COMPLEX INTERFEROMETRY: ITS PRINCIPLES AND APPLICATIONS TO FULLY AUTOMATED ON-LINE DIAGNOSTICS*)

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An interferometric technique which enables simultaneous recording of up to three sets of data into just one interferogram is discussed. The possibilities of the reconstruction of these data are studied. Three important particular cases allowing such a reconstruction are analyzed.

Introduction

Interferometry in its classical form is used for phase imaging of optically transparent objects. Up to now many different techniques for the phase shift reconstruction from interferograms have been developed: from the most primitive and the least accurate use of the ruler through the extremes of fringes seeking computer algorithms up to the most sophisticated and very accurate analysis based on the fast Fourier transform (FFT) [1].

Because this last mentioned technique makes possible a simultaneous calibration of the recording medium, it became immediately apparent that in the case of high quality beams (i.e. both the probe and the reference beam) not only the phase shift of the probe beam (encoded as a frequency modulation) but also the amplitude of the probe beam (encoded as an amplitude modulation) should have a good chance for the reconstruction from just one interferogram. This approach would bring substantial advantage over the usual method of recording two sets of data separately as it is very difficult to spatially superimpose these two sets of data during analysis.

This idea of two sets of data recorded into one interferogram led to the development of the phase-amplitude imaging technique which was successfully tested on simulated data [2]. The first real application of this technique was aimed at the fully automated analysis of megagauss magnetic field measurements in laser-produced plasmas. During the analysis of experimentally obtained interferograms, however, one more phenomenon — fringe blurring caused by the phase shift changes during an exposure time — was found to have a detrimental effect on the accuracy of reconstructed data [3]. On the other hand, this initially rather unpleasant surprise revealed the fact that the FFT analysis technique is so sensitive that it can be used, in principle, for the

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reconstruction of up to three independent sets of data encoded into single interferogram: the phase shift, the amplitude and the phase shift time derivative.

This generalization of classical interferometry we shall, from now on, call complex interferometry. Its mathematical description in general, as well as several particular examples, will be given in subsequent paragraphs.

General description

If a coherent probe beam with its amplitude varying in time is shone through an object that modifies both its phase and amplitude, the resulting beam may be described by

\[ \psi_p(r, t) = a(r, t)f(t) \exp[ik_p r + i\phi(r, t)] . \] (1)

After this has interfered with a reference beam

\[ \psi_r(r, t) = a_0 f(t) \exp(ik_r r) \] (2)

and choosing the \((y, z)\) plane as the plane of interference, a time dependent intensity pattern described by

\[ i(y, z, t) = a_0^2 f^2(t) + a_0^2(y, z, t)f^2(t) + 2a_0 a(y, z, t)\cos[2\pi(\omega_0 y + v_0 z) + \varphi(y, z, t)]f^2(t) \] (3)

will result, where the relations between two sets of corresponding variables, i.e. the wave vectors \(k_p\) and \(k_r\), and the phase shift \(\phi(r, t)\) on one side and the spatial frequencies \(\omega_0\) and \(v_0\) and the phase shift \(\varphi(y, z, t)\) on the other side, can be calculated in the usual way. Thus we have encoded both the amplitude and the phase changes of the probe beam introduced by the object. Original temporal profiles of the amplitudes of both beams were denoted by \(f(t)\) with the following normalization:

\[ \int_{-\infty}^{\infty} f^2(t) \, dt = 1 . \] (4)

Up to now, the expression (3) in its general form has not been solved. In following paragraphs we shall describe the most important particular cases where this solution can be found.

Stationary phase-amplitude objects

In the case of stationary phase-amplitude objects, integrating the intensity pattern (3) in time, the following expression will result:

\[ i(y, z) = a_0^2 + a_0^2(y, z) + 2a_0 a(y, z)\cos[2\pi(\omega_0 y + v_0 z) + \varphi(y, z)] . \] (5)

One example of the interferogram illustrating this particular case is shown in Fig. 1 (see Plate I, p. 792a).