§14. Conceptual Design of a Dispersion Interferometer with a Ratio of Modulation Amplitudes

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A conventional heterodyne interferometer is widely used and has a high density resolution. It, however, suffers from fringe jump errors, which degrade reliability of the interferometer, in a high density range. The mechanical vibrations also cause measurement errors. One of candidates of the solution is a dispersion interferometer. The dispersion interferometer uses both fundamental and second harmonics, which is generated with a nonlinear crystal, as a probe beam. After passing through a plasma, the probe beam is injected into another nonlinear crystal, to generate the second harmonic from the fundamental again. The remained fundamental is cut by a filter. The phase of interference signal between two second harmonics includes only the phase due to the dispersion of a plasma not due to mechanical vibrations. Hence, the dispersion interferometer does not need a vibration isolator and the two-color interferometry system even if a short-wavelength laser (a CO₂ laser or a Nd:YAG laser), which can reduce fringe jump error, is used.

Since the detected interference signal of a usual dispersion interferometer is similar to that of a homodyne interferometer, the dispersion interferometer has the same problem as the homodyne one; changes in the detected intensity lead to phase errors. In order to be insensitive to intensity variations, a photoelastic modulator (PEM) is placed between the nonlinear crystal and the plasma as shown in Fig. 1 [1]. In this optical configuration, the detected interference signal is given by as follows.

\[ I(t) = A + B \cos \left( 2 \rho_0 \sin \omega_0 t + \frac{3 c_e \overline{n}_0 L}{\omega} + \phi \right) \]  

where \( A \) and \( B \) are constant, which are determined by the detected intensity of the probe beam, \( \rho_0 \) is the maximum retardation of the PEM, \( \omega_0 \) is the modulation frequency of the PEM, \( c_e \) is the line averaged electron density, \( L \) is the optical path length in the plasma and \( \phi \) is an initial phase. The amplitudes of fundamental and the second harmonics \( I_{\omega_0} \) and \( I_{2\omega_0} \) of the modulation frequency \( \omega_0 \) of Eq. (1) can be measured with lock-in amplifiers and are described with the Bessel function of the first and second order \( J_1 \) and \( J_2 \).

\[ I_{\omega_0} = 2 BJ_1(2\rho_0) \sin \left( \frac{3 c_e \overline{n}_0 L}{2 \omega} + \phi \right) \]  

\[ I_{2\omega_0} = 2 BJ_2(2\rho_0) \cos \left( \frac{3 c_e \overline{n}_0 L}{2 \omega} + \phi \right) \]  

From the ratio of these amplitudes, \( \overline{n}_0 \) can be obtained.

\[ \overline{n}_0 = \frac{2}{3} \frac{\omega}{c_e L} \tan^{-1} \left( \frac{I_{\omega_0}}{I_{2\omega_0}} \right) \]  

Here, \( \rho_0 \) is set at 1.3 radian by adjusting the voltage to the photoelastic material for \( J_1(2\rho_0) = J_2(2\rho_0) \). This new method of the phase extraction from the dispersion interferometer is completely free from variations of detected intensities \( A \) and \( B \). In addition, the processing way is simple and suits to real time measurements.

An important component for a good SNR is a nonlinear crystal for second-harmonic generation (SHG), because the power of the second harmonics is generally small in the case of a continuous wave laser (i.e. small power density) and depends strongly on the specifications of the nonlinear crystal. Silver gallium selenide (AgGaSe₂) has the relatively high conversion efficiency and the small absorb coefficient. Figure 2 shows the generated power of the second harmonics. In the case of the crystal with a length of 15 mm-long, about 100 µW is generated when the beam waist at the crystal is 0.69 mm. This power corresponds to several-volts-interference signal, which is enough to be detected.

[1] T. Akiyama et. al., to be published to Plasma and Fusion Research.