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Optical Systems of Laser Interferometers**

An optical arrangement of a laser interferometer with a separate beam splitter increases the temperature stability and accuracy of interferometric distance measurements. The described optical system of the distant interferometer provides some further application possibilities — measurements of flatness, angles, differential measurements, etc.

The method of the direct optical contact applied to the interferometer for non-contacting measurements allows to make dynamic measurements and to indicate small shifts in fine components.

1. Introduction

Basic types of laser interferometers, of which one is schematically shown and described in Fig. 1, are (altogether a one-purpose device) intended, above all, to precise measurements of length [1, 2]. With these types of laser interferometers the beam

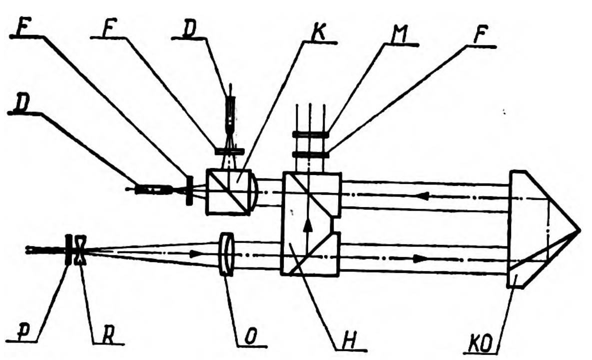

Fig. 1. Optical diagram of the basic type of prism laser interferometer

P — quarter-wave plate, *R* — divergent lens, *O* — collimation objective, *H* — prism beam splitter, *KO* — cube-corner reflector, *K* — splitting cube, *F* — polarizing filters, *D* — photodetectors, *M* — viewing screen

splitters are in a tight mechanical connection with laser heads. Consequently, the stability of the resulting interference field is determined by the total mechanical and thermal stability of the considered system.

The increase in thermal stability, and thereby in the measurement accuracy of laser interferometers can be achieved by separating the beam splitter from the intrinsic laser head. In this case the zero point of the interferometric measurement is shifted towards the corner reflector, and the connection with the laser head is only optical. The laser head, developing heat, can be located far from the principal measured system. When the separate arrangement is used the functional movement of the interference field depends only on the relative shift in the beam splitter towards the corner reflector. Vibrations and thermal shifts of the laser head do not affect the measurement accuracy. This arrangement permits for various applications of laser interferometry [3]. This implies, above all, the measurements of flatness, angle, differential length and non-contacting measurements of small shifts.

2. Design of the Optical Arrangement of the Distant Interferometer

The principle of the functional arrangement of the remote laser interferometer is illustrated in Fig. 2. The collimation optics and the detection part of the interferometer are in a tight mechanical connection with the laser head, except for the prism beam splitter which is separated and shifted towards the corner reflector. The beam propagation is the same as with the basic type of interferometer. The only difference is that the optical output is located on the separate part of the beam splitter.

The comparison arm of the interferometer being compensated geometrically by the rectangular prism in the perpendicular plane only, the rotation of the prism beam splitter in the horizontal plane is critical. This yields the deflecting and the change in the number of the interference fringes, and — due

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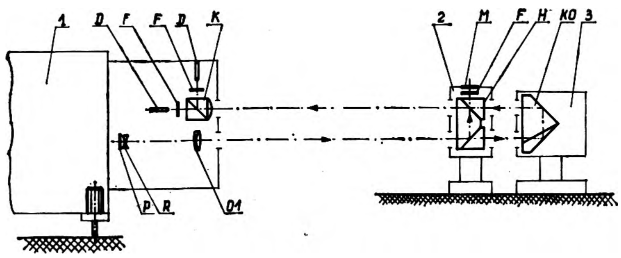

Fig. 2. Optical diagram of the remote interferometer with a prism beam splitter

1 — Laser head with a collimation and a detection parts of the interferometer: *P* — quarter-wave plate, *R* — divergent lens, *O1* — collimation objective, *K* — splitting cube, *F* — polarizing filters, *D* — photodetectors; *2* — Unit of the remote interferometer: *H* — prism beam splitter, *F* — polarizing filter, *M* — viewing screen; *3* — back reflector: *KO* — cube-corner reflector

to the decrease in the integral contrast — the proper operation of the interferometer ceases entirely. The above arrangement requires a fine adjustment and a perfect alignment of the prism beam splitter around the perpendicular optical axis of the reference beam.

In order to obtaina geometrical self-compensation of both arms of the interferometer and a simple adjusting of operation of the remote interferometer is better to use an optical arrangements schematically shown in Fig. 3 with a splitting system in form of a semi-transmissive plane plate, including a fixed

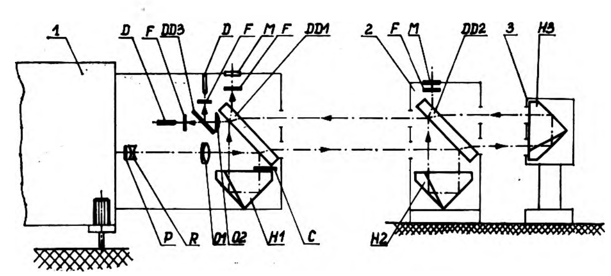

Fig. 3. Optical diagram of the remote interferometer with a splitting plate and a fixed cube-corner reflector

1 — Laser head with the interferometer: *P* — quarter-wave plate, *R* — divergent lens, *O1* — collimation objective, *H1* — fixed cube-corner reflector of the basic interferometer, *C* — shutter, *DD1* — separating plate of the basic interferometer, *F* — polarizing filters, *M* — viewing screen, *O2* — focusing lens, *DD3* — semi-transmissive plate, *D* — photodetectors; *2* — Unit of the remote interferometer: *DD2* — splitting plate of the remote interferometer, *H2* — fixed cube-corner reflector of the remote interferometer, *F* — polarizing filter, *M* — viewing screen; *3* — Back reflector: *H3* — cube-corner reflector

corner reflector placed symmetrically in the reference path. According to this arrangement both measuring and the reference paths, are equipped with corner reflectors [4]. In the reference path the corner reflector is firmly connected with the splitting plate and in the measuring path the reflector performs the functional shift. The zero point of the interferometric measurement is shifted from the laser head to the plane of the splitting plate of the remote unit *2*, the splitting and the interference of laser beams occur in its lower and upper parts, respectively. Detection and further electronic processing of optical signals are the same as with the basic prism type of laser interferometer.

In some cases when the laser interferometer is applied to a stationary arrangement the remote unit can constitute a part of the laser head and the measurements may be taken either in the fundamental arrangement or in a separate one by inserting another splitting system. In the latter case the undesirable reference path in the laser head being interrupted with a shutter the disturbing interference of the first splitting system is eliminated. The splitting semi-transmissive plate placed in the laser head, causes a total energetical attenuation of the outgoing collimated beams but does not affect essentially the interference of the remote interferometer.

3. Flatness and Angle Measurements

A remote interferometer with the splitting plate and a fixed corner reflector creates other application possibilities. By inserting a fully reflecting plane mirror into the beams of the comparison path (Fig. 4) and meeting the requirement that the functional surface of the plane mirror be parallel to the functional surface of the splitting plate the direction of the reference beams is angle-deflected by 90°, and the beams of the measuring path are parallel to those of the reference path. The primary fixed corner reflector of reference beams is tight by connected mechanically with a movable corner reflector

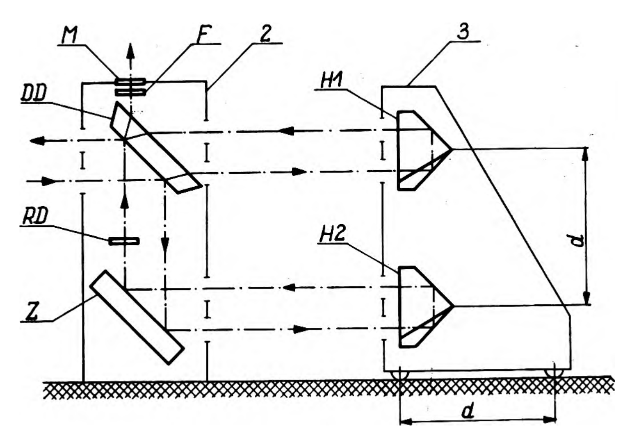

Fig. 4. Optical diagram of the interferometer for the measurement of flatness

2 — Splitting unit of the interferometer: *DD* — semi-transmissive splitting plate, *Z* — plane mirror, *RD* — retardation plate, *F* — polarizing filter, *M* — viewing screen; *3* — Dual back-reflecting system, *H1* — cube-corner reflector, *H2* — cube-corner reflector of measuring beams to form a movable back-reflecting system of the interferometer *3*. During the functional movement of the dual back-reflecting system toward the optical axes of both beams the difference in opical paths remains unchanged the fringes of the interference field do not shift and the digital reading of the computing unit of the interferometer gives either a zero or a constant value.

If the interference field is to be shifted it is necessary to change the positions of corner reflectors in the direction of the functional movement. Since, however, they are fixed this change may be performed only by tilting the whole back-reflecting system. The angular change $\Delta\varphi$ in the back-reflecting system (cf. Fig. 5) will cause a relative shift in the corner

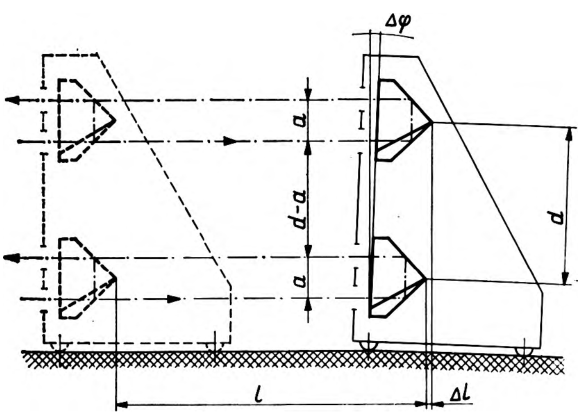

Fig. 5. Principle of angular measurements and measurements of surface flatness

reflectors by Δl; and this change in distance will yield a shift in the interference field, and hence a change in the digital reading on the computing unit of the interferometer.

An appropriate choice of the pitch of the corner prisms makes it possible to read off the angular changes either directly in seconds of the radian measure or in angular units of the order as high as 1×10^{-6}, because

$$\Delta\varphi = \frac{\Delta l}{d}$$

holds and for the limiting resolution of the interferometer $\lambda/8 = 0.0791\times10^{-3}$ mm the least readable angular displacement $\Delta\varphi = 1\times10^{-6}$, if $d = 79.1$mm. It should be pointed out that the measurements may be done only for small angular changes or small deviations from flatness for which $\sin\Delta\varphi = \tan\Delta\varphi = \Delta\varphi$ is true with a sufficient accuracy.

Shifting the dual back-reflecting system stepwise along a chosen straight line we can read of individual angular changes of each step and determine the whole elevation profile of the measured object by summing the incremental changes. The digital data can further be printed or chart-recorded or possibly directly analog-recorded. An isometric form of flatness of a granite surface plate is given in Fig. 6.

Separation of the dual reflecting system into two motion independent back-reflecting elements gives the possibility for the differential length measurement (schematically shown in Fig. 7).

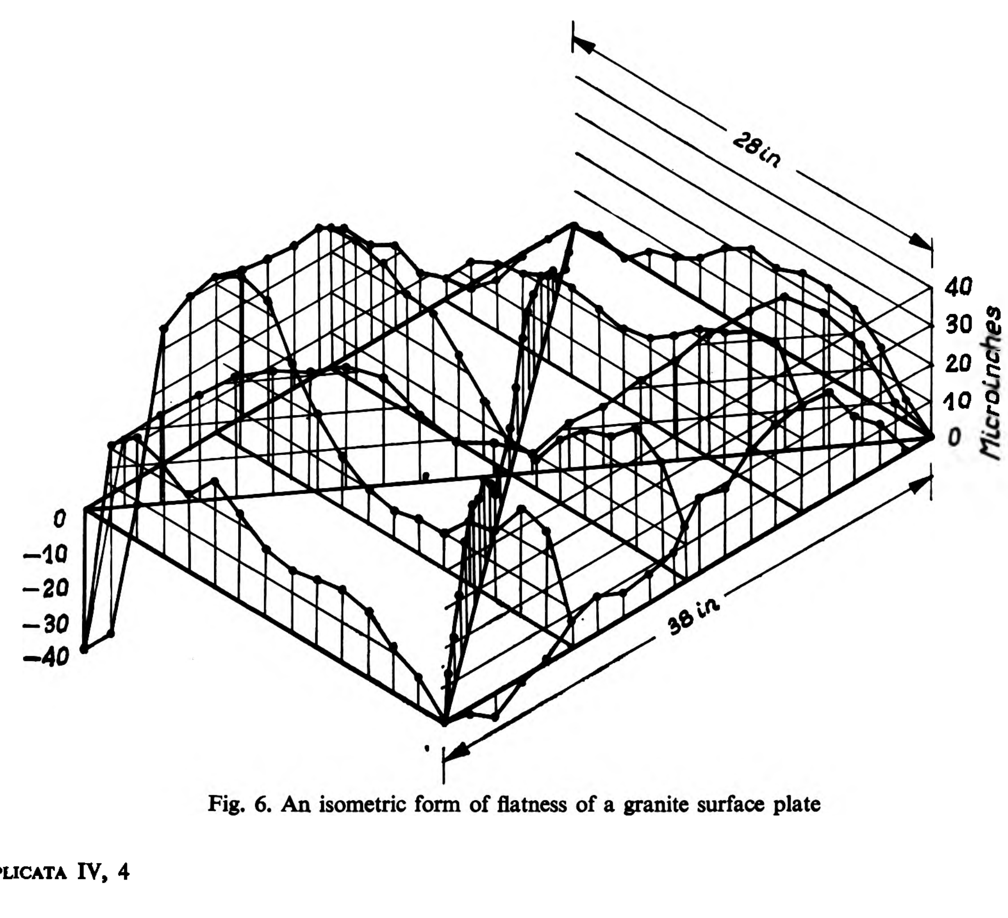

Fig. 6. An isometric form of flatness of a granite surface plate

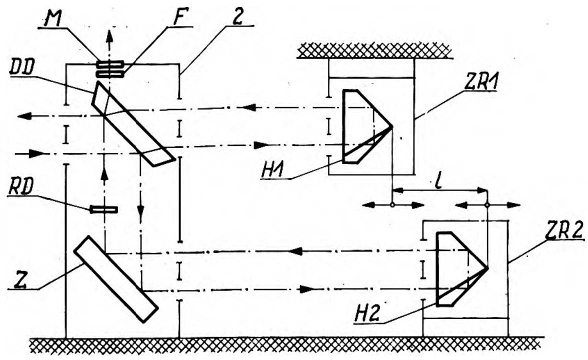

Fig. 7. Optical diagram of the interferometer for differential length measurements

2 — Splitting unit of the interferometer: *DD* — semi-transmissive splitting plate, *Z* — plane mirror, *RD* — retardation plate, *F* — polarizing filter, *M* — viewing screen, *ZR1* — upper back reflector, *ZR2* — lower back reflector, *H1* — cube-corner reflector, *H2* — cube-corner reflector

4. Interferometer for Non-Contacting Measurements

The main feature of the laser interferometer for non-contacting measurements of small shifts is that the optical connection of the measuring path with the comparison one is not ensured by the corner reflector but directly by the beam reflection on the measured object, i.e. the indication contact is optical only. This requirement is fulfilled by inserting a positive optical system behind the beam splitter. This system focuses the parallel beam onto a very small surface of the measured object.

The optical contact is important everywhere the mass of geometrical dimensions of the back reflector cause imperfections in the adjustment and detection of the measured dimensions, and when the back reflector cannot be used. This chiefly concerns dynamical measurements, and then the measurements of thickness of reflective coatings on mirrors, thickness of magnetic tapes, measurements of memory discs, etc.

The principle of the optical arrangement with basic type of prism interferometer is given in Fig. 8.

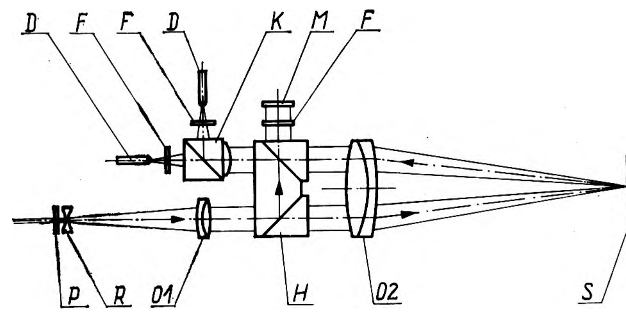

Fig. 8. Optical diagram of the interferometer for non-contacting measurements of small shifts

P — quarter-wave plate, *R* — divergent lens, *O1* — collimation objective, *H* — prism beam splitter, *O2* — focusing objective, *S* — sufficiently reflective object, *F* — polarizing filters, *M* — viewing screen, *K* — splitting cube, *D* — photodetectors

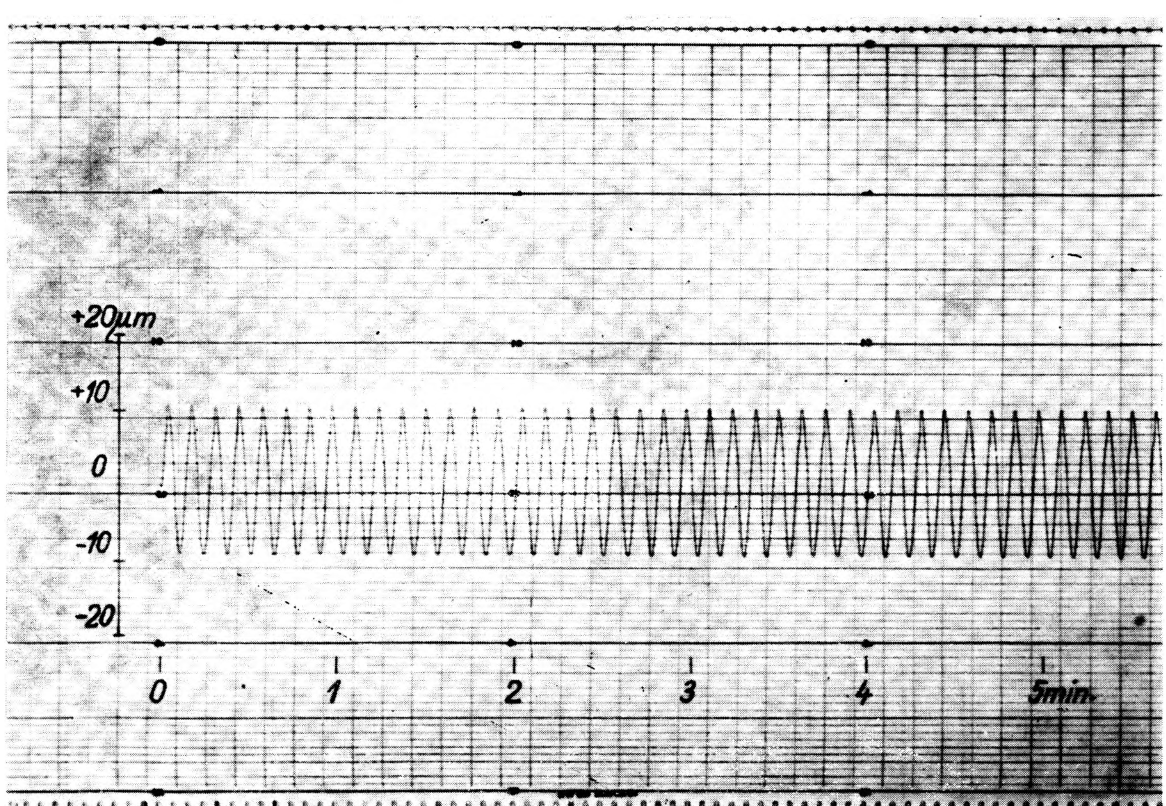

Fig. 9. Recording of axial displacements of the front eccentricity of a ring gear of an electric watch mechanism

The measuring beam issued from the prism beam splitter is focused by the lower part of the achromatic objective on a sufficiently reflective surface of the measured object where it is reflected and returns symetrically through the upper part of the objective to the prism in which it interferes with the reference beam [5]. The range of the non-contacting measurements of shifts, the so-called "depth of field", dependes on the focal length of the used objective and on its aberration properties.

For an experimental functional non-contacting measurement an achromatic objective with the focal length $f = 118$ mm was used. The achieved depth of field was about 0.2 mm. The front eccentricity of a ring gear of an electric watch mechanism was measured. Its maximum value was 20μm. The recording of axial displacements from the basic plane is shown in Fig. 9.

The described method of non-contacting measurements can be used successfully for rapid dynamical measurements in which materials of contact mechanism exert always an undesirable influence on the obtained results.

Les systèmes des interféromètres de laser

On a donné l'ensemble optique d'interféromètre de laser avec le diviseur de la lumière séparé qui augmente la stabilité de la température et la précision des mesures interférométriques des distances. Le système optique ci-décrit avec l'interféromètre agissant à distance donne plus de possibilités de l'application comme, par exemple, l'appareil de mesure de la planéité des angles, des mesures differentielles, etc.

On a appliqué la méthode du contact optique direct à l'interféromètre pour les mesures sans contact, pour la réalisation des mesures dynamiques et pour la mesure des déplacements insignifiants des éléments fins.

Оптические системы лазерных интерферометров

Представлена оптическая часть лазерного интерферометра с отдельным делителем света, повышающая температурную устойчивость и точность интерферометрических измерений расстояния. Описанная оптическая система интерферометра, действующего на расстояние, расширяет возможность таких применений, как измерение плоскостности, углов, дифференциальное измерение и т. д.

Применены методы прямого оптического контакта с интерферометром для бесконтактных измерений, производение динамических измерений и измерение малых смещений мелких элементов.

References

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