Phase invariance in a recently proposed common-path laser interferometer

Can Feng (冯　灿)*, Lifeng Li (李立峰), and Lijiang Zeng (曾理江)

Department of Precision Instruments, Tsinghua University, Beijing 100084, China

Corresponding author: fengc03@mails.tsinghua.edu.cn

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This study shows that the principle of a recently proposed common-path laser interferometer containing a planar grating is nonexistent and apparently caused by a mathematical derivation error. Both p- and s-polarized beams in the proposed setup experience once the +1st-order diffraction and once the –1st-order diffraction by the grating. As a result, the phase of each beam remains unchanged and the interference fringes formed by the two beams are not expected to move when the grating is translated in the grating vector direction. We perform an experiment to confirm this prediction. Both our analysis and experimental observation cast doubt on the experimental results of the authors who proposed the interferometer.

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In several recent publications, Qu *et al.*[1−3] proposed a common-path laser interferometer for displacement measurement. We point out that their analysis contains an error, rendering the principle of their displacement measurement nonexistent and their experimental results questionable.

The optical phase of a beam diffracted from a grating changes by $\Delta\phi$ after the grating is moved a distance Δx in the grating vector direction, and

$$\Delta\phi = -mK\Delta x, \quad (1)$$

where m is the diffraction order number and $K = 2\pi/d$, with d being the grating period. This formula can be proven based on the grating theory (Ref. [4]) or by considering the Doppler effect when the grating is moved and integrating the phase change caused by the frequency shift over the time of displacement. Depending on the sign convention adopted for m, the negative sign may or may not appear in Eq. (1). The important point is that $\Delta\phi$ is independent of the incident angle (and wavelength), but dependent on m.

In Fig. 1, which is essentially the same as the Fig. 1 of Refs. [1–3], the s- and p-polarized beams are shown in solid and dashed lines, respectively. They share common paths but are drawn laterally shifted for clarity. In research papers and textbooks different ways of writing the grating equation exist, and different sign conventions for the angles of incidence and diffraction, as well as for the diffraction order number m are used. However, as long as a set of conventions is used consistently, the diffraction order numbers at points A and B have the same absolute value but opposite signs. The sign difference is also easy to understand with the Doppler effect interpretation, wherein the light frequency is upshifted at one point (A or B) and downshifted at the other (B or A) by an equal amount for a given grating movement direction. The end result is that both the p- and s-polarized beams have no phase change resulting from the displacement of the grating when they reach the polarizer P. One of the mistakes made in Refs. [1–3] is that the diffraction order numbers for both beams at both points A and B were set to +1.

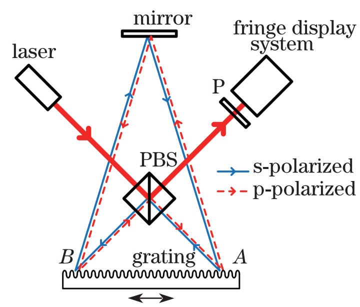

Fig. 1. (Color online) Common-path laser interferometer proposed in Refs. [1–3]. PBS: polarizing beam splitter.

We set up the simple common-path interferometer to confirm our prediction. A 632.8-nm wavelength He-Ne laser was used as the light source, and the grating line density was 1 740 line/mm. The grating was mounted on a translation stage with its travel direction along the grating vector. The angles of incidence and diffraction at points A and B were 45° and 23.2° (in absolute values). The differences from the corresponding values used in the experiment reported in Refs. [1–3] are nonessential. As expected, the interferometer was very stable because of its high degree of common path. We observed change of the fringe inclination angle when the grating was rotated about the normal of the grating plane. However, we could not observe any movement of the interference fringes when the grating was translated by distances as large as 1 cm.

In conclusion, this study shows that the principle based on the interferometer proposed in Refs. [1–3] is nonexistent. The interferometer cannot be used for displacement measurement at all. Our theoretical analysis and our experimental test cast doubt on the experimental results in Refs. [1–3].

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