe (HIBP) technic is being used (CHS) or prepared (TJ-II, LHD) for measurement of plasma potential. This technic needs special ports on device and is expensive. Indirect method of electric field measurement is observation of poloidal plasma rotation in crossed radial electric and toroidal magnetic fields. Change exchange spectroscopy (CHXS) is being used for observation of Doppler shift of ion spectral lines and calculation of poloidal rotation velocity (W7-AS, CHS). This diagnostic needs a special diagnostic neutral beam or uses plasma heating neutral beam. Therefore any new and possibly more simple diagnostics for observation of poloidal plasma rotation with a good spatial resolution are welcomed.

Microwave reflectometry is a well-known technic for measurement of electron density profiles and its fluctuations. It has a rather good spatial resolution (few mm). Microwave reflectometry is being extensively used on Uragan-3M (U-3M) torsatron for radial electron density and its fluctuation profiles measurements [1-2]. Microwave (O- and X- mode) reflectometry setup on U-3M uses 3 monostatic (launch/receive) antennas ported in one of toroidal crossections of l=3 torsatron between helical conductors (Fig.1). This setup allows to study crosscorrelation between microwave signals reflected in different poloidal locations and was used for measurement of poloidal propagation velocity of plasma fluctuations in experiments on RF plasma production/heating in U-3M torsatron [3]. It was observed that both auto (AC)- and crosscorrelation (CC) of signals had periodical structures. Closer look showed that period of modulation of both AC and CC is proportional to the time delay of CC between signals of different antennas. To understand this phenomenon we performed a model experiment on observation of microwave reflection from rotating rippled surface metallic cylinder. It was shown that the period of both AC and CC modulation is equal to the period of rotation of cylinder. This conclusion became a basis of simple measurement of poloidal rotation velocity of plasma via microwave reflectometry in U-3M torsatron.

In this paper we present results of this model experiment along with explanation (II), compare them with data obtained on U-3M torsatron (III) and conclude (IV) that modulation of AC of microwave power reflected from plasma in tilted antenna geometry can be used for measurement of poloidal rotation velocity in toroidal magnetically confined plasmas.

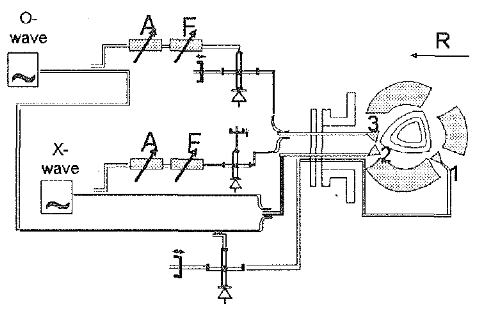

Fig.1 Reflectometry setup at U-3M

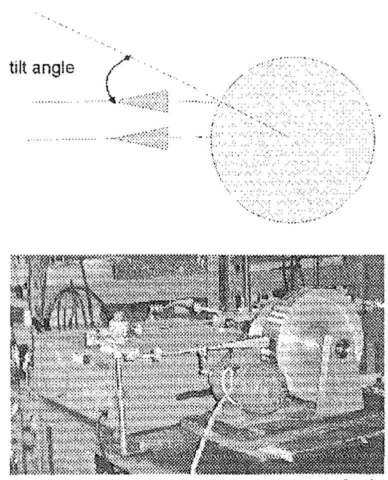

Fig.2 Model experiment setup and photo

II.MODEL EXPERIMENT

The experiment was performed using the 37.5 GHz fixed frequency homodyne reflectometer similar to that one installed on U-3M torsatron. Up to 10 mW cw incident power was launched via a 20 dB standard gain horn on the rippled rotating metallic surface. The same antenna received reflected power. The reflecting rippled surface was formed from 0.2-mm-thick stainless shim mounted on the surface of grooved Al cylinder (diameter of 240 mm and height of 40 mm). This cylinder was previously used as the phase shifter of λ=337 mkm laser interferometer and had a triangular shaped grooves (period = 0.3 mm , height =0.3 mm).

The shim was pressed to form a periodical structure with triangular teeth (period = 16 mm, height=3 mm). This shim was mounted on cylinder surface without of special care about saving periodicity of teeth and could cover 90 % of cylinder circumference or total cylinder surface. The cylinder was rotating with frequency of 6 Hz.

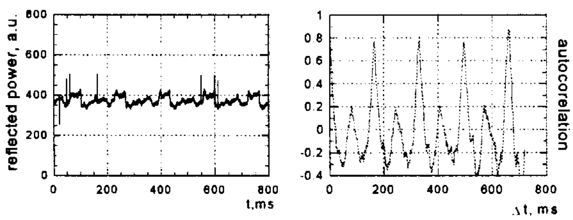

Fig.3 Reflection from grooved cylinder (left-detector signal, right- AC)

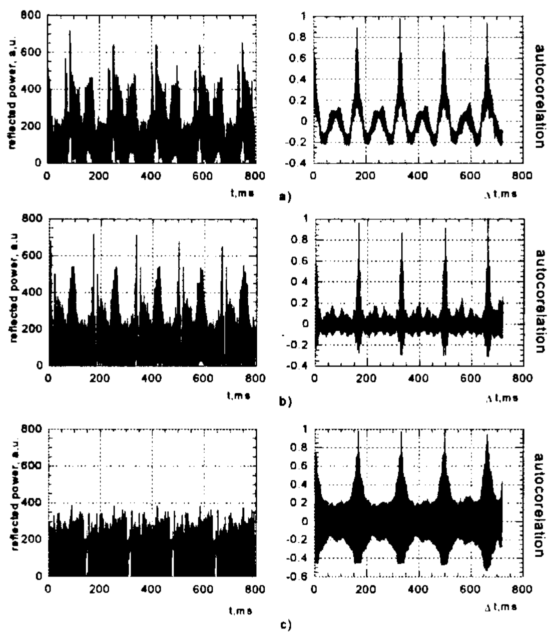

Fig.4 Reflection from 90% shim for different antenna tilt angle α [a) α=0°, b) α=6°, c) α=16°]

III.EXPERIMENT ON U-3M

Periodical structures in both auto and crosscorrelation of signals were observed previously on U-3M torsatron [1]. The typical forms of AC and CC observed at simultaneous probing of plasma by antennas 2 and 3 are shown on Fig.5. The observed periodicity can be interpreted now as result of poloidal rotation of plasma reflecting layer with frequency F ≈ 10 kHz. This rotation results in a corresponding time lag in crosscorrelation between signals of 2 antennas.

Autocorrelation approach is now used in reflectometry system of U-3M torsatron for measurement of plasma poloidal rotation velocity. One of the data obtained is shown on Fig.6. This figure presents the radial distribution of poloidal rotation velocity obtained at simultaneous plasma probing with both inside and outside antennas with probing frequency change on shot-to-shot basis. The most striking feature of this observation is existence of strong poloidal velocity shear in outer plasma.

The antenna was put on a distance of 30 mm from reflecting surface along a horizontal line intersecting cylinder center and could be moved vertically on a distance up to 33 mm. This movement resulted in a tilt of antenna to cylinder surface up to 16° (Fig.2).

The signal of microwave detector was digitized with ADC (τ= 4 mks) and stored. The typical signals of detector along with crosscorelation of signals are shown on Fig. 3-4.

It was observed that in all cases : no shim (Fig.3), 90 % shim (Fig.4) and 100 % shim – the signal of reflectometer exhibit periodical changes corresponding to rotation period. These changes result in a well-pronounced periodicity of crosscorrelation. As for as in the case when the reflective surface was definitely inhomogeneous (90 % shim) the periodicity of reflected signal corresponds to the cylinder rotation period, one can conclude that the period of crosscorrelation modulation is equal to the cylinder rotation period.

This observation is general. Changes in rippled surface shape and antenna tilt angle resulted only in reflected power change. For shorter periodicity of reflecting surface perturbations the modulation of reflected power was smaller. More oblique wave launch resulted in smaller backward reflection.

These observations are in a very good correspondence with data of G.D.Conway [4] and one can use all his arguments for explanation of backward reflection of microwaves from rippled reflecting surface as a result of Bragg diffraction. The novelty of our experiment is in using of a **rotating** rippled surface and showing that the periodicity in crosscorrelation of reflected power is equal to reflecting surface rotation period.

The periodic structure on autocorrelation can be understood if to take into account a fact that the frequency of microwaves reflected from moving surface is Doppler shifted. This was clearly shown in experiment on W7AS stellarator [5]. In homodyne reflectometer this results in modulation of output signal with frequency of Doppler shift. This modulation is reflected in modulation of autocorrelation of output signal.

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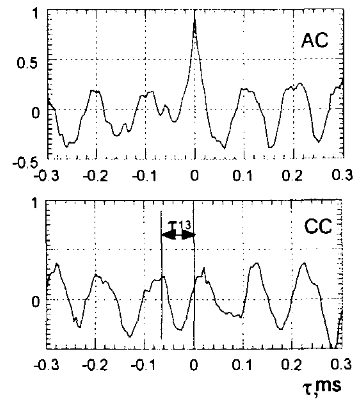

Fig.5 Typical autocorelation and crosscorelation (between antennas 1 and 3) on U-3M

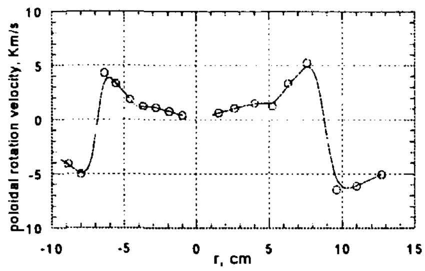

Fig.6 Radial distribution of plasma poloidal rotation velocity for RF produced plasma in U-3M torsatron measured from AC and CC

IV. CONCLUSION

It was shown that when microwaves are launched in tilted antenna geometry and are backscattered from rotating rippled plasma cut-off layer, both auto and crosscorrelations of output of homodyne reflectometer have the periodicity corresponding to rotation period. This gives a very simple and cost effective way of measurement of plasma poloidal rotation velocity. If plasma probing is being performed in one poloidal location, one can measure the value of poloidal rotation velocity only. A direction of rotation can be measured if one can port 2 antennas in different poloidal locations and use crosscorelation.

The radial distribution of poloidal rotation velocity can be measured in both tokamaks and stellarators by using multi-frequency homodyne reflectometers similar to that one used on many toroidal magnetic systems.

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