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(54) **Michelson interferometer**

(57) A Michelson interferometer has a wedge-shaped beamsplitter (7) and compensator (9) plates of substantially identical wedge angle and thickness. The compensator plate is positioned to cancel out beam displacement and deviation introduced by the beamsplitter plate.

R = Beamsplitter reflectance
T = Beamsplitter transmittance

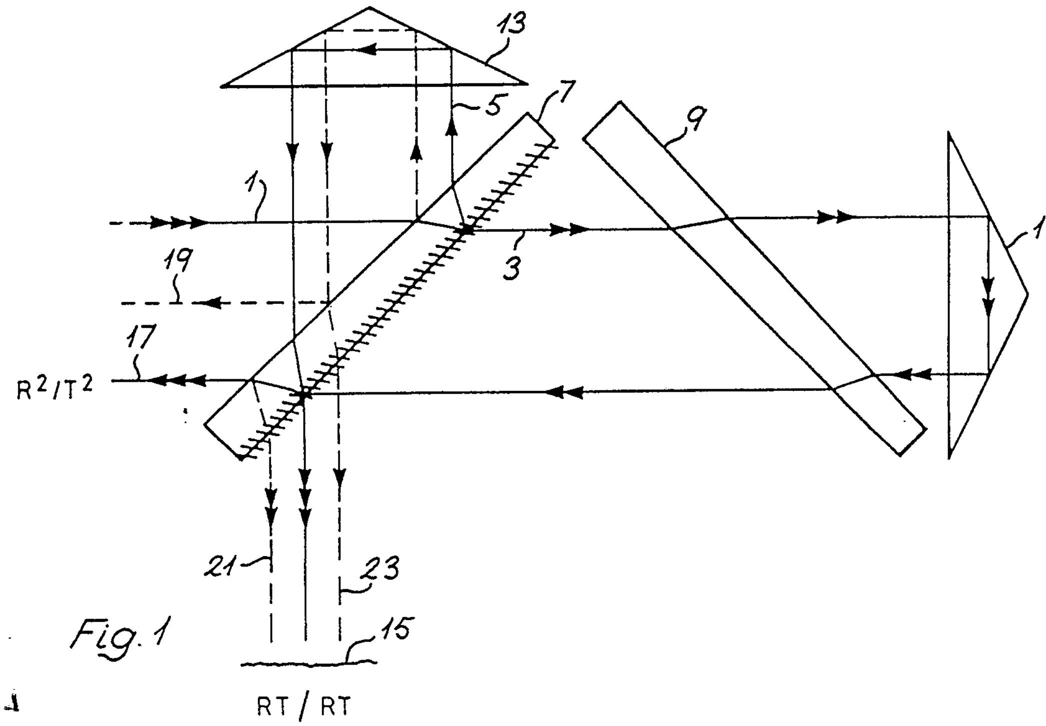

Fig. 1

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R = Beamsplitter reflectance
T = Beamsplitter transmittance

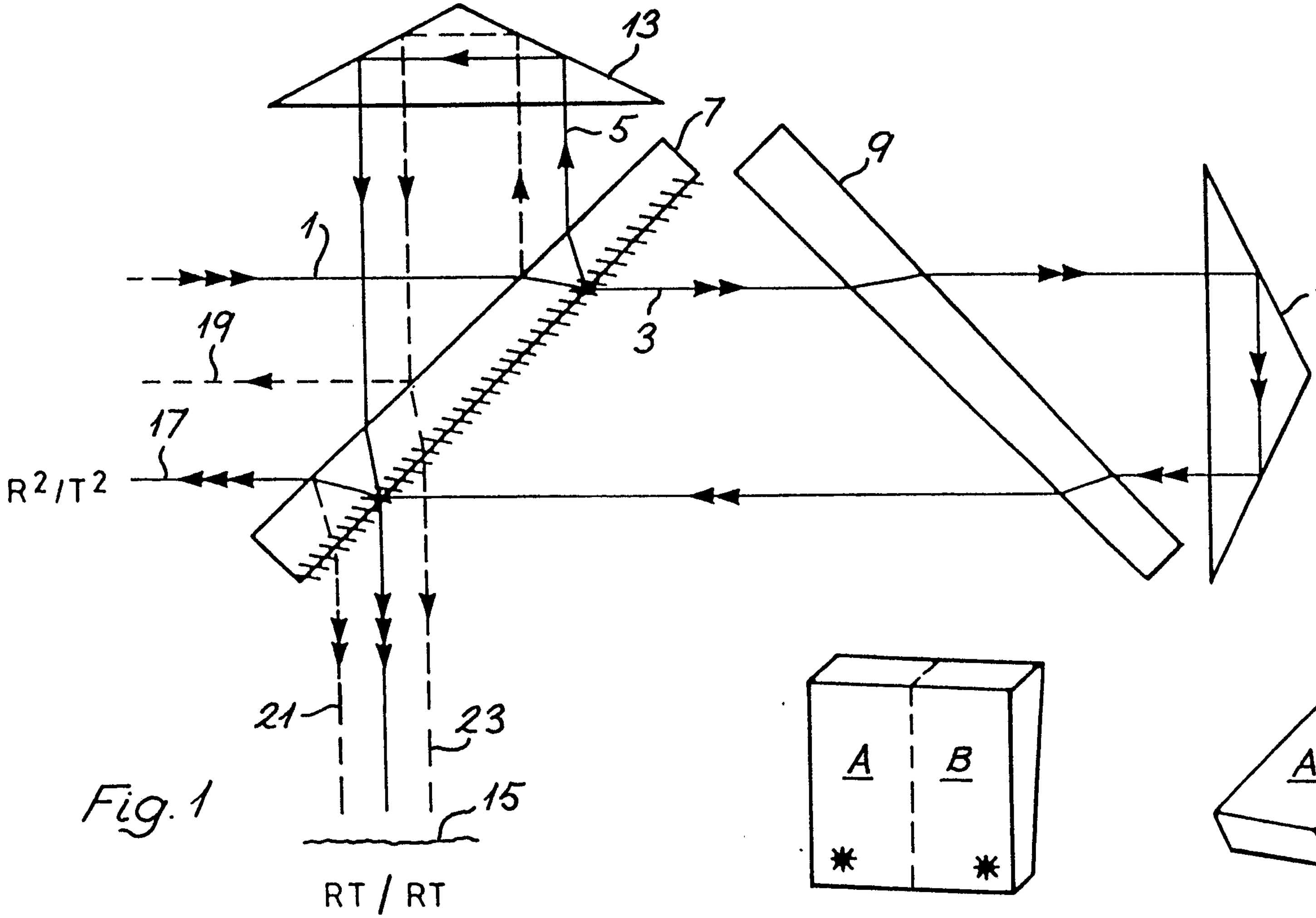

Fig. 1

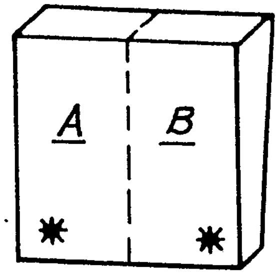

Fig. 2a

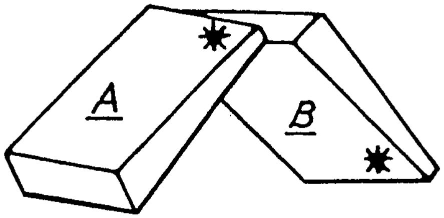

Fig. 2b

R Beamsplitter reflectance

T Beamsplitter transmittance

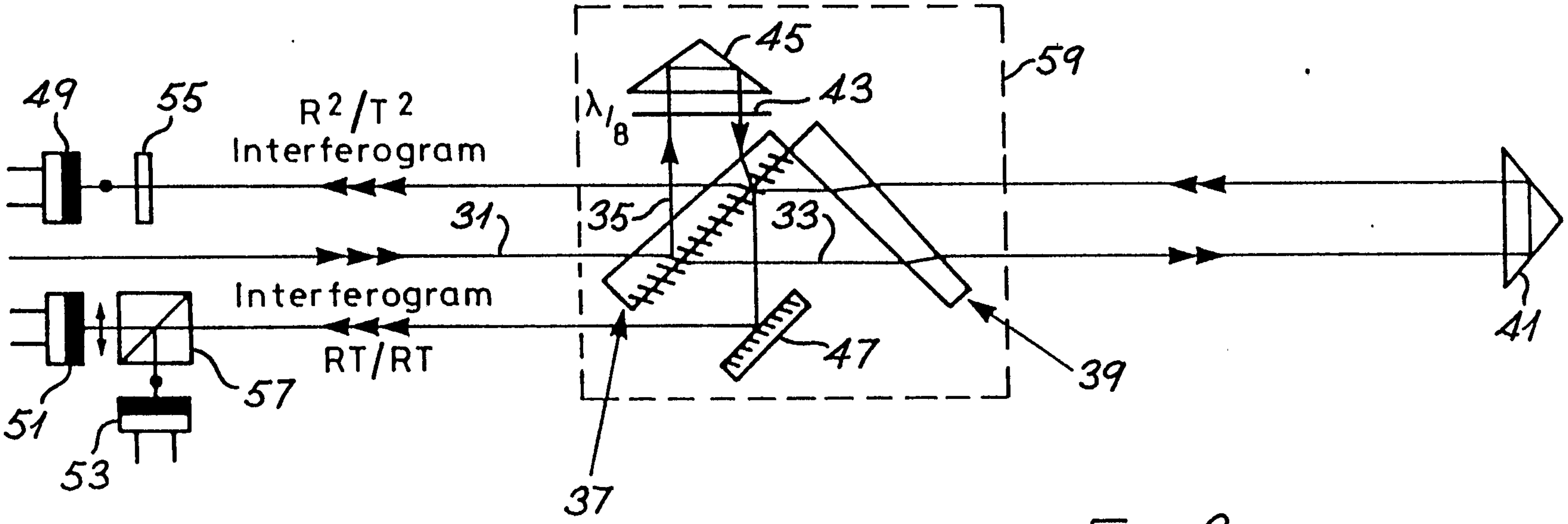

Fig. 3

Optical measuring instruments

This invention relates to optical measuring instruments and, in particular, to laser interferometers.

Optical interferometry is widely used for the measurement of length and the coherence of laser radiation permits fringe-counting systems with measurement ranges in the free atmosphere of up to 50 metres. The most commonly used radiation sources are frequency stabilised helium-neon lasers. These devices are readily available commercially and experience has shown that their frequencies do not usually change by more than a few parts in 10^8 over the lifetime of the laser tube. Interferometers measure length in terms of the wavelength of the radiation and, when they are used in the free atmosphere, it is essential to apply a correction for the refractive index of the air. The two techniques currently used for performing this correction are the calculation of a refractive index value using Edlen's equation by measuring the atmospheric pressure, temperature and humidity, and the direct measurement using an interference refractometer. The results of comparisons between calculated and measured values have shown that where an uncertainty of the order of ±1 part in 10^7 is acceptable in the refractive index of the air, a calculated value may be employed. This source of uncertainty is reduced to approaching a part in 10^8 when a refractometer is used.

By using electronic systems to analyse the electrical signals generated from the optical path length changes, sub-nanometric solutions can be achieved by interferometer systems, provided that disturbances due to temperature, vibration and air turbulence etc. are minimised. However, there are two basic systematic limitations to the accuracy achievable when realising this high resolution.

Many interferometric systems employ polarisation techniques to derive the electrical signals required for reversible fringe counting from their optical outlets. The signals should be sinusoidally related to path difference and, ideally, they should be in phase quadrature, equal in amplitude and their mean DC levels zero. In practice the signals are not ideal and, when resolving to sub-nanometric precision, the imperfections impose a limit on the accuracy achievable by the interferometer system. Thin film polarising beamsplitter designs providing sufficient isolation between the two orthogonally polarised beams are not available and it is sometimes difficult to maintain the required alignment of the polarisation azimuth of the optical components. However it is possible to correct systems for non-ideal optical signals electronically. This is achieved by scanning the optical path in the interferometer through at least one fringe and examining the phases, amplitudes and DC levels of the signals both to compute any necessary changes and also to confirm the sinusoidal quality of the interferometer signals.

Stray reflections are another severe systematic limitation to achieving both accuracy and resolution in interferometers. With a laser source the unwanted beams are coherent, so that even one tenth of a percent of the beam energy can cause an anomalous variation in the interferometer signal and a non-linearity error of 1.6nm in the optical path length measured.

In British Patent No.2012450B there is described an interferometer (hereinafter referred to as the NPL interferometer) which utilises a plate beamsplitter. It is standard practice with this type of interferometer to minimise the effects of reflections from the non-beamsplitting surface by both employing a standard anti-reflection coating on the surface and by slightly wedging the beamsplitter plate. The latter practice is the most efficient way of solving the problem. From the equations of Rowley (WRC Rowley "Signal strength in two-beam interferometers with laser illumination" Optica Acta **16** (1969) 159-168) it may be shown that the beam divergence caused by a wedge of 1½ minutes of arc introduces sufficient fringes across the aperture of a 1mm diameter Gaussian distribution beam for any stray reflections falling on the photodetectors to have less than nanometric influence on the phase of the interferogram.

Although wedging removes the problems due to stray reflections it presents another problem in that it effectively turns the beamsplitter into a weak prism. The resulting beam divergence, together with the displacement caused by the 45° angle of incidence on to the plate impose the condition that the beamsplitter must be in position when the optical beam is aligned to the mechanical axis of movement. In practice this makes the alignment procedure extremely difficult and, in addition, prevents the interchange of beamsplitters other than those fabricated with a specified thickness and wedge angle. In order to realise accurate sub-nanometric resolution in interferometers having a beamsplitter plate, a beamsplitter and compensator plate system has been devised.

According to the present invention there is provided a Michelson interferometer having wedge-shaped beamsplitter and compensator plates of substantially identical wedge angle and thickness wherein the compensator plate is positioned to cancel out beam displacement and deviation introduced by the beamsplitter plate.

This enables the optimum alignment of the optical and mechanical axes of the system to be achieved before the interferometer block is introduced into the system as it leaves the alignment totally unaffected.

An embodiment of the invention will be particularly described with reference to the accompanying drawings, in which:-

Figure 1 shows, in schematic form, a Michelson interferometer in accordance with one embodiment of the invention;

Figure 2 shows beamsplitter and compensator plates for the interferometer of Figure 1; and

Figure 3 shows a length measuring interferometer in accordance with another specific embodiment of the invention.

Referring now to the drawings, Figure 1 shows a Michelson interferometer with a compensator plate. Radiation from a laser source enters the interferometer as a laser beam 1. It is separated into a transmitted beam 3 and a reflected beam 5 by a wedge-shaped beamsplitter 7. The transmitted beam 3 passes by way of a wedge-shaped compensator plate 9 to a retroreflector 11 and back through the compensator plate to the beamsplitter. The reflected beam 5 is further reflected by a retroreflector 13 and passes again to the beamsplitter 7 where it is combined with the returning transmitted beam 3 to form two interferograms 15,17. One plate acts as a compensator, cancelling out the beam displacement and deviation introduced by the beamsplitter plate.

A beamsplitter plate of twice the required size is fabricated. This is then cut into two equal parts A,B (Figure 2a), which are used in the optical configuration shown in Figure 2b. It will be appreciated that it is important to introduce some means of orientation identification on to the plate, for example by slightly chamfering two corners at one end, before it is cut. (Indicated by a star on the drawing.)

This arrangement is completely insensitive to the thickness and wedge angle of the orthogonal plate. If the direction of the wedge in the beamsplitter plate is confined to the direction in which the beams are displaced, the interferometer system is also chromatically corrected when the outgoing and reflected light beams are symmetrically disposed about the centre of the beamsplitter plates. This would be an advantage if a multi-wavelength source were to be employed. The main stray reflections from the non-beamsplitting interface labelled 19, 21 and 23, are shown in Figure 1 by the dashed ray path. Beams 2 and 3 are deviated, but it is important to note that the beamsplitter wedge does not introduce any angular deviation between reflection 1 and the main interferogram. Although this is a potential source of error the beam undergoes two relatively low intensity reflections, of the order of 1% and it is significantly displaced so that it will not fall on the photodetector, provided that a beamsplitter plate several millimetres thick is employed.

In accordance with a further aspect of the invention, a length-measuring interferometer may be modified by the addition of a reflector, as shown in Figure 3, to allow both interferograms to be examined remotely from the interferometer block.

In this apparatus, an incident laser beam 31 is separated into a transmitted beam 33 and a reflected beam 35 by a wedge-shaped beamsplitter 37. The transmitted beam passes via a wedge-shaped compensator plate 39 to a movable retroreflector 41. The reflected beam 35 passes by way of a λ/8 phase plate 43 to a retroreflector 45 and thence back to the beamsplitter. A reflector 47 permits both the transmittance and the reflectance interferograms to be examined in the same remote location by photodetectors 49,51,53, polariser 55 and polarising beamsplitter 57.

This arrangement permits the critical components to be mounted on an interferometer block 59.

By electronically analysing the sinusoidally varying path length signals provided by interferometers, sub-nanometric accuracy and resolution can be achieved. However, stray reflections can cause significant systematic errors when resolving to this accuracy and it is essential to design the optics to tilt the wavefront of any stray reflections that reach the photodetectors.

Claims

1. A Michelson interferometer having a wedge-shaped beamsplitter (7) and compensator (9) plates of substantially identical wedge angle and thickness wherein the compensator plate is positioned to cancel out beam displacement and deviation introduced by the beamsplitter plate (7).

2. A Michelson interferometer as claimed in claim 1 wherein the beamsplitter (7) and compensator (9) plates are fabricated from a common plate.

3. A Michelson interferometer as claimed in claim 2 wherein said common plate is provided with means of orientation identification (*) to serve as means of orientation identification after fabrication into separate beamsplitter and compensator plates.

4. A Michelson interferometer as claimed in claim 3 wherein said means of orientation identification comprises a chamfer.

5. A Michelson interferometer as claimed in claim 1 wherein the direction of the wedge of said beamsplitter plate (7) is selected for chromatic correction when outgoing and reflected light beams are symmetrically disposed about the centre of the beamsplitter plates.

6. A Michelson interferometer as claimed in claim 1 wherein the thickness of said beamsplitter (7) is such that a beam undergoing multiple reflections is displaced so that it does not fall upon the detector (49).

7. A Michelson interferometer as claimed in claim 1 having reflector means (47) to permit both interferograms to be examined remotely from the interferometer block (59).

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