Comparison of Dispersion Interferometer and 2-Colour Interferometer for W7-X with Respect to their Sensitivity to Mechanical Vibrations

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1. Introduction

In W7-X a one channel interferometer is planned for machine density control and cross calibration of the Thomson scattering profiles. The sightline of the interferometer and the Thomson laser beam share the same ports. The main components of the interferometer will be arranged on a vertical optical bench directly in front of the entrance port, whereas outside the exit port a corner cube reflector (CCR) mounted onto the support structure of the Thomson scattering diagnostics on the inner side of the torus, returns the laser beam along the same path. For the 30 min discharges foreseen in W7-X, the CCR is expected to move about100µm. In most fusion devices 2-colour interferometers are used to compensate such mechanical motion, so that the phase shifts resulting from plasma density changes and mechanical movements can be separated [1, 2, 3]. Until recently, the solution foreseen for W7-X was a CO_2/CO two-colour interferometer, where the larger wavelength was chosen to avoid fringe jumps even for high density plasmas and the shorter wavelength to be far enough from the visible range where thermo-optical effects and degradation of windows lead to significant errors [4, 5]. An alternative concept that is now being pursued, is the dispersion interferometer (DI), where mechanical effects are intrinsically compensated because both interfering beams travel the same geometrical path. In principle, only effects caused by a misalignment could influence the phase measurement. First test results at a fusion experiment were obtained at TEXTOR [6] in cooperation with the Budker Institute where the dispersion interferometer setup had been developed [7]. This paper reports on a direct comparison of the ability of vibration compensation of both types of interferometers. Therefore, the same laboratory setup was used. Well defined test vibrations and drifts were introduced by a corner cube reflector (CCR) mounted to a piezo nanopositioner. The vibration peak-to-peak amplitudes were varied up to 130µm with two different frequencies: 20 and 70 Hz. For simulating large-scale thermal movements with large amplitudes up to 1 mm a manual linear stage was used. This setup was implemented in both the laboratory 2-colour interferometer in Greifswald and the laboratory test line of one of the TEXTOR modules.

2. Setup and results of the 2-colour interferometer tests

Previously, for W7-X, a two-colour CO_2/CO interferometer was planned with wavelengths in the infrared being well adapted to phase shifts of less than 2π in high density plasmas of $10^{20}m^3$. Laboratory tests revealed that the lasers should be positioned outside the torus hall due to necessary daily maintenance of the CO laser. To simulate later torus hall conditions in the laboratory set-up (fig. 1), the CCR was mounted to the wall, well separated from the main interferometer components.

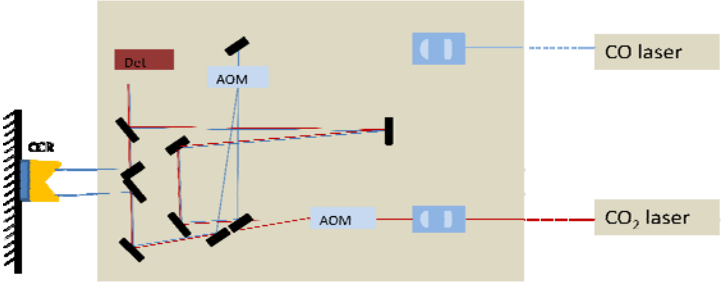

Figure 1: Laboratory setup of the 2-colour interferometer for vibration tests

It was found that the compensation of vibrations - parallel and perpendicular to the direction of the incoming beam - can be compensated to a factor of 0.001 (fig. 2).

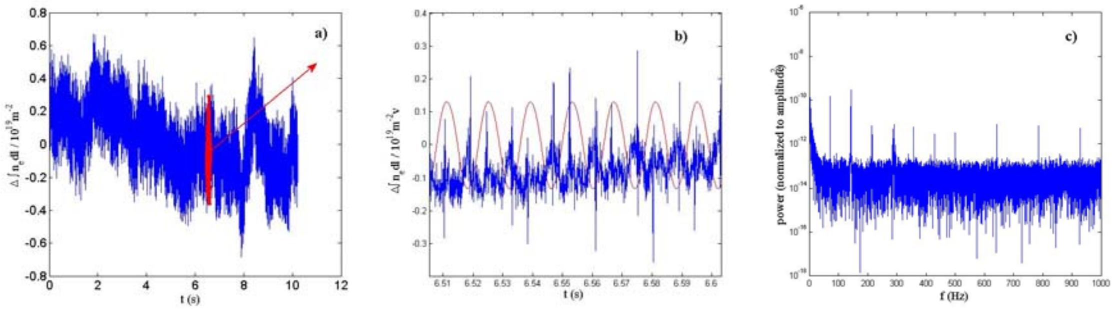

Figure 2: Compensation of vibrations with an peak-to-peak amplitude of 130µm and a frequency of 70Hz: a) compensated signal, b) time resolved compensated (blue) and CO_2 interferometer (red, down scaled with a factor of 1000) signals and c) fast Fourier analysis of the compensated signal

Even for amplitudes of 130µm, drifts of the phase caused by air effects between acousto-optical modulators and beam combiners as well as uncompensated vibrations of the beam combiners which cannot be compensated in principle, are in the same order of magnitude.

3. Setup and results of the dispersion interferometer tests

For testing the sensitivity of the dispersion interferometer, the CCR unit was placed at a distance of 5.5m behind the exit of one of the TEXOR modules used as test mock-up in the laboratory as shown in figure 3.

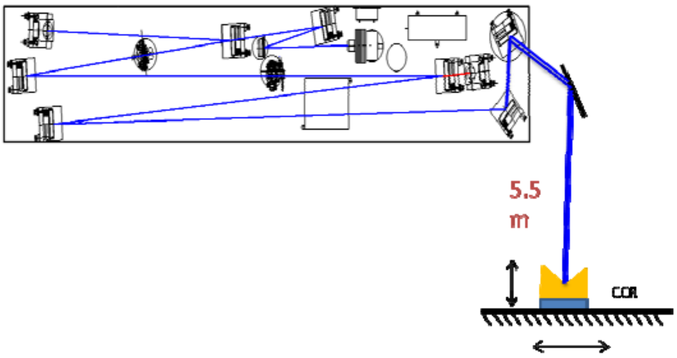

Figure 3: Experimental setup of the vibrations tests of the dispersion interferometer

It was found that the compensation of vibrations - parallel and perpendicular to the direction of the incoming beam can be compensated by a factor of 0.0005 (fig. 4). However, for the dispersion interferometer slow phase drifts are present and represent the major error. Thermal air instabilities can be a possible reason for these drifts. This would also explain the magnitude of the drifts being about five times less than those, found in the tests using the 2-colour interferometer which has a second arm for reference and the way between acousto-optical modulators and beam combiners where compensation is not possible at all.

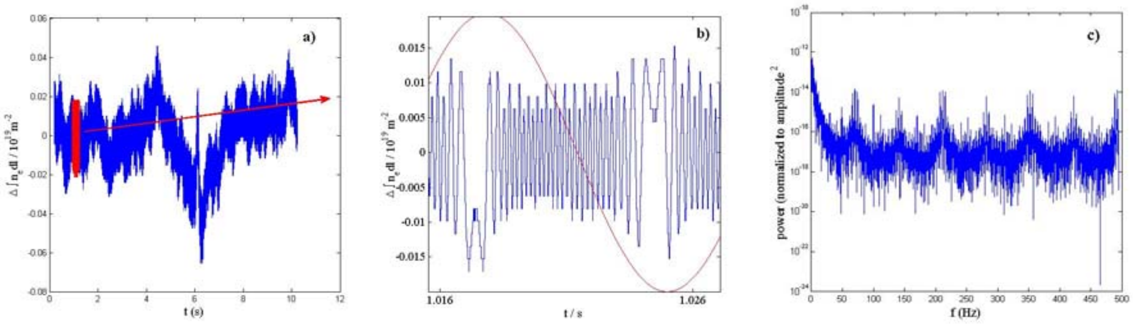

Figure 4: Compensation of vibrations with a peak-to-peak amplitude and a frequency of 70Hz in the case of the DI: a) raw signal showing thermal drifts, b) time resolved signal (blue) and amplitude of the piezo displacement (red, a. u.) and c) fast Fourier analysis of the DI phase signal signal

The small phase disturbances caused by vibrations as plotted in fig.3 b) and c) have the typical form of phase modulated signals. The signals can be modelled analytically by assuming that a small part of the 10.6µm beam reflected from the CCR enters the laser resonator again, becomes amplified in the laser resonator (seeding the de-excitation of the laser levels) and thus leads to a modulated laser beam.

4. Conclusions

The DI is the most appropriate type of interferometer to deal with large beam path changes due to thermal effects and possible vibrations of the CCR. Nevertheless, the limiting factors are the sensibility to a disturbance of the laser operation by the returning beam, the instability of the laser wavelength and fluctuations of the air temperature. Further experimental tests showed that only for a distance between the beams incoming and leaving the CCR more than 6 times the beam radius no impact to the laser output was observed. These effects are also present in the 2-colour interferometer as can be seen from the Fourier spectrum. But, because of the poor signal/noise ratio, they are not obvious directly from the data.

Thus, the dispersion interferometer will be the best choice for the single channel interferometer for W7-X. A two crystal setup of the DI would ensure both a proper separation of outgoing and incoming beams and optimal focusing on the second crystal. Stabilizing the laser resonator will help to reduce the phase drifts. Thermal air effects will be investigated in future experiments in order to decide whether air-conditioning of the covered bench is necessary. However, a proper water-cooling of the laser, the shutter, the 10µm filter in front of the detector and the detector itself will be installed.

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