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Routine density profile measurements by AM reflectometer on T-10 tokamak

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First experiments with time delay measurements by the AM reflectometer were done on T-10 tokamak [1]. In experiments on TJ-1 [2] and PBX-M [3] plasma density profiles were reconstructed from time delay vs. frequency dependence measured by AM reflectometers. On PBX-M density profiles were compared with density profiles measured by the laser beam scattering diagnostic. The comparison had shown no noticeable difference between results of two diagnostics.

Now the AM reflectometer for routine density profile measurements with high spatial resolution is put into operation on the T-10 tokamak. The scheme and main parameters of the T-10 AM reflectometer are the same as parameters of reflectometers [2,3]: the accuracy of the time delay measurements is 0.06 nanoseconds, that is 1.5% on the period of amplitude modulation 4 nanoseconds, that defines the absolute spatial accuracy (accuracy of calibration) about 0.9 cm; the frequency range for the time delay changes is 50 kHz (about 10 microseconds time resolution).

Two circular antennas with 18 mm diameter are used: emitting and receiving antennas are separate. The antennas are installed in the equatorial plane of the T-10. Waveguides inside the chamber and the vacuum vessels for the microwave signal are circular too, that provides with the possibility to use both O and X mode reflectometry. The distance from the center of the T-10 chamber to the edge of antennas is 40 cm. Reflectometer antennas are installed in the cross section of T-10 far from the cross sections where the ECRH is done. This is very important for the AM reflectometer, because with the sweeping microwave frequency the use of the resonant rejecting filter for the ECRH signal is impossible: the resonant filter cause sharp changes of time delay in waveguides with the microwave frequency, that makes calibration of the time delay complicated or impossible. The ECRH signal itself is not an interference for the AM reflectometer scheme. Nevertheless with a powerful (5 mW or more) microwave signal coming to the detector sensitivity to the weak reflected signal of the AM reflectometer is falling. With more powerful signal the detector may be destroyed. The calibration of the time delay of the reflectometer signal in the waveguide system was done by the signal, reflected from the opposite wall of the tokamak chamber. The calibration may be done between any two discharges of the T-10.

The main difference between the T-10 AM reflectometer and reflectometers [2,3] is the regime of the microwave oscillator. In the T-10 AM reflectometer the microwave source with BWO tube was used. The voltage on the BWO tube anode was sweeping inside all the working range linearly 1.1 ms upwards and 1.1 ms downwards during all the T-10 discharge. With the nonlinear dependence of the microwave signal frequency on the voltage this gave almost linear change of the O-mode cut-off density in time. In this experiments 33-54 GHz frequency range and O-mode operation were used. This range is the most useful for the T-10 regimes. It is not difficult to use 53-78 and 26-53 GHz ranges (electric parameters of BWO tubes are the same) and to operate with X-mode. In future the simultaneous operation of two AM reflectometers with different frequency ranges using the same pair of antennas is planned. It is possible to use more than two ranges too, but in this case signals on detectors would be decreased in comparison to a single reflectometer.

Registration of the AM reflectometer signals was done with 20 microseconds period, that gave more than 50 points per the reconstructed part of the density profile, corresponding to the frequency range of the AM reflectometer. Profiles were reconstructed for both directions of the frequency sweeping, that gave about 1 ms temporal resolution of density measurements for the mid of the range and about 2 ms resolution for the edges of the range.

In fig.1 an example of density profile evolution reconstructed from the AM reflectometer data is shown. The plot contains about 360 density profiles. The range of densities is 1.4 – 3.6 $*10^{19}$ m^{-3}. In the discharge the sharp change of the density profile was caused by gas puffing on 650 ms of the discharge. In discharges with average density more than $2*10^{19}$ m^{-3} difference in spatial positions of points with equal density in profiles by AM reflectometer and interferometer did not exceed 2 cm. Taking into account the accuracy of both diagnostics this is a good agreement. At lower density the agreement is worse. Reasons for this are not clear yet.

Features of the AM reflectometer as the diagnostic for the density profile measurement are well seen in fig.1. Contrary to interferometer and laser beam scattering diagnostics, that provide with density value in definite spatial points, the AM reflectometer provides with spatial position of plasma layers with definite density. The range of densities depends on the range of microwave oscillator. That is the spatial region where the density measurements are carried out depends on the value of density. Due to big number of spatial and temporal points it is possible to study spatially localized features of the density profile. The relative spatial resolution (sensitivity to local features of density profile) of the AM reflectometer is higher than the absolute spatial resolution because of strong dependence of time delay of the reflected signal on the density gradient near the cut-off density. The O-mode reflectometer may work only in plasma regions where density gradient is high. The top of the density profile may be resolved by X-mode reflectometer only. The density profile reconstruction is mathematically correct operation. Nevertheless for O-mode it is necessary to know the density profile for the densities below the lowest cut-off density of the reflectometer. Otherwise the spatial position of lowest densities would be reconstructed with an error. For higher frequencies the error should relax. As well as the interferometer the reflectometer works during all the discharge providing with hundreds profiles per second.

Features of the AM reflectometer make it a good diagnostic for routine density profile measurements. But the realization of this task makes it necessary completely automatic data processing from the data registration to density profile vs. time reconstruction. An important obstacle for this are “bad” points in time delay vs. frequency profiles, where the measured time delay is significantly different from one, that correspond to the real density profile. Reasons for the “bad” points appearance are different: heterogeneity of characteristics of the microwave source and detector may cause the loss of reflected signal at some frequencies; two-dimensional turbulent structures in plasma [4] may also lead to the loss of signal; electronic interferences and breaches of computer may lead to significant deviation of registered data. In experiments up to 10% of registered data may be “bad”, depending on the average amplitude of reflected signal. In the fig.2 the raw time delay vs. time at fixed microwave frequency 43 GHz is shown. The time delay is extracted from the signal of the AM reflectometer with sweeping frequency. Deviations of time delay may cause significant deviation of density profile.

An example of density profile vs. time reconstructed from raw time delay data without “bad” points selection is shown in fig.3. Though some of reconstructed profiles have no deviations and in other profiles only part of is deviated the visual estimation of density evolution for this 3-D projection becomes difficult. The most reliable way to select “bad” points appeared to be temporal averaging of measured time delays separate for any microwave frequency. For this the temporal evolution of time delay is extracted from the reflectometer signal for all frequencies (more than 50 frequencies). Than Fourier-spectrum is computed for any of the extracted temporal evolutions and the averaged temporal evolution is computed again from the limited in frequency range Fourier spectrum. The result of the Fourier averaging of the signal in fig.3 with the spectrum limited up to 100 Hz is shown in fig.4. In fig.5 the evolution of the density profile reconstructed from the time delay data averaged by this method with 100 Hz frequency limit is shown. In the averaged profile the radius of saw-teeth oscillations is clearly seen, that is impossible for the profile evolution without averaging in the fig.3. This method appeared to be more effective than other methods based on different ways to distinguish between real evolution of time delay and “bad” points, though the temporal resolution for this method is worse than the period of frequency sweeping. This method provides with density profiles at different Fourier frequency limit depending on the needs of experiment: higher temporal or higher spatial resolution for density changes.

Experiments with the AM reflectometer on T-10 tokamak have shown that the reflectometer may be used as a routine diagnostic for density profile measurements. Data registering and processing up to the reconstruction of density profile evolution may be completely automatic. Taking into account that the every-day exploitation of the AM reflectometer does not need significant human’s work and attention input, the AM reflectometer is a convenient diagnostic for the small tokamaks and may be used together with other diagnostics for density measurements.

References

1. V.Vershkov,V.Zhuravlev, Sov.Phys.Tech.Phys. 32 (5), 523 (1987)
2. E.de la Luna, V.Zhuravlev, B.Branas, J.Sanchez, T.Estrada Proc. 20-th EPS Conf. On Controlled Fusion and Plasma Physics (Lisboa, 1993) v.17, part III, p.1159
3. E.de la Luna, G.Hanson, J.Sanchez, J.B.Wilgent, V.Zhuravlev, M.Ono, R.Kaita Plasma Phys. Control Fusion, v.37 (1995), p.925-935
4. V.Zhuravlev, J.Sanchez, E.de la Luna Proc. 22-nd EPS Conf. On Controlled Fusion and Plasma Physics (Bournemouth, 1995) v.19C, part IV, p.433

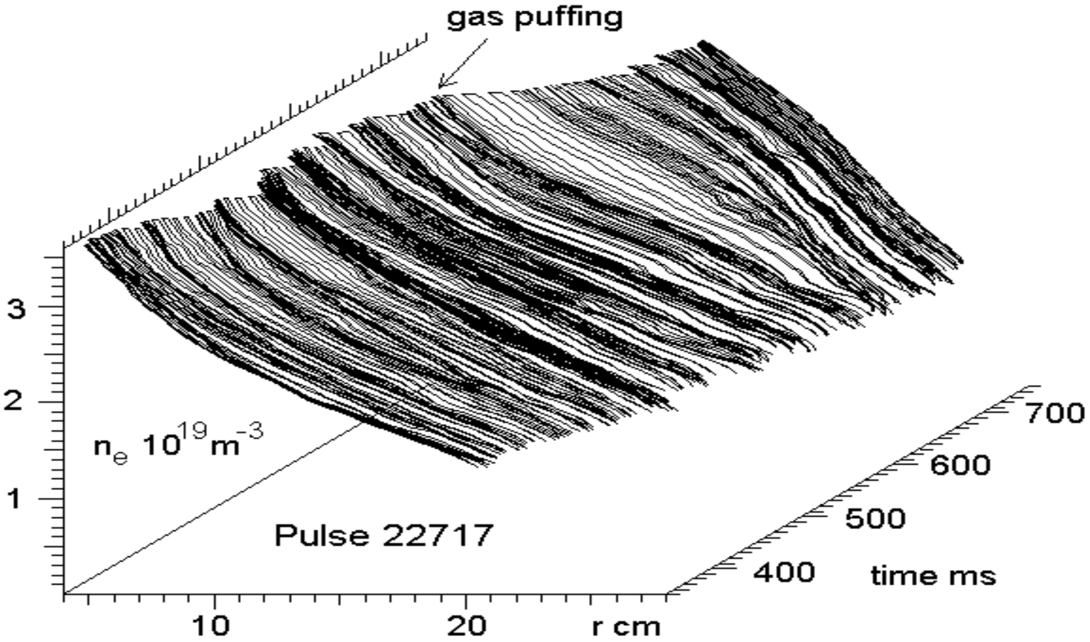

Fig.1 An example of density profile evolution measured by AM reflectometer.

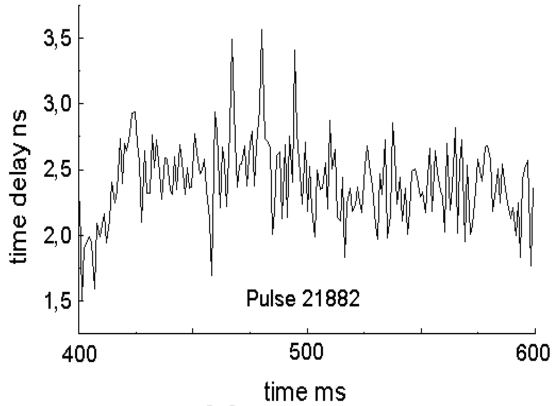

Fig.2 Raw time delay vs. time at 43GHz.

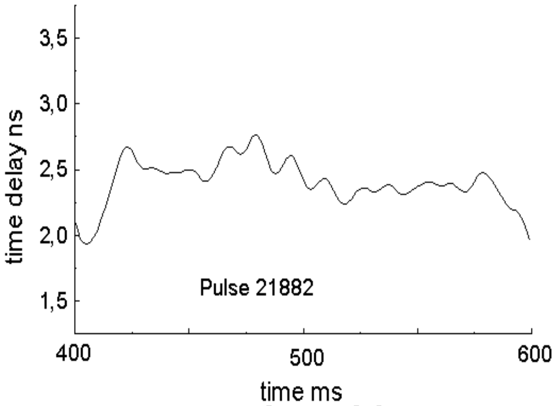

Fig.4 Averaged time delay vs. time.

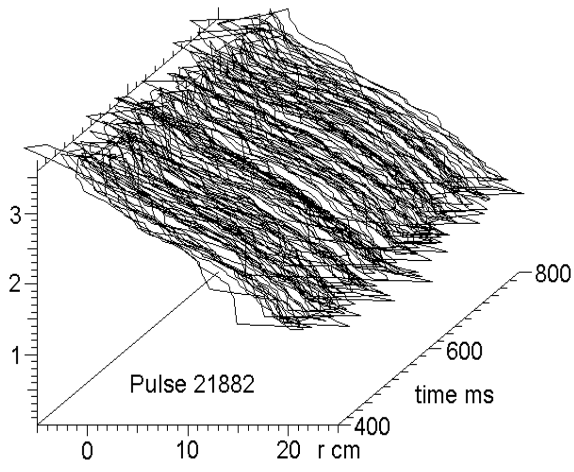

Fig.3 Raw density profile evolution.

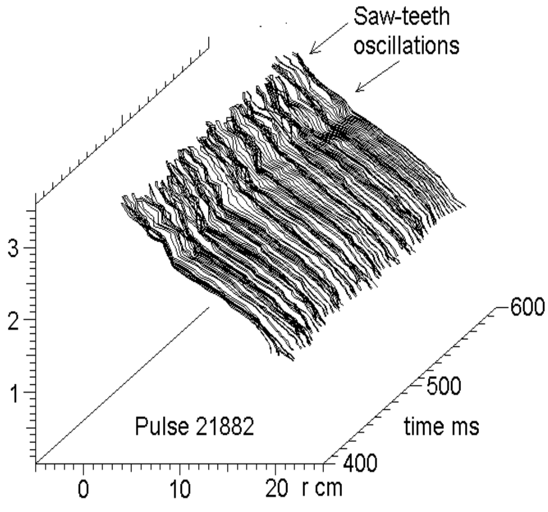

Fig.5 Averaged density profile evolution.