RECENT DEVELOPMENTS IN HOMODYNE INTERFEROMETRY

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Abstract

Continuing developments in homodyne laser interferometer systems [1] are improving both their measurement performance capability and their ease of installation. This paper gives an overview of such a system and explains several of the key design features. Firstly, an overview of the optical detection scheme is given. Secondly, a novel method for improving the Sub Divisional Error (SDE) in a Column Reference (CR) interferometer is described. Finally a technique for improving the frequency stability of fibre optic coupled laser sources is explained.

1. Introduction

Applications where the highest levels of laser interferometer measurement performance are required typically involve positioning within vacuum chambers where the effect of air turbulence on measurement stability is removed. This paper describes an interferometer system suitable for these applications which has the benefits of a fibre optic coupled laser source to simplify installation. The interferometer system consists of a fibre optic coupled laser source and one or two detector heads.

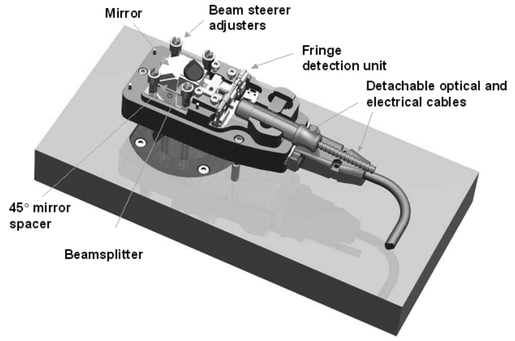

Figure 1 CR detector head with cover removed

The detector heads mount onto the outside wall of a vacuum chamber and contain a CR interferometer, integrated beam steering optics for both pitch and yaw adjustment and an integrated fringe detection unit. Common mode errors, like for example the vibration of the vacuum chamber sidewall, are minimised because the interferometer measures the differential position of two objects inside the chamber. The laser source is situated remotely from the chamber and a fibre optic cable is used to route the laser beam to the detector heads. The detector head is shown in figure1.

2. Integrated fringe detection unit overview

The laser interferometer system contains an integrated fringe detection unit. The detection scheme is shown in figure 2.

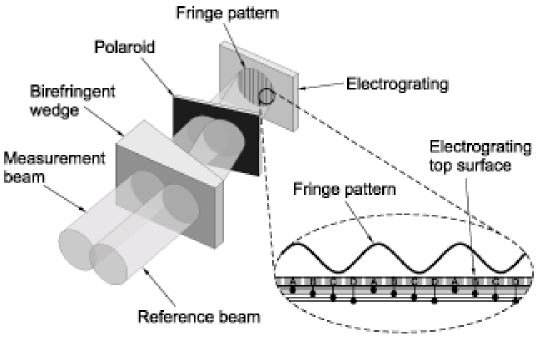

Figure 2 Fringe detection scheme

When the orthogonally polarised measurement and reference beams enter the signal detection unit they pass through a birefringent wedge that creates an angular deviation between the beams. The beams then pass through a Polaroid aligned at 45º to make them interfere. The resultant interference pattern is a linear array of fringes. These fringes are aligned with an integrated linear photodiode array, called an electrograting. The electrograting produces four electrical signals of relative phase 0º, 90º, 180º and 270º. Sine and cosine output signals are produced by differencing the 0º and 180º signals and the 90º and 270º signals. Because of the excellent gain matching of the electrograting, the differential amplifier removes common mode intensity changes on the signals due, for example, to an intensity change of the laser.

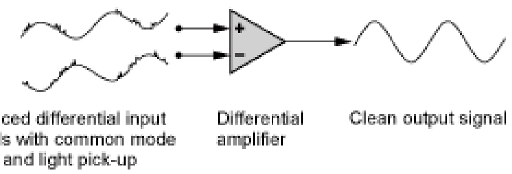

Figure 3 Common mode rejection

3. *Sub Divisional Error (SDE) performance*

A significant degradation to the SDE performance occurs in CR interferometers when the measurement and reference mirrors are well aligned. A solution to this problem has been developed and the test results are shown.

3.1 *SDE in retro reflector interferometers*

Imperfections in polarising beamsplitter and retro reflector performance typically cause a degradation in the SDE performance of an interferometer [2].

The magnitude of the effect is typically quite small. This is because the leaked beams which cause the degradation are attenuated twice by the polarising coating before they enter the detector optics. This is illustrated in figure 4. Only one of the two leaked beams is shown for clarity.

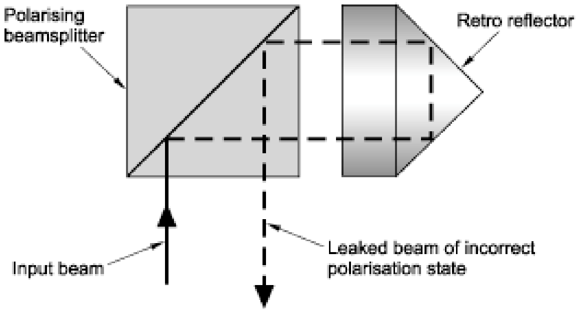

Figure 4 Leaked beam in retro reflector interferometer (only the leaked beam is shown for clarity)

If α is the extinction ratio of the beamsplitter and β is the polarisation cross coupling of the retro reflector then the equation for the intensity of the interference signal of a leaked beam and a measurement beam as a ratio of the measurement signal is:

$$\text{Iratio} = (\alpha^2 + \alpha\beta)^{0.5} \qquad (1)$$

With a typical performance polarising beamsplitter (extinction ratio ~ 0.5%) and retro reflector (polarisation cross coupling ~ 1.5%) the SDE contribution is around +/- 0.5 nm (assuming a laser wavelength of 633 nm and a single pass interferometer). In many systems this is negligible.

3.2 *SDE in column reference interferometers*

In a CR interferometer light which has passed once around one arm of the interferometer may leak into the other arm and then return to the detection unit as shown in figure 5. Only one of the two leaked beams is shown for clarity. The leaked beams in the CR interferometer are produced mainly due to imperfections in the beamsplitter polarisation performance.

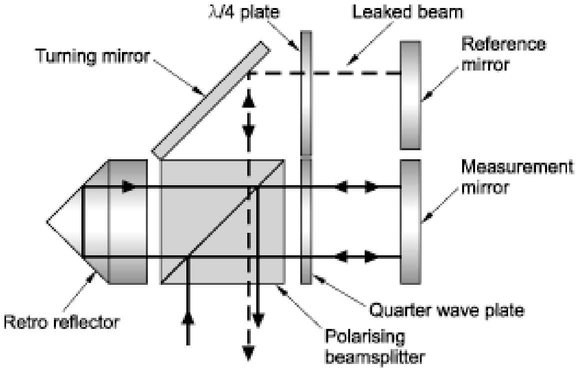

Figure 5 Leaked beam in CR interferometer

To align the system the reference and measurement beams are adjusted so that they return into the detection unit. This is required so that good signal strength is achieved. This means that the beams will be nominally normal to the reference and measurement mirrors.

Because the mirrors are aligned, the leaked beams will also return into the detection unit parallel with the measurement and reference beams. This will cause a significant degradation in the SDE performance of both homodyne and heterodyne interferometers.

The intensity of the signal from the interference of a leaked beam and a measurement beam as a ratio of the measurement signal is described by equation 2. Second order terms have been ignored.

$$\text{Iratio} = \alpha^{0.5} \qquad (2)$$

With a typical performance polarising beamsplitter (extinction ratio ~ 0.5%) the SDE contribution of a single leaked beam is around +/- 2.5 nm for both homodyne and heterodyne interferometers (assuming a laser wavelength of 633 nm and a double pass interferometer). In a typical CR application the reference mirror is nominally stationary and therefore a leaked beam, which is incident on the measurement mirror once, is a single pass signal and therefore has half the frequency of the main signal.

In a homodyne interferometer this creates a 'double lissajous' as shown in figure 6.

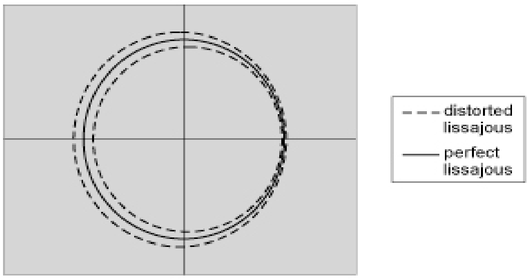

Figure 6 Lissajous distortion from CR interferometer

In a heterodyne interferometer system the phase of the interference signal between the measurement and reference arm will be variably shifted by the 'leaked beam'. Figure 7 shows the shift in the zero crossing point between a perfect heterodyne signal and a distorted heterodyne signal.

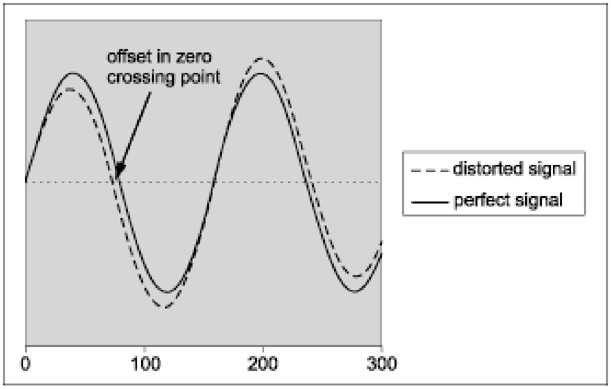

Figure 7 Phase shifting of heterodyne signal

3.3 *Solution in homodyne systems*

A solution to this problem is to generate an angular offset between the leaked beams and the main beams before they enter the detection unit. This means that the interference pattern generated does not match the electrograting. The resultant signal from the electrograting is therefore common on all four of the output channels and has no effect on the measurement.

This may be implemented by angularly offsetting either the measurement mirror or the reference mirror. However, over even relatively short axis lengths, this can create a significant drop in signal strength. Also, especially on a heterodyne system, the user typically has no easy way of detecting if the mirror is sufficiently offset to reduce the SDE. A better way of angularly offsetting the beams is to insert a glass wedge into the first pass of the reference beam of the interferometer as shown in figure 8.

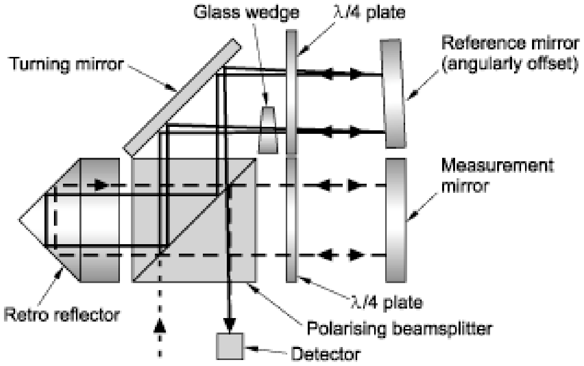

Figure 8. CR interferometer setup with glass wedge.

This will cause the reference beam to be angularly offset from the measurement beam when it enters the detector optics which will alter the fringe pattern generated. If the glass wedge is aligned correctly then the electrograting may simply be rotated to match the fringe pattern again. See figure 9.

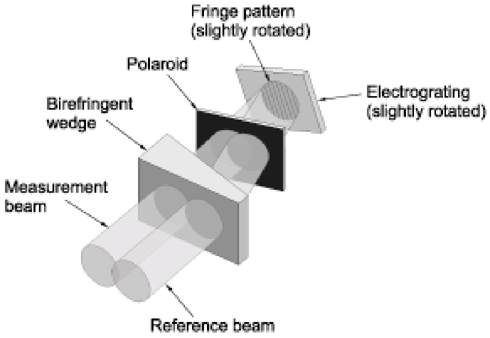

Figure 9 Electrograting rotated to match fringe pattern

Now, when the plane mirrors are aligned to optimise the signal strength, the reference mirror will not be quite normal to the reference beam. The leaked beam returns into the detector optics with an angular offset as shown in figure 10. As it is aligned at a different angle to the other beams, the interference pattern generated does not match the electrograting and therefore does not cause a measurement error.

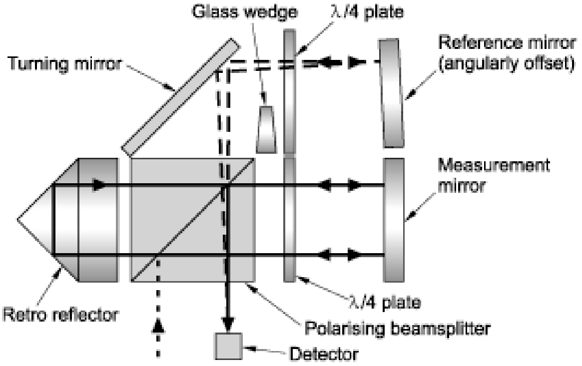

Figure 10 Angularly offset leaked beam – the main reference beam is not shown for clarity

The SDE performance of a batch of CR interferometers with the glass wedge modification was tested. The SDE of all the units were found to be less than +/- 0.5 nm.

3.4 *Solution in Heterodyne systems*

The SDE degradation in heterodyne systems can also be solved with a similar method to the technique described in section 3.3. However, a birefringent wedge is required after the measurement and reference beams have been recombined in order to make the wavefronts parallel again.

4. *Laser frequency stability improvement*

A He-Ne gas laser may be frequency stabilised by controlling the laser tube length. This may be done by controlling the temperature of the tube. The feedback signal for the temperature control comes from the difference in the intensity of the two laser output modes. The intensity of the modes may be measured by separating the modes with a polarising material before shining them onto separate photodiodes [3].

However, the output frequency stability of a laser may be degraded by back-scattered light returning into the laser tube. There are a number of sources of back-scattered light in any interferometer system. With a fibre coupled laser source, a significant source of back-scattered light is the fibre optic itself.

4.1 Degradation of laser frequency stability

When back-scattered light returns into the laser tube, it interferes with the light inside the tube. As the phase of the back-scattered light changes, the interference with the light inside the tube varies between constructive and destructive interference. This causes a variation in the intensity of the laser beam emitted from the tube. The intensity and phase of the back-reflected light in each of the two polarisation states is typically different. Therefore, the intensity variation will occur in the two orthogonal laser modes independently. This causes a difference between the signals from the stabilisation photodiodes. The control algorithm cannot distinguish this intensity difference from a genuine laser frequency change and therefore tries to compensate for it by changing the temperature of the tube to balance the photodiode signals. An overview of the system is shown in figure 11.

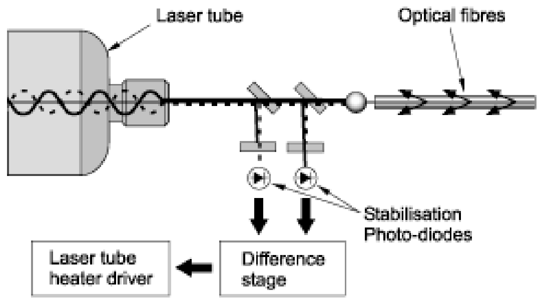

Figure 11 Frequency stabilisation of laser

4.2 Solution

The effect of the back-scattered light on the laser frequency stability may be dramatically reduced if an optical path length modulator is inserted into the optical path between the laser tube and the source of back reflected light. The modulator changes the relative phase of the back-scattered light relative to the laser light inside the tube. If a heater is used to control the length of the tube, then the bandwdith response of the frequency control is fairly slow. If the frequency of the phase modulation is significantly higher than this then the effect of the backreflections on the frequency stability is greatly reduced. The frequency stability of a fibre coupled laser source with and without a phase modulator is shown in figure 12.

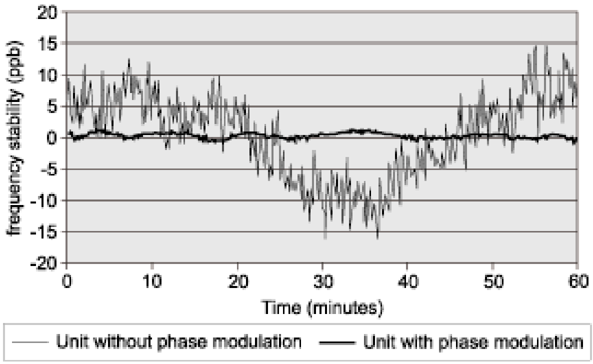

Figure 12 Comparison of frequency stability of laser sources

The phase modulation is also of benefit in CR and plane mirror applications where, due to imperfections in the performance and alignment of optical components, light may leak back into the laser tube when the plane mirrors are aligned normal to the beam. This can degrade the frequency stability of the laser. The effect of this is also minimised by the phase modulation technique.

5. *Conclusions*

Recent developments in homodyne interferometers have improved both their measurement performance capability and their ease of installation. An improvement to the SDE of CR interferometers has been demonstrated. A technique for reducing the sensitivity of laser tubes to back-scattered light has also been shown.

References

[1] Chapman M., Attwood L: Heterodyne and homodyne interferometry, SEMI Technical Symposium: Innovations in Semiconductor Manufacturing 2003.

[2] Bobroff. N: Recent advances in displacement measuring interferometry, Meas. Sci. Technol. 4 (sept 1993) 907-926

[3] Bennet S. J.,Ward R. E.,Wilson D.C.: Frequency stabilzation of Internal mirror He-Ne Lasers. Applied optics vol.12 No.7 (July 1973).