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Diagnostic Development for the H-1 Heliac

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Abstract

This paper describes the principal diagnostic systems installed or planned for plasma measurements on the H-1NF heliac at the ANU. Emphasis is given to diagnostics that are either novel in concept or which exploit the excellent diagnostic access available in H-1NF.

Keywords:
plasma diagnostics, heliac, interferometry, spectroscopy, magnetic surface, Langmuir probe.

1. Introduction

The H-1 heliac is a university-scale research-oriented helical axis stellarator. Its coil-in-tank construction allows almost unhindered access to the plamsa volume for both active and passive diagnostic systems. To take advantage of this, approximately 25 % of the budget for the H-1 NF National Plasma Fusion Research Facility is allocated for the development and installation of high resolution plasma diagnostic systems. This paper describes the principal diagnostic systems with particular emphasis on those that are either novel or which exploit the above-mentioned advantages.

2. Surface Mapping

Prior to plasma studies it is necessary to confirm the integrity of the magnetic surfaces produced by the helical-axis magnetic coil set. Magnetic surfaces have been mapped in H-1 using both fluorescent probe techniques[1] and the novel tomographic collecting wire grid array described briefly here[2,3]. Both techniques rely on mapping the "punctures" or intersections within a fixed poloidal plane of an electron beam injected toroidally at different radial positions in the magnetic volume. In the first method, the beam is visualized using a multi-wire fluorescent target and imaging optics. In the second, 64 parallel, closely spaced molybdenum wires that span a poloidal cross section of the magnetic surfaces and are mounted on a rotatable platform collect the intercepted current for a set of fixed platform orienations. The approximately line-integrated current measurements are inverted using tomographic techniques. Some advantages of the wire array are that it can image low-energy electrons (that closely follow the magnetic lines of force), is capable of millimetre spatial resolution, and can readily provide temporal resolution both for transient magnetic fields and time-of-flight analysis. It is also possible to simultaneously map a number of surfaces at different radii using a multi-beam gun, though this has not yet been attempted. Fig. 1 shows superimposed reconstructions of three different surfaces of the standard configuration of H-1NF.

3. Probes and Magnetic Diagnostics

Under low electron temperature conditions a number of probe diagnostics is used. This includes a 2D-scanning triple probe (electron temperature, density, plasma potential, their fluctuations and correlations), a

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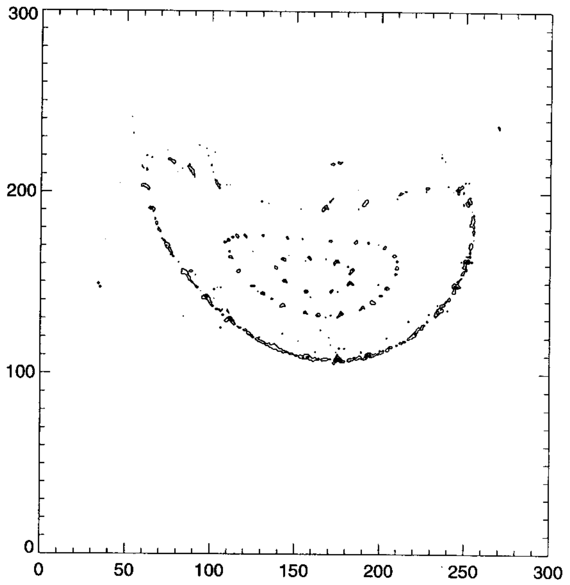

Fig. 1 Superimposed reconstructions of wire-integrated current data for three surfaces in the H-1NF standard magnetic configuration. The *x* and *y* axis units are in millimetres.

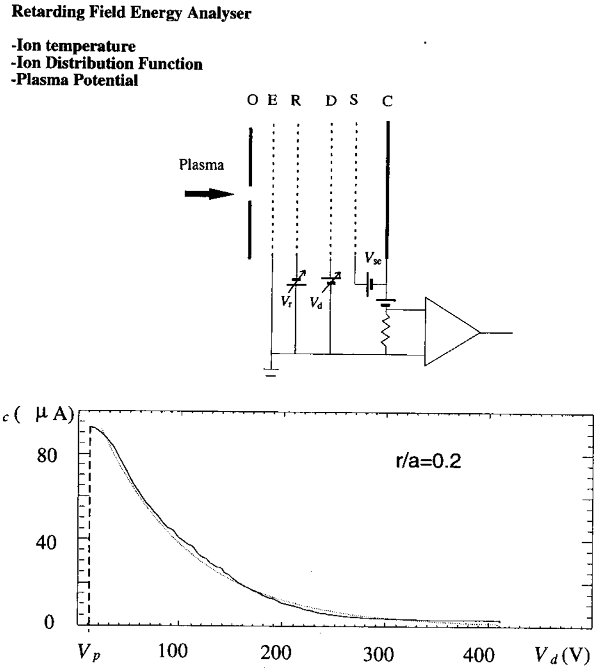

Fig. 2 Schematic of RFEA circuit and measured argon ion distribution function.

"double-triple" probe (time resolved), a Mach probe (ion flow velocity), a multichannel linear probe array (fluctuation phase velocity) and a retarding field energy analyser (plasma potential, ion temperature). The probes have revealed much about the physics of heliac confinement during low power operation[4].

A retarding field energy analyser (RFEA) is used to measure the ion distribution function and plasma potential in the H-1 plasma. The RFEA includes four separate grids between the entrance slit and the collector as shown in Fig. 2. A repeller grid is biased negatively (typically $V_r \sim -500$ V) in the ion mode to remove all the electrons, while the discriminator grid voltage is swept from $V_d = 0$ to 400 V in about 10 ms. An earthed grid is placed across the entrance zone of the analyser to define an equipotential surface and prevent plasma perturbation by the repeller and discriminator fields. This diagnostic has been extensively used in studies of the improved confinement mode[5].

Plasma energy is measured by several diamagnetic loops at different toroidal positions, integrated both digitally and electronically and compensated primarily by subtracting a toroidal field coil current signal. This removes the effect of the external TFC power circuit parameters on the signal, the small ($< 5 \times 10^{-5}$) ripple in the TFC supply current and corrects for small currents flowing from the buswork inside the vacuum vessel. Diamagnetic stored energy measurements are within a factor of two (or better) of kinetic estimates derived from line average density data and Langmuir probe and spectroscopic measurements of T_i. The accuracy of this comparison is mainly limited by the availability of more detailed profile information. Peak beta values of up to 0.5 % have been observed, and the minimum stored energy density detectable is 0.2 J m^{-3}.

4. Electron Density and Temperature

Ideally one aims to measure the distribution functions $f(r, v, t)$ for both ions and electrons and the electric and magnetic fields that conifne the plasma. In practice, however, the best that can be obtained is spatially and temporally resolved measurements of the low order velocity moments of f for the dominant species – *i.e.* the species number density, its nett flow and temperature.

The electron density is routinely monitored using single channel 8 mm (homodyne) and 2 mm (quadrature) interferometers respectively. The spatial distribution of the plasma density is measured using a multi-view far-infrared (433 μm) interferometer[6,7]. To date, useful information from 40 chords in four viewing directions has been obtained. This will be upgraded to five views in 1998. Time and frequency multiplexing methods are used to accommodate the

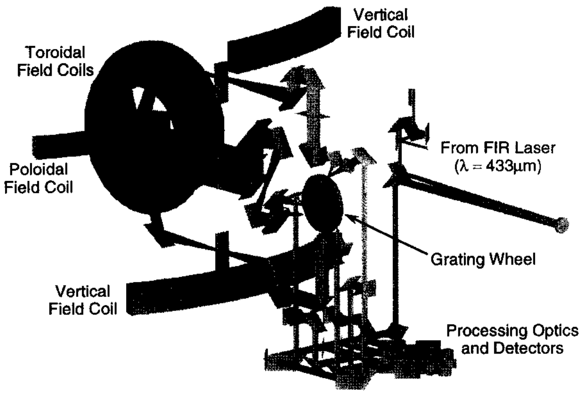

Fig. 3 Optical system for the three-view, 40-beam H-1NF interferometer.

large number of spatial channels. Time multiplexing is achieved using a rotating cylindrical diffraction grating that sequentially scans the laser beam by having the grating groove constant vary discretely with rotation angle. Up to 15 beams are generated in a given fan array, the beams being collected and directed to the plasma using cylindrical mirrors (see After executing a double pass of the plasma, the probe beams are returned to the grating where they are diffracted back along the incident path and sampled using a beam splitter. The plasma probe is doubly Doppler shifted by the rotation of the grating to give an intermediate frequency carrier signal (up to 400 kHz) when mixed with part of the original laser radiation. The Doppler shift depends on diffraction angle, so the IF frequencies of the resulting fringe bursts change stepwise with the grating angle. The frequency multiplexing method exploits this frequency tagging by reflecting simultaneously the beam into a number of diffraction orders in different directions[8].

Interferograms and reconstructions for an argon discharge exhibiting a large global $m = 1, 2$ oscillation are shown in Fig. 4. Apart from probe techniques electron temperature will be measured using a scannable multi-point ruby-laser Thomson scattering system. The feasibility of ECE and ECA techniques[9] are also being assessed.

5. Ion Temperature and Flow

Atom and ion temperatures and flow velocities are presently being measured using a novel electro-optically modulated solid-state (MOSS) spectrometer[10]. This will be combined with an array of lens-coupled fibres mounted on a rotatable apparatus that encircles the

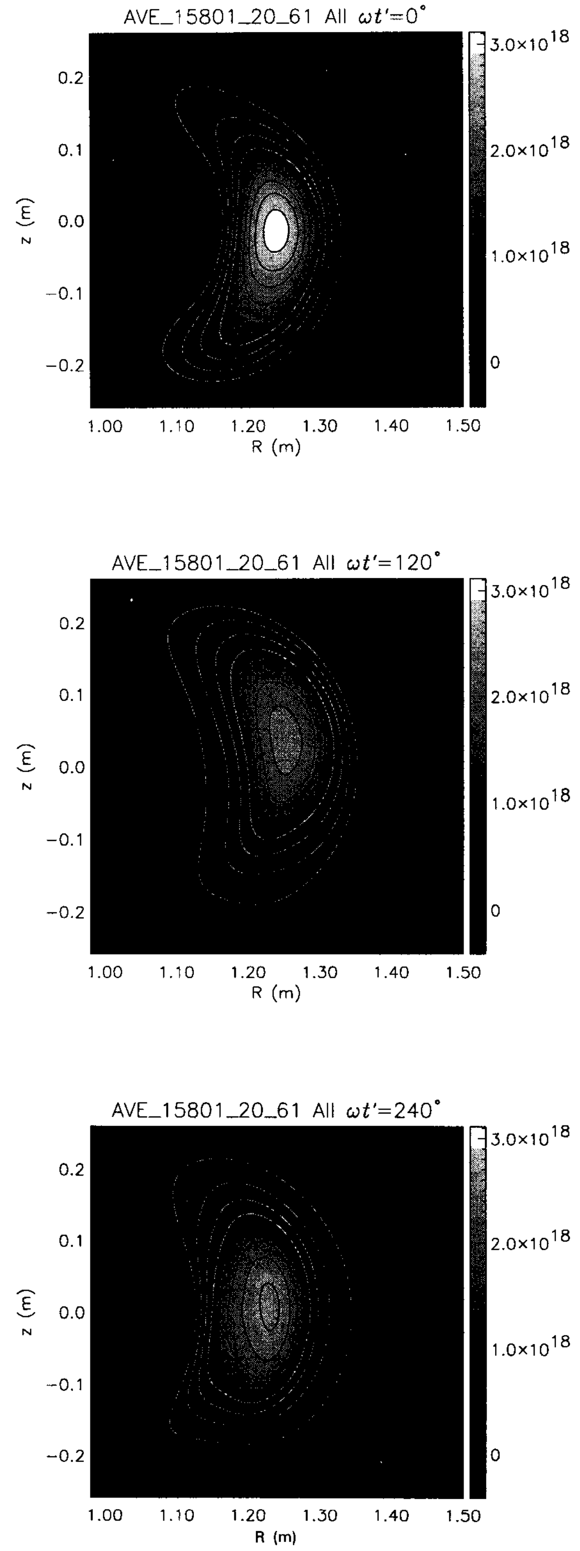

Fig. 4 Tomographic reconstructions of the total electron density profile at three equispaced phases in one period of the fundamental component of a strong drift-type instability for discharge 15801.

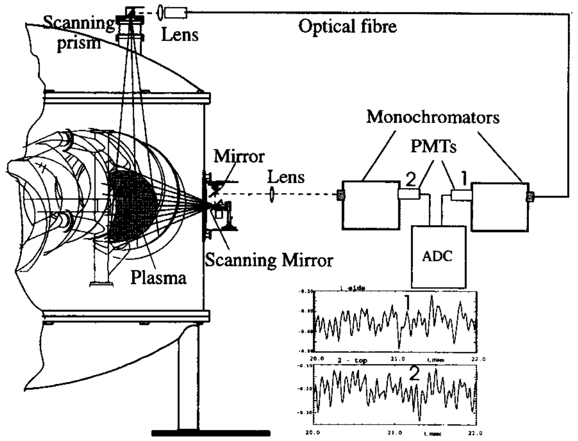

Fig. 5 The layout for the correlation spectroscopy diagnostic.

plasma to produce detailed two-dimensional maps of the temperature and flow vorticity distributions[11]. Combining the density profile and spectrosopic techniques, it is hoped to be able to infer the plasma electric field using force balance considerations. We have also setup a bench experiment to test an alternative technique using LIF from an injected supersonic helium beam[12] for direct electric field measurements.

As well as the above mentioned systems a 2 m radius grazing-incidence spectrometer will be installed for VUV spectral studies. Tomographic soft X-ray and bolometer systems are also underway for estimates of electron temperature, Z_{eff} and radiated power distributions. The soft X-ray system will comprise fixed and rotatable arrays for high spatial resolution measurements.

6. Fluctuations

A correlation spectroscopy diagnostic has been devised for measuring density fluctuations (Fig. 5)[13]. The diagnostic uses a cross-correlation technique to extract local frequency spectra, spatial distribution or (in case of low mode numbers) the mode structure from the chord-average fluctuating intensities of the visible light in the H-1 heliac. Under certain discharge conditions, the plasma is dominated by strong low-frequency (15– 20 kHz) oscillations. Although, such discharges are not quite suitable for implementing the main idea of the diagnostic (since in this case, the fluctuation correlation length is of the order of the plasma diameter), the measurements allow the poloidal mode number and spatial localization of the fluctuations to be determined after comparison with numerical modelling results and show good agreement with the Langmuir probe results.

The diagnostics presented here are a cross section of the systems already installed or planned for H-1NF. Our main emphasis has been on systems which are already operational and which are novel either in concept or application.

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References

[1] M. Shats *et al.*, Nucl. Fusion **34**, 1653 (1994).

[2] B.D. Blackwell, J. Howard and R.B. Tumlos, Rev. Sci. Instrum. **63**, 4725 (1992).

[3] B.D. Blackwell, R.B. Tumlos and J. Howard, Rev. Sci. Instrum. **68**, 388 (1997).

[4] M. Shats and D.L. Rudakov, Phys. Rev. Letts **79**, 2690 (1997).

[5] M. Shats, D.L. Rudakov, R.W. Boswell and G.G. Borg, Phys. Plasmas **4**, 3629 (1997).

[6] J. Howard *et al.*, *6th International Symposium on Laser Aided Plasma Diagnostics*, p.154 (1993).

[7] G.B. Warr, B.D. Blackwell, J. Wach and J. Howard, Fusion Eng. Design **34-35**, 387 (1997).

[8] J. Howard, P. Dodds and G.B. Warr, Rev. Sci. Instrum. **63**, 4965 (1992).

[9] J.F.M. Van Gelder, Phd. thesis, FOM Instituut voor Plasmafysica, Rijnhuizen, Nieuwegwin, The Netherlands, 1996.

[10] J. Howard, Rev. Sci. Instrum., *in preparation* (1997).

[11] J. Howard, Plasma Phys. Control. Fusion **38**, 489 (1996).

[12] T. Oda and K. Takiyama, *Proceedings of the 7th International Symposium on Laser Aided Plasma Diagnostics*, p.227 (1995).

[13] M. Shats and J. Howard, Fusion Eng. Design **34-35**, 271 (1997).