A phase quadrature feed back interferometer with a frequency stabilized two mode He-Ne laser

A PHASE QUADRATURE FEED BACK INTERFEROMETER WITH A FREQUENCY STABILIZED TWO MODE HE-NE LASER

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INTRODUCTION AND PRINCIPLE. The feedback interferometer, FBI, consists of a laser cavity weakly coupled to an external cavity. This type of interferometer can be used for the measurement of small changes in the refractive index, e.g. of a transient plasma located in the external cavity. If the radiation reflected by mirror M_3, Fig. 1, reenters to laser cavity it has a phase difference ψ with respect to the internal laser field. This phase difference is determined by the optical length of the external cavity and thus by the refractive index of the plasma. Depending on ψ positive or negative interference with the internal laser field occurs giving rise to a modulation of the laser output. This FBI, in which the laser is both source and detector, has an extremely simple configuration. This results in a good mechanical stability and a simple alignment procedure.

With most interferometers we encounter the problem that only one singular phase information is obtained. Especially when phase changes are larger than π it is impossible to determine unambiguously the sign of the phase change from the observed interference. To solve this problem it is sufficient to obtain two independent phase informations. This can be achieved among others by using two interference singals instead of one. With two beams which are $\frac{1}{2}\pi$ out of phase we obtain the phase information as $\sin\psi$ and $\cos\psi$ and the ambiguity is eliminated [1,2]. In the phase quadrature FBI of ref. 2 two adjacent axial modes of a He-Ne laser without Brewster windows, serve as the two independent beams to obtain two independent phase informations. It is shown there that for specific ratios of the external-cavity length and the laser-cavity length the phase information is in quadrature. The adjacent axial modes of the laser are orthogonally polarized [3] and therefore the two different phase informations could be easily separated with polarizers.

The interrelation between the two phase data ψ_1 and ψ_2 depends on the ratio of the external-cavity length, L_{ext}, to the laser-cavity length, L_1. We assume that the two adjacent axial modes are independent and that there is no coupling between the two polarisation directions in the external cavity and the mirror M_3. Then one can derive for the difference between ψ_1 and ψ_2

$$\Delta\psi = \psi_2 - \psi_1 = (L_{ext}/L_1) \, 2\pi$$

If we choose L_{ext} such that $L_{ext}/L_1 = i \pm \frac{1}{4}$, where i is an integer, the phase data differ by $\frac{1}{2}\pi$ and we obtain phasequadrature. This is of course related to the mode spacing, $\Delta f = c/2L_1$, In [4] it is derived that when only a small part of the beam is reflected back into the lasercavity, the modulations of the intensities of the two modes $\Delta I_{1,2}$ depend on the phase shifts $\psi_{1,2}$ as

$$\Delta I_{1,2}(\psi_{1,2}) = C_1 + C_2 \, \cos\psi_{1,2}$$

For the situation $L_{ext}/L_1 = i \pm \frac{1}{4}$, we obtain $\Delta I_1 = C_1 + C_2 \cos\psi_1$; $\Delta I_2 = C_1 \pm C_2 \sin\psi_1$ and we have ψ_1 in phase quadrature.

STABILIZATION OF THE LASERCAVITY. Without any precautions temperature changes will cause variations of the lasercavity length. This results in a drift of the two modes through the Doppler profile. With regard to the use in a FBI, in a strict sense, stabilization is not necessary since density variations of e.g. a transient plasma are much faster than temperature drift. But of course, stabilization would make the system more useful, since mode changes are avoided.

Stabilization of the laserlength and thus the frequency can be achieved by keeping the amplitude of the axial modes equal in magnitude. The difference between the measured intensities of the two modes is kept zero by means of a difference amplifier, integrater and a high voltage amplifier connected to piezo element P_1, Fig. 1. In our experiment the lasercavity length temperature variations are compen-

sated for by the variation due to piezoelement P_1 which is attached to lasermirror M_2. In this manner a frequency stabilized source for the FBI is obtained,
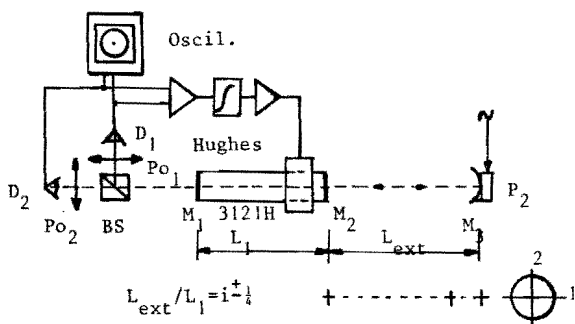

Fig. 1 Experimental set up of the FBI with specified position of mirror M_3. $M_{1,2}$ = laser mirrors, M_3 = reflectence mirror, $P_{1,2}$ = piezoelements, B.S. = beamsplitter, $Po_{1,2}$ = polarizers, $D_{1,2}$ = detectors.

EXPERIMENTAL RESULTS. In our experiments a change of the refractive index of a plasma is simulated by modulating the position of M_3 by the application of an AC voltage to piezoelement P_2 on which M_3 is mounted. The signals from detectors D_1 and D_2 are recorded on a x-y oscilloscope to produce a lissajous pattern which for the considered case of quadrature is a circle. In the first experiment described in [2] the phase quadrature position of mirror M_3 was not in agreement with the expected position of the ratio $L_{ext}/L_1 = i \pm \frac{1}{4}$. This was probably due to the fact that the laser used in ref. 2 was sometimes functioning as a three mode instead of a two mode. In the presented experiment a two mode laser Hughes 3121 H is used and the phase quadrature positions of mirror M_3 are in very good agreement with the relation $L_{ext}/L_1 = i \pm \frac{1}{4}$. To investigate the stability and the possible use of the laser as a secondary wavelength standard, we have calibrated the stabilized two mode laser ($\lambda = 632.8$ nm) against an iodine stabilized He-Ne laser. By beat experiments we have found that the absolute frequency distance between one of the modes and the iodine stabilized laser is 22 MHz. Of course this depends on the electronic zero setting of the two mode laser. The uncertainty mainly due to electronic gain variations is roughly 0,2 MHz during serveral houres and determines the limit of its stability.

CONCLUSIONS. We have devloped a phase quadrature feedback interferometer which is very useful to solve the ambiguity of the sign of changes in the refractive index of e.g. a transient plasma. The source, a frequency stabilized He-Ne laser ($\lambda = 632.8$ nm) can also be used as a wavelength substandard.

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