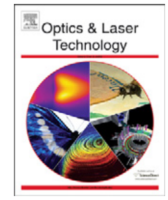
Optics & Laser Technology 44 (2012) 1620–1628

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

journal homepage: www.elsevier.com/locate/optlastec



Interference fringe detection system for distance measuring interferometer

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ARTICLE INFO

Article history:
Received 28 October 2011
Accepted 1 November 2011
Available online 20 December 2011

Keywords:
Interferometer photodetection system
phase-quadrature signals
Interferometer distance measuring errors

ABSTRACT

A novel photodetection system for a homodyne distance measuring interferometer by means of fringe counting method is presented. The system is based on applying compact size integrated photodetector operating with fringe pattern having fixed, finite period. 13-element integrated photodiode arranged in novel signal processing scheme receives interference fringes movement. Additional lens is used to adjust the fringe period to photoelements' distances. Due to the proposed configuration of the photoelement's signal processing and the applied lens the system has reduced sensitivity to interference fringe period errors caused by the angular misalignment of interfering beams. The theoretical analysis and experimental verification of the system metrological feasibilities are presented. Comparison of performance of examples of standard and novel detection systems is shown finally.

1. Introduction

Measurement of linear and angular displacements by a laser interferometer is based on generation of interference fringe zone (the light and dark fringe alternately), which move in front of a photodetector as a result of interferometer's reflector movement. Cyclic changes of a light intensity generated during reflector displacement produce proportional change of photodetector's electrical signal. Generation of the two $\pm 90^\circ$ phase shifted output signals is essential to make possible detection of the movement direction. Displacement direction is indicated by the sign of the phase shift. The phase shifted output signals also allow to increase the measurement resolution by various interpolation techniques.

The output of typical interferometric displacement measurement by means of fringe counting method is sum of two components: number of full periods of interference signals I_I and I_{II} received during displacement of the measuring reflector and a partial phase calculated from relation:

$$\alpha = \arctan(I_I/I_{II}) \tag{1}$$

I_I and I_{II} are so-called phase-quadrature signals, i.e. 90° phase shifted sinusoidal signals. The inaccuracy of phase angle α determination is significant component of interferometric measurement total inaccuracy. The precise fringe phase measurement depends on fulfillment of two requirements; (i) absolute phase shift between signals has to be as close as possible to 90°, and (ii) DC parts of those signals should be zero.

For the purpose of phase shifted interferometer output signals generation, polarizing beam splitters and optical retarders (such as half, and quarter wave plates) are usually applied. An example of the optical popular setup for interference fringes phase shift generation is shown in Fig. 1. A beam 1 consists of measuring and reference beams returning from the interferometer. Both superimposed beams are linearly s- and p- polarized. After transmission by a quarter retarder plate QWP the polarizations are changed into circular clockwise and counter clockwise respectively. Next these beams are divided into two beams 2 and 3 by non polarizing beamsplitter BS. A reflected beam 2 is divided into two beams 4 and 5 with orthogonal polarizations by polarized beamsplitter PBS1. Those beams are directed toward photodiodes D1 and D2, and produce two signals (S1, S2) differing by 180° in phase. Transmitted beam 3 is divided onto two beams 6 and 7 with orthogonal polarizations by polarizing beamsplitter PBS2. These beams are directed toward photodiodes D3 and D4, and produce signals (S3, S4) having 180° phase shift. The beamsplitter PBS2 and so its polarization planes are shifted by 45°. It causes the additional 90° phase shift of the signals S3 and S4 in comparison to signals S1 and S2. Since the interfering beams are parallel, photodetectors receive interference fringes having infinite period. In this type of the interference fringe detection system, inaccuracies of applied polarizing optical elements are major sources of the phase shift errors and so interferometer nonlinearities [1–3].

From among many factors that determine optimal parameters of the interferometer output signals, there are accuracy of alignment of the initial interferometer geometrical setup and further stability of the interferometer configuration during measuring reflector displacement. Also, interferometer optical elements, accuracies of operation, and electronics that converts the measuring signals are very important [4–7]. The mentioned above factors

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doi:10.1016/j.optlastec.2011.11.030

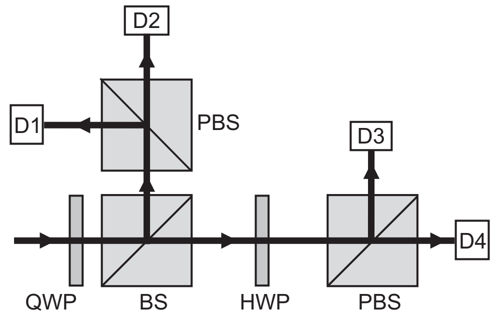

Fig. 1. Schematic diagram of standard detection system used in interferometer for distance measurements.

affect, in particular, high measurements resolution interferometer setups with plain mirror retroreflector [4,8]. High purity sine and cosine signals allow high accuracy interpolation.

Many different techniques are used to limit the influence of discussed sources of measuring errors. Proper design of the interference fringe detection system ensuring attainment of correct interference signals irrespective to the angle between the interfering laser beams could be included to the fundamental group. Two types of interference fringe receiving systems may be distinguished; (i) photodetection system working with infinite interference field [1,3] and (ii) systems operating with fringe pattern of fixed, finite period [9]. The second group allows significant reduction of the necessary polarizing optical elements, and application of a single, compact size integrated photodetector that can be characterized by easy alignment, high stability, balanced differential sine and cosine outputs, immunity to effects of ambient light variation and beam intensity.

In this paper, solution of discussed problem by application of a new kind of detection system working with fringes of finite period is proposed. For the purpose of fringe movement conversion to the sine and cosine outputs multi elements integrated photodetector is used.

There are known many different electrical configurations of the multi photoelements outputs to provide the required final sine and cosine signals. We refer herewith only to techniques that are most similar to our solution. For example the configurations with 3 [10] and 4 [11,12] photoelements distributed by 90° of fringe period were reported. Also 3 photoelements [10,14] distributed by 120° and 12 [15] photo-elements distributed by 30° of fringe period are applied in the scale reading devices.

The mentioned above systems are very sensitive to the fringe period instability that generates phase error between output signals. Little more sophisticated setups developed by Kaczmarczyk [13] and Kaczmarczyk and Dobosz [16] based on 5 photoelements and 3 photoelements respectively, are highly resistant on the fringe constant changes.

The drawback of all the configurations with small amount like 3, 4 or 5 photoelements is high susceptibility of those systems on local disturbance of fringe pattern, which may be caused by contamination of interferometer's optical components.

Increase of number of photoelements by multiplying base 3 or 4 element's structure proposed by Renishaw [10] to the form of so-called electrograting, or by using self-scanning photodiode array [17] or similar to it 1-D CCD increases signal averaging resulting in reduction of mentioned above drawback. However it does not reduce these structures sensitivity to the fringe constant variability. Also in the case of multi pixel CCDs that are commonly used for interference fringe analysis the signal processing is to slow for fast displacement measurement.

To keep all the advantages of earlier mentioned 3 or 5 photoelement system and simultaneously to provide better fringe signal averaging we propose new photodetector system based on 13 photoelements. The one of the novelties of our proposition is the way of the photoelement's signal processing.

Several different optical methods of the finite fringe period generation are known. In the interferometer systems with polarization separated reference and measuring beams optical wedge of birefringent crystal can be applied [14]. It is also possible deflection of one of the interfering beams by means of one of the optical elements used in interferometer configuration [9].

2. Proposed interference fringe detection system

2.1. Optical unit

Proposed detection optical set-up for the interferometer is shown in Fig. 2. Light beam 1 emitted by laser 2 is divided into two mutually coherent beams 3 and 4 by means of a polarizing beam splitter 5. Laser 2 (for example He–Ne laser) is placed inside the laser head LH. The beams 3 and 4 have mutually orthogonal linear polarizations and run in perpendicular directions. The beam 3 is reflected parallel to the incidence direction by fixed, reference reflector 6, while the beam 4 is reflected by moving, measuring reflector 7, which displacements are measured. Next, the beams 3 and 4 recombine at the polarizing beam splitter 5 and run approximately parallel, and coaxially toward laser head LH. Both beams, returning from measuring system, after entering the laser head LH, go through the optical wedge 8 made of birefringent crystal (for example calcite), that deflect them by an angle dependent on the state of light polarization. Since the beams 3 and 4 are orthogonally polarized they are not still parallel behind the optical wedge 8. The deflected beams are transmitted by polarizer 9, that leads them to parallel polarization. In the effect it enables the beams to interfere. As there is non-zero angle between interfering wavefronts, parallel interference fringes are observed. The fringe period obtained behind the polarizer 9 (for small interference angle) equals to [19]

$$\delta \approx \frac{\lambda}{2\theta} \tag{2}$$

where 2θ is the angle between beam 3 and 4 behind the birefringent crystal. Since the interference angle depends on birefringent crystal 8 optical parameters, the above fringe period can be also expressed by the relation [19]

$$\delta \approx \frac{\lambda}{(n_e - n_0)\tan\varepsilon} \tag{3}$$

where ε is the wedge angle, n_0 is index of refraction for ordinary ray and n_e is index of refraction for extraordinary ray. The second index of refraction depends on the angle of optical axis of the wedge. The above dependence is valid for the zero angle of the optical axis of the crystal.

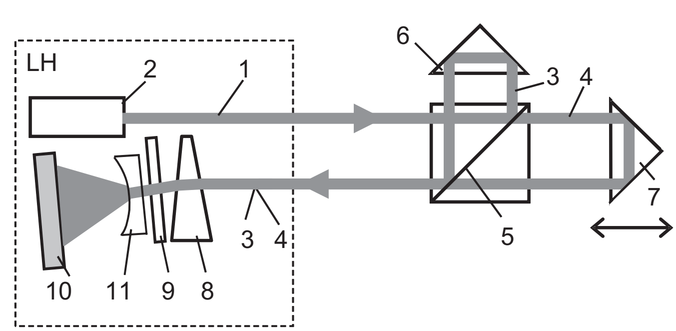

Fig. 2. Proposed detection optical set-up for the interferometer.