Plasma Diffusion Investigation in T-10 by Means of Periodic Gas Puffing technique.

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Plasma diffusion study is the important issue for the prediction of the density profile in a reactor grade tokamak like ITER. The technique of such studies requires the perturbation of the stationary state either by gas puffing or by pellets and non-linear modeling of the experiment can be needed. So it is important to decrease the perturbation level and to develop non-linear models for the experiment interpretation. In present report the decrease of the perturbation level is obtained by means of periodic gas puffing technique [1]. The measurements are compared with simulation using constant or variable in space and time transport coefficients. Periodic gas puff was made though piezoelectric valve and was switch on in the stationary stage of the Ohmic discharge. It was used modulation periods of T = 60 and 90 ms.

The series of reproducible discharges were taken for each discharge type to decrease interferometer data errors by averaging and to scan the reflectometer frequency from shot to shot. The experiments were carried out in Ohmic discharges with $B_T = 2.4$T. Measurements were made in two series of discharges: the first one with current value $I_p = 200$ kA and plasma densities were 1.7, 2.5 and 3.5×10^{19} m^{-3}; second one with plasma density 2.5×10^{19} m^{-3} and current values 130, 200 and 300 kA.

The typical raw time traces of the interferometer chord signal and reflectometer signal for one of the frequencies are shown in the Fig. 1. The modulation with relative amplitude of about 1% is clearly seen even for a single shot. The data averaging in series of similar shots

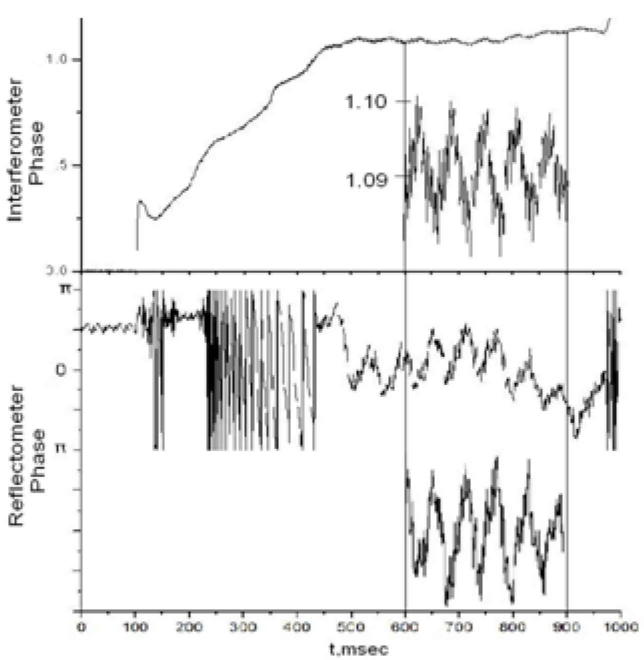

Fig.1Raw time traces of interferometer and reflectometer and application of the synchronous detection enabled to decrease the error bars for the amplitude down to 6 % and for the phase shifts to 3°. The amplitudes and the phases of the oscillations of the interferometer chords signals are shown in Fig. 2a-c for the discharges with

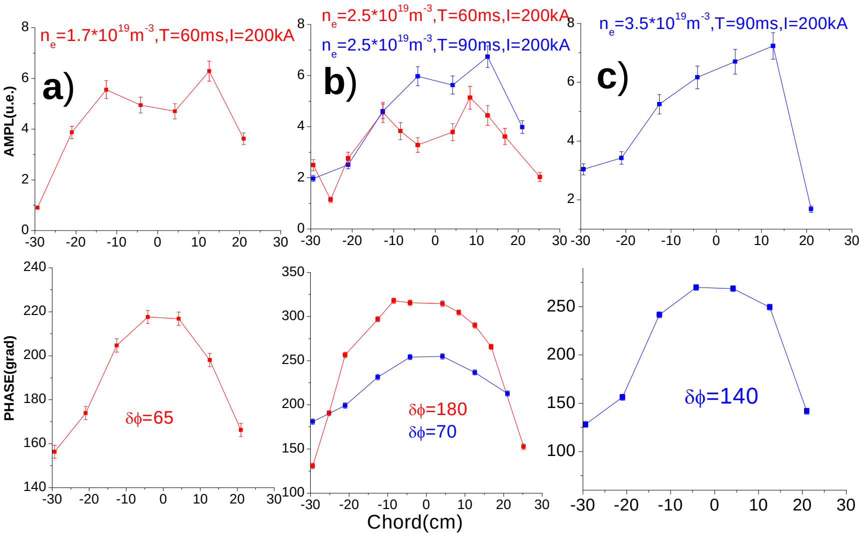

Fig. 2 Amplitude and phase delay chord profiles of perturbations for discharges with Ip=200 kA and three densities

I_p = 200 kA and densities 1.7, 2.5 and 3.5×10^{19} m^{-3} respectively. The data for puffing period 60 ms are plotted in red and for period 90 ms – in blue. It is clearly seen that the gradual increase of the phase delays between the central and edge chords with the density. The amplitude profiles have significant asymmetry, while the phases are more symmetric.

The numerical simulations were carried out according to the following model:

$$\Gamma = -\left(D\frac{dn}{dr} + rVn\right) \qquad (1)$$

$$\left.\begin{array}{l} D = D_0\ (1 + A\sin(2\pi t/T + C1(1 - x))) \\ V = V_0\ (1 + A\sin(2\pi t/T + C1(1 - x))) \\ x = \rho/\rho_{max} \end{array}\right\} \qquad (2)$$

Here D_0 and V_0 are the diffusion and pinch velocity coefficients, A and B are the amplitudes of their variation during the puffing; $C1$- the radial phase shift, corresponding to the penetration of the perturbation from plasma edge to the core. All coefficients did not depend on the radius. The radial distribution of the neutral source was calculated using 1.5D code ASTRA [2]. The ratio

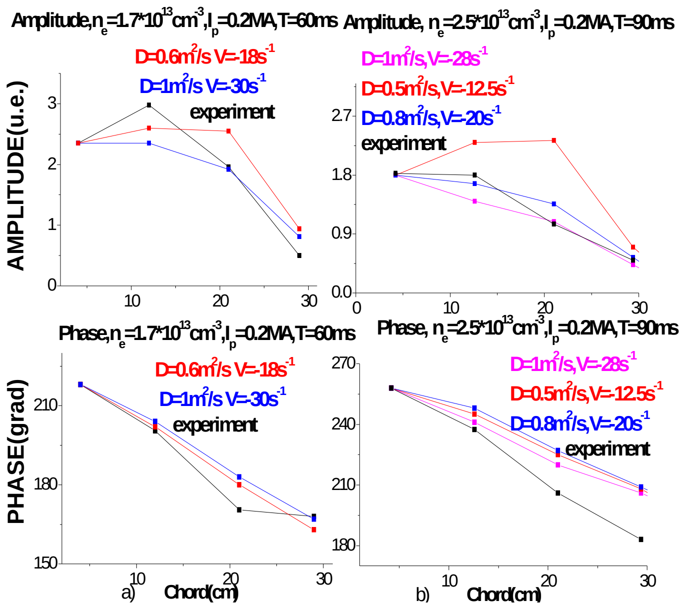

Fig.3. The comparison of the experimental and the simulated data with model A = B = 0, a) n_e = 1.7×10^{19}m^{-3}, I_p = 200 kA; T = 60 ms, b) n=2.5×10^{19}m^{-3}, I_p = 200 kA, ,T = 90 ms

V_0/D_0 was determined by the condition of the correct description of the stationary density profile, while their values and values of A, B and $C1$ were determined from the condition of maximal coincidence with the experimental amplitudes and phases of the oscillations of the chord signals of interferometer. In current experiments the reflectometer data were used only for verification of the interferometer data. The analysis confirms good agreement of the interferometer and reflectometer data.

The comparison of the experimental and the simulated data with the simplest model with $A = B = 0$ is shown in Fig. 3. The values of D_0 and V_0 are constant in time and radius. The left column show the data for the discharge with average density 1.7×10^{13} cm^{-3}, while the right one - for 2.5×10^{13} cm^{-3}. It can be seen from Fig.3 that the simplest model describes well the space behaviour of amplitudes and phases for low density, but not for higher density shots. The experimental phase shift is markedly higher than the calculated one. Our attempts to increase the phase shift in the frames of the simplest model changing D_0 and V_0 keeping their ratio did not achieve a success. The difference between the experimental and calculated phase shifts are maximal for the highest density 3.5×10^{13}cm^{-3}. These facts lead us to the more complicated model (1)-(2) with not zero coefficients A, B and $C1$. This model is practically nonlinear one as the transport coefficients have the space and time characteristics of the density perturbations. It is also seen from Fig.3 that for shot with lower density the best description is possible for D_0 = 0.6 m^2/s and V_0 = -18 sec^{-1}. These values are 3 times greater then predicted from the scaling T-11 [3].

The results obtained with the full model (1)-(2) are presented in Fig. 4 for the shot with I_p = 300 kA and $n_e = 2.5\times10^{13}$ cm^{-3}. The results obtained with the simplest model are

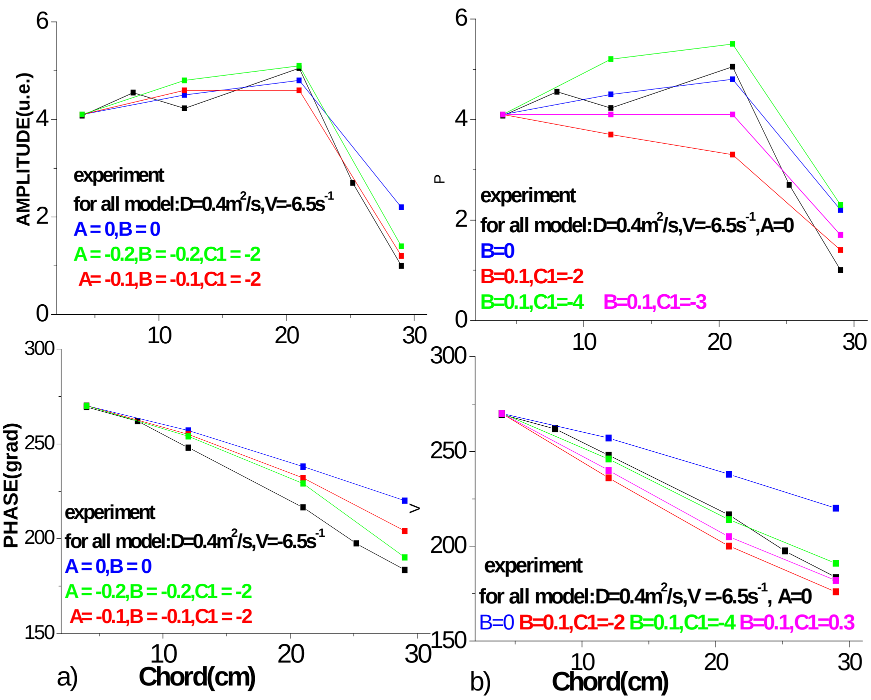

Fig.4. The comparison of the experimental and the simulated data. Shot: n_e=2.5×10^{19} m^{-3}, I_p=0.3MA, T=90msec:a) A=B b) A=0

also shown for comparison. The left hand side plots present simulations with $A = B$ and both diffusion and convection were simultaneously varied in time and space. For the right hand side plots $A = 0$ and only convection was varied. It is clearly seen, that both kinds of variation of the diffusion in space and time brings the simulations in better agreement with experiment, pointing out possible essential influence of non-linearity. The best result was obtained with convection variation only.

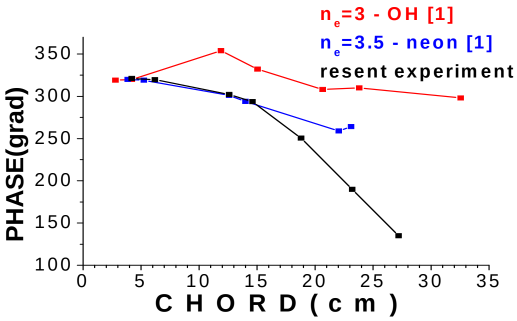

Fig 5 The comparison of old and new experiment

It is of interest to compare the present results with the previous one [1]. Such comparison of the phase shifts for the regimes with I_p = 200 kA and density n_e about $3{\times}10^{13}$ cm^{-3}is shown in Fig. 5. It is important to note that in previous experiments the typical phase shifts were low (red solid line). Those discharges were characterized by low diffusion coefficients about 0.05 – 0.1 m^2/s and the pinch velocities about neoclassical ones. But with the neon puffing it was possible to transfer the discharge into the regime with high confinement of impurities. The high values of diffusion (0.3 – 0.4 m^2/s), pinch velocity coefficients up to 10 sec^{-1} and the higher phase shifts (blue solid line) were found for such a discharge. In contrast with plasma diffusion, the diffusion of the impurities was much lower in such regimes. It was suggested earlier that this discrepancy may be explained by the high non-linearity behaviour of plasma. Namely if discharge is close to the marginally stability state, the periodic puffing could cause periodic transition from the mode with high confinement to the low one. Thus the discharge is highly sensitive to the perturbations. It is clearly seen that the new experiments (solid black line) even without any neon puffing are close to the previous ones with neon. The hypothesis is consistent with the better description of the new experiments with the non-linear model. The difference of the conditions in the previous experiments and the new ones is supported by the change in the energy confinement time from 50 to 80 ms.

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