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First results from the three-view far-infrared interferometer for the H1 heliac

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Abstract

A three-view, 40 beam far-infrared ($\lambda = 433$ μm) scanning interferometer has recently been installed and operated on the H1 heliac. The optical system is described and first plasma results are presented. © 1997 Elsevier Science S.A.

1. Introduction

The design of the H1 heliac [1] allows relatively unhindered access to the plasma region so that the plasma density distribution in the bean-shaped magnetic surfaces can be measured using a three-view, 40 beam Michelson configuration interferometer. Some new approaches have been necessary to accommodate such a large number of probing beams, such as the use of a scanning grating wheel to produce a fan of beams, off-axis parabolic and elliptical mirrors to shape and steer the beams, and polarizing optics to produce extra sets of beams for greater plasma coverage and also for the reference interferometer.

In Section 2 we describe the unique features of the interferometer including a discussion of the optical design. The first results obtained with the interferometer are presented in Section 3.

2. Optical Design

The optical system for the interferometer is shown in Fig. 1. This figure was generated using a three-dimensional gaussian beam ray-tracing programme developed by one of us (G.B.W.).

The source for the interferometer is an approximately 80 mW OPFIR laser operating on the $\lambda = 433$ μm line. A quarter-wave optical isolator [2] is used to reduce laser susceptibility to feedback from the Michelson interferometer. After expansion and collimation the far-infrared (FIR) beam is transported on to a horizontal optical table. A small amount of beam power is split off at this stage as local oscillator for the various detectors. The remaining beam power is divided equally into three beams incident on the grating wheel at equi-angular locations.

The circumference of the wheel is divided into 3 sets of 11 equal length gratings with different grating constants d. The constants are chosen so

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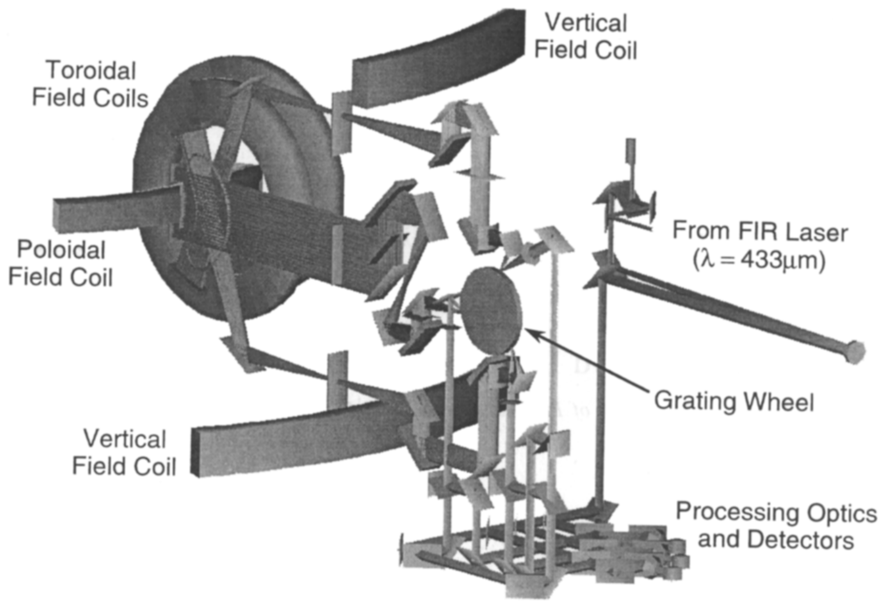

Fig. 1. Optical system for three-view, 40-beam H1 interferometer.

that as the wheel rotates the incident beam is sequentially diffracted through a fan of beams of full angle 12°. Different spatial positions of the diffracted beam are thereby multiplexed in the time domain. Complications due to propagation of higher order ($m > 1$) diffracted beams are avoided by choosing the incident and diffraction angles so that these beams are not generated.

Cylindrical lenses are used to correct for the cylindrical grating reflection asymmetry [3,4]. Cylindrical parabolic, elliptical and circular mirrors are used to collect, collimate and shape the beams so they are of minimum diameter (about 3 cm FWHM (full width at half-maximum)) in the plasma region while ensuring the return beam geometry is symmetric with the incident beam geometry. For the diagonal views the beams are uniformly distributed in a fan spanning 6°, while for the horizontal view the beams are equispaced and parallel. Each set of beams is about 15 cm wide in the plasma region.

Polarizing optics are used to generate two extra sets of beams. A vertical polarizer is inserted in the upper interferometer before the beams enter the vacuum chamber to return a set of vertically polarized beams to the grating for a reference phase signal. A vertical polarizer is also used on the central interferometer to generate an additional set of beams for greater plasma coverage. However, in order to maximize the number of beams passing through the port aperture, four beams are absorbed.

After executing a double pass of the plasma, the probe beams return to the grating where they are diffracted back along their incident path, sampled using a beam splitter and mixed with the local oscillator on a Schottky diode corner cube detector. The system requires just five detectors, since only a single detector is required for each set of 11 beams. The beams are doubly Doppler shifted by the double pass of the rotating grating. Since the Doppler shift depends on the diffraction angle, the intermediate frequencies (IFs) of the resulting fringe bursts change stepwise with the grating angle to give a full range of variation of 20%. The grating is driven using an air turbine capable of smooth operation at speeds in excess of 10 000 rev min^{-1} for rapid plasma scan.

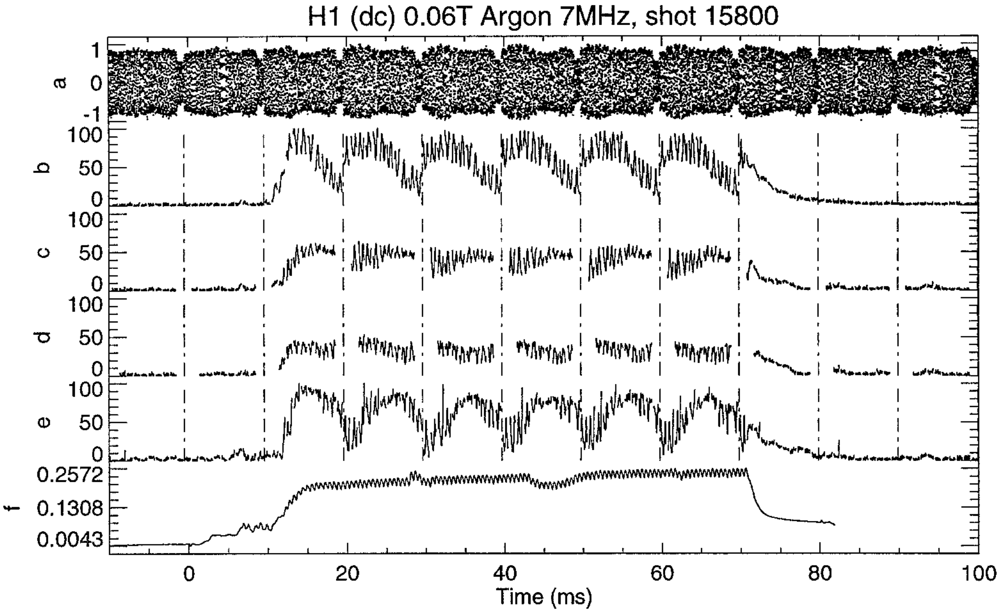

Fig. 2. Interferometric data for typical H1 high density argon plasma discharge.

3. Results

Data obtained for an argon discharge under conditions that favour a strong oscillatory behaviour at 1.9 kHz are shown in Fig. 2: (a) is the IF signal for the upper interferometer, (b)–(e) are phase signals (in degrees) obtained from the upper, lower central, upper central and lower interferometers respectively and (f) is the plasma β derived from the diamagnetic flux loop signal. Detail of two consecutive scans of the plasma is shown in Fig. 3.

The IFs range from 125 to 155 kHz are sampled at 200 kHz and phase demodulated by computing and comparing the analytic signals with that of the reference interferometer. Integrating reduces the phase signal bandwidth to 20 kHz and the r.m.s. phase noise to about 2° or less. The flat phase baseline before and after the discharge shows that vibrations are insignificant. The practical duty cycle is about 85% as information is lost between stepping from one sector to the next. The broken vertical lines in the figure indicate transition times between consecutive plasma scans.

As the wheel rotates, the beams in the upper interferometer scan the plasma from the outside to the inside, while the beams in the lower interferometer scan in the reverse sense. The beams in the central interferometers scan from below the midplane to above. Since the diagonal views are symmetrically disposed with respect to the plasma, apart from the scan direction, the phase profile should be identical. During oscillatory discharges this clearly is not the case, nor is the oscillation amplitude symmetric about the midplane. Observe that this behaviour is highly reproducible from one scan to the next and that the oscillations have significant harmonic content. Preliminary investigations suggest that the observation can be modelled in terms of a toroidal rotation of phase-locked $m = 1$ and $m = 2$ modes.

Good agreement between simulated and measured global profile shapes is obtained for a centred gaussian profile of peak density 4×10^{18} m^{-3}. At the low peak densities presently attainable with the installed 60 kW r.f. generators, refraction is negligible.

Fig. 4 shows a discharge in a different magnetic configuration (reduced current to the outer vertical field coils) for which the coupled modes are marginally stable. The upper interferometer signal shows a 20% increase in plasma density accompa-

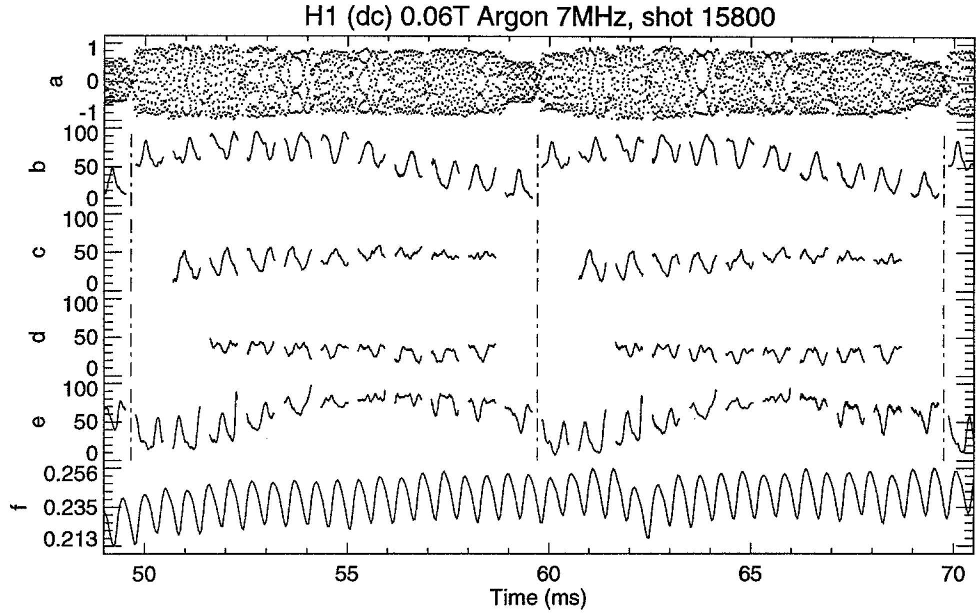

Fig. 3. Detail of two consecutive scans in Fig. 2.

nying the oscillation decay evident in the β signal and the reduced oscillation amplitude in the interferometer signal. A small amount of high frequency noise remains on the interferometer signal after the oscillation terminates due to noise in the CO_2 pump laser for that shot.

4. Future work

The three-view interferometer has been designed with a number of enhancements in mind. The grating wheel can be easily interchanged with a wheel with either constant groove spacing or continuously varying groove spacings. The former

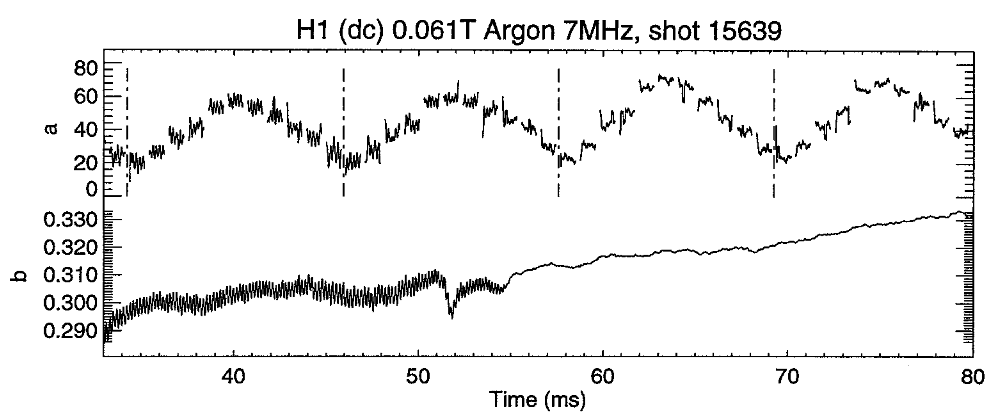

Fig. 4. Termination of plasma oscillation.

will be useful for careful study of the confinement-relevant plasma decay, while the latter maximizes the duty cycle. An alternative multiorder grating wheel may be used to probe the plasma with many beams simultaneously [5]. Additional views can be incorporated using the polarization-multiplexing method employed for the central view and reference interferometer. Alternatively, the Faraday rotation angle can be recovered using heterodyne polarimetry [6].

Acknowledgements

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