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Application of Pulsed Radar Reflectometry/Delayometry to the Large Helical Device Plasmas

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Abstract

In the large fusion devices (tokamaks and recently helicalsystems) much more attention will be paid to enhance thediagnostic tools for reliable measurements during steady stateplasma operation. In this article we describe the bistatic,heterodyne, dual-mode pulsed radar reflectometer, which wasinstalled at the Large Helical Device (LHD) and present theinitial results obtained by it. This system was designed to testthe possibility of using radar techniques to monitor edge plasmadensity. If we take into account the operational frequency andcertain wave polarization this diagnostic tool can be also usedas line density monitor (like ordinary interferometry). Suchregime of operation is known as a delayometry.

Keywords:
fusion, plasma diagnostics, LHD, long pulse operation,reflectometry, delayometry, pulsed radar

1. Introduction

In the past several years, reflectometry became a well-established and common diagnostic technique for measurements of the plasma electron density and its fluctuations [1,2]. It has been shown that in tokamaks [3-5] and helical devices [6,7] plasma experiments the pulsed radar works reliably giving density values which are consistent to those from the conventional diagnostics (i.e. Thomson scattering and interferometry).

The principle of the pulsed radar is to measure the time delay between a launched pulse and its reflection by a plasma cutoff layer. The time delay is directly defined by the coordinates of cutoff layer and the line integral density up to that point.

2. Instrumentation and Techniques

For third phase of the LHD plasma experiments one channel, bistatic, heterodyne, dual-mode pulsed radar, was installed at 9-O port. Probing of the plasma was conducted from the low-field (LFS) side. The main components of the experimental setup is shown in Fig. 1. Taking into account the magnitude of the magnetic field (2.75 T) the operational frequency of 51 GHz and 60 GHz was chosen to meet reflection conditions for the extraordinary polarized (X-mode) radiation at the

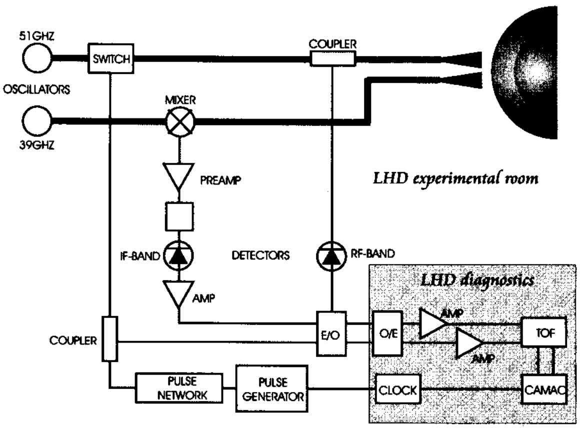

Fig. 1 The block diagram of the LHD U-band pulsed radar reflectometer.

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plasma edge (for 51 GHz) and at the density profile gradient region (for 60 GHz). Almost all microwave components (oscillators, switches, mixer, etc.) were placed close to the device on D-stage in LHD room. Short (about 1 ns) microwave pulses are launched into the plasma. This pulse is produced by a CW oscillation modulated by a fast microwave switch.

To deliver maximum microwave power a transmitter and receiver are placed close to the diagnostic port and a special teflon lenses were attached to launching and receiving corrugated conical horns. Such arrangement allows to deliver radiation with both polarizations into the plasma. To optimize reflection conditions during plasma experiments we change direction of the antennas in the horizontal plane. Thus, the position of the beams cross-point could be readjust from outer edge of the plasma to inner port surface. The output of the receiver (IF frequency amplification unit) was connected to time measurement system at diagnostic room via ~100 m 0.01–1.5 MHz electrical-to-optical link. The time measurement system utilizes classical setup for pulsed radar [3,5,7]. This system is based on a constant fraction discriminator technique, where timing is measured between the leading edges (at the half of the maximum amplitude) of the transmitted and received pulse, disregarding pulse deformation effects.

3. Experimental Results

For the standard (B_t = 2.75 T, R_{ax} = 3.60 m) LHD operation scenario, pulse delay measurements by plasma were conducted for 51 GHz and 60 GHz using X-mode polarized radiation. The time evolution of the main plasma parameters as well as pulsed radar signal for the LHD shot #12746 is shown in the Fig. 2. At the beginning of the discharge after the small increasing of the plasma density the pulses start to reflect from cutoff layer which is located at the edge of the plasma (t = 0.25 s). When NBI heating was applied (t = 0.75–2.0 s) the considerable growing of the plasma density cause the further increasing of the pulses delay in plasma. Because of X-mode operation even after the consecutive plasma density increasing there are no indications of the changing in the cutoff position (Fig. 3).

During LHD experiments at low magnetic field (B_t = 1.52 T, R_{ax} = 3.60 m) the situation becomes quite different. In this case the initial position of the cutoff layer appear more close to the plasma center. Measurements show a significant movement of the cutoff position to outer plasma boundary region (t =

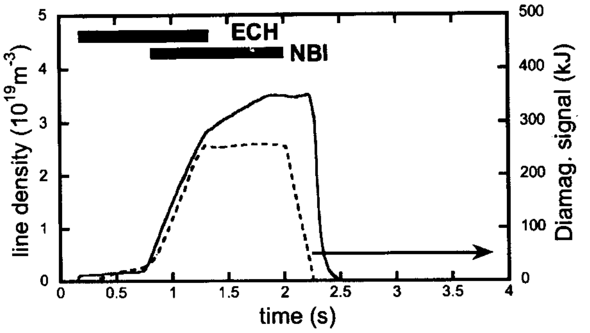

Fig. 2 Time evolution of the electron line density (solid line) and the plasma diamagnetism for the LHD combined heating plasmas; shot #12746 (dotted line).

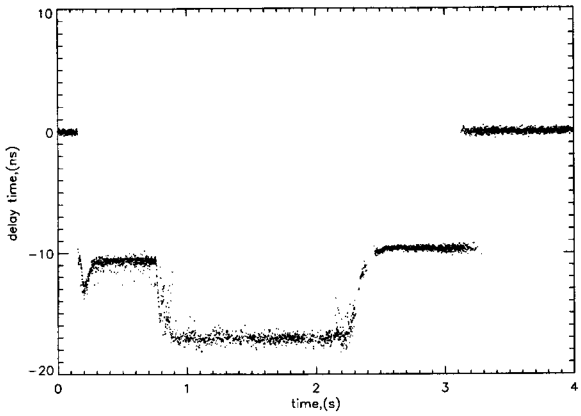

Fig. 3 Measured time of flight (pulse delay) for the shot #12746.

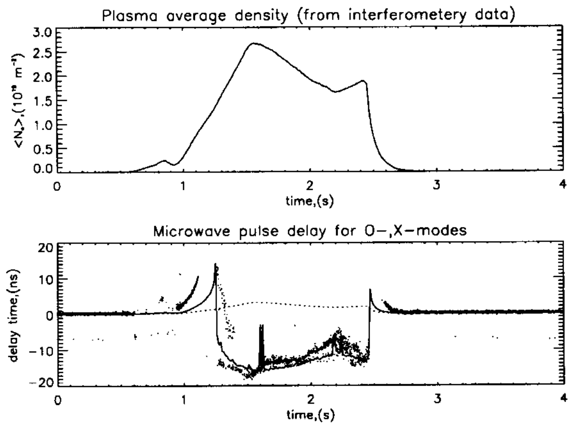

Fig. 4 Low magnetic field operation, upper plot is time evolution of the electron average density, lower one is pulse delay measured at 51 GHz and calculated delays of the O-/X-modes; shot #13228.

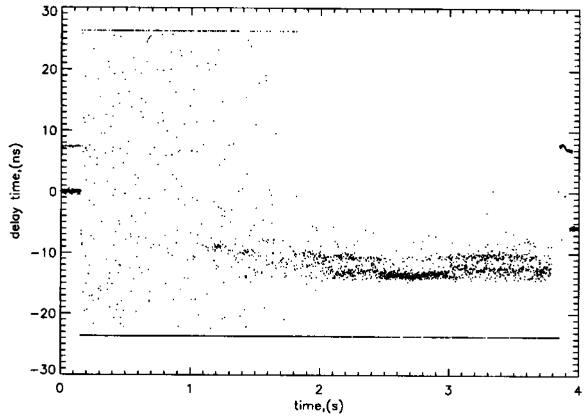

Fig. 5 Dual-polarized experiments, because of poor reflection with respect of pure O- or X-mode case timing system start to be triggered by noise (with timing about 26 ns), or not reflected backward (−23.5 ns); shot #13771.

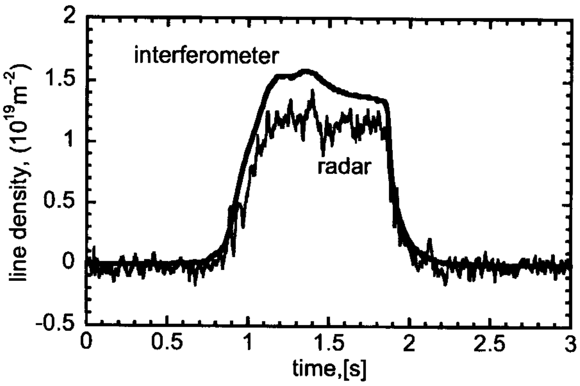

Fig. 6 Delayometry type of operation. A comparison of line integral density obtained by means of interferometry and a pulse radar system. Reflectometry raw data was smoothed within 15 points; shot #12694.

1.2–1.5s). There is a quite obvious disagreement between simulation results and measured data at the lower density. This could be explained by the fast changing of the plasma density profile gradient.

Up to present time, all radar experiments have been carried out for tokamaks (without separatrix) and mirror systems. At those devices magnetic shear is considerably low. At helical systems the presence of the shear can deteriorate microwave measurements due to the mode scrambling. Because of the fact that the orientation of the magnetic field can change within one-two wavelength the power conversion from the O- to the X-mode and vice versa may occur. That is why, simultaneously O-/X-mode operation could be of great interest. Both antennas were rotated by 45° with respect to the direction of the magnetic field at the edge. The energy of the incident wave suppose to be equally divided between two modes. As a result the amplitude of the reflected radiation decreases significantly. One can see (in the Fig. 5) an appearance of the second reflected signal. That part of the wave that has O-mode polarization at the edge can penetrate into the more dense center region, where it meets the reflection condition.

In low-density plasmas experiments at LHD, where for O-mode polarized radiation, maximum density is below the critical one (for 51 GHz: 3.22×10^{19} m^{-3} for 60 GHz: 4.46×10^{19} m^{-3}), pulsed radar reflectometers operate as interferometers. Microwave pulses launched into the plasma will not be reflected, but pass through the plasma. At the opposite side these pulses will be reflected by the inner wall of the vacuum vessel and pass through the plasma again where they will be detected.

As differ from the interferometry the above outlined approach is characterized by a significantly lower frequency of operation. It makes delayometry a possible contender in monitoring plasma turbulence even for low density case. Also due to the minimal port requirements for pulsed radar it is possible to use pulsed radar delayometry for the measurement of diverter plasma line density. However, it is beyond the scope of this paper to discuss this problem.

4. Summary

During the third cycle of the LHD experiments the bistatic, heterodyne, dual-mode pulsed radar reflectometer, was installed. The initial measurements were done at 51 and 60 GHz. It was shown that pulsed radar could be a promising tool for edge density fluctuation measurements as well as a line monitoring diagnostic for the special plasma conditions.

The major advantage of the pulsed radars compared with the conventional reflectometers and interferometers is that these systems are insensitive to measurement fails even after temporal loss of the signal. In the steady state operation this feature is of major importance.

We have to mention also some distinctive difficulties that arose from the implementation of the technique under consideration to the particular case of LHD device. Due to the complex plasma geometry microwave sources with much power are required for successful measurements. The alignment of the horns in the vertical cross-section seems to be more favorable.

Probing along the smaller half-axis of the plasma (which requires a special antenna systems) could improve measurements and data treatment dramatically.

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