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An electro-optical sensor for microdisplacement measurement and control

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Abstract. Development of a new type of noncontact electro-optical sensor based on the optical triangulation principle is presented. The sensor exhibits maximum sensitivity with a resolution of 0.01 μm for the displacement of polished flat surfaces. The sensitivity of displacement of curved and rough surfaces is also good. The experimental set-up described provides a linear range of ±75 μm which could be increased by changing the optical parameters of the sensor, if needed.

1. Introduction

The modernisation of the production industry has reached a stage where hundred per cent quality control has become a necessity. To keep production costs down, quality must be built-in during the machining operation without losing the high production speed. The contact type conventional sensors are unable to meet the present day automation demands because of their inherent limitations (Novak 1981). Noncontact electro-optical (EO) systems (Bertani *et al* 1983, Constans *et al* 1980, Dickers *et al* 1981, Kerr 1969, Shiraishi 1979 and Yoshimoto *et al* 1980) offer the desired solution and can be adopted to a fast moving line without sacrificing accuracy and speed. Several EO systems (Buecken 1981 and Hockley 1980) have already been developed and commercialised during the past few years. The present paper describes the development of a new electro-optical sensor based on the optical triangulation principle.

2. Principle

The working principle of the sensor is shown schematically in figure 1. A slit aperture S illuminated by a white light source is projected by lens L_1 at oblique incidence onto the test object surface. The light image S′ is in turn imaged as S″ by lens L_2 in the optical reflection direction at the detector plane P. With the displacement x of the test surface along the normal N, the intersection of the incident beam with the test surface moves to C, causing the shift of the final image in the detector plane to C′.

Let the mean angle of incidence on the surface be θ. The image shift y' at the detector plane due to the normal displacement x of the surface is given by

$$y' = m \cdot 2x \sin\theta \qquad (1)$$

where m is the magnification of the detection optics. If $m=1$, and $\theta=45°$, the shifts of images y and y' are equal. Further

$$y' = \sqrt{2} \cdot x.$$

The image shift y' at the detector plane is linearly related to the normal displacement x provided x is very small. The displacement x must be within the depth of focus of the detection optics.

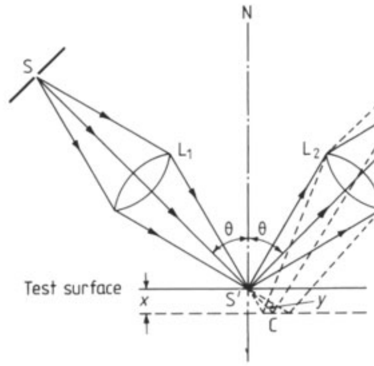

Figure 1. Principle of operation of EO sensor.

3. Experimental set-up and the sensitivity curves

In the experimental set-up used for studying the sensitivity curves for different test surfaces, a 0.2 mm wide slit is illuminated by a 150 W halogen lamp through an optical glass fibre bundle. Unit magnification with $f/4$ optics at 45° incidence and detection are used. A photograph of the experimental set-up is shown in figure 2. A universal measuring microscope and a circular rotating table provide the different degrees of displacement. A laser interferometer is attached to measure the displacement in the measuring direction. An oscilloscope and X–Y recorder are used for necessary amplification and display of the photo-signal. The small positional detection has been achieved by using the Siemens PB 48X differential photo-diode pair. A 10 kΩ potentiometer was connected across the two anodes with the adjustable terminal connected to the common cathode. This helped in setting the no photo-signal value to zero. When the light image S″ falls symmetrically on the two photo-diodes, zero difference signal is produced. For non-zero positions, one photo-diode receives more light than the other. Thus the difference signal varies with the displacement of the object surface. The test object surfaces were mounted on an X–Y cross-slide in order to facilitate the measurements.

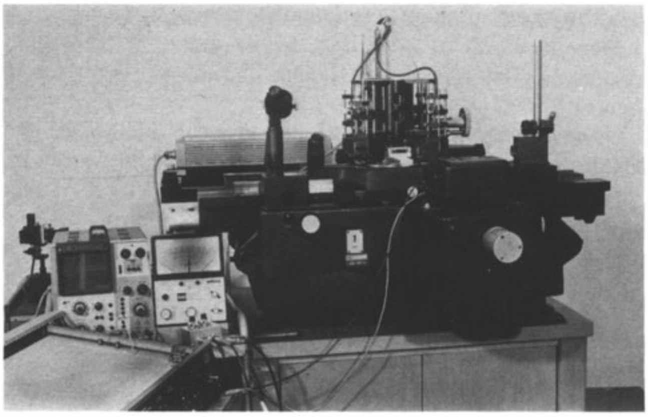

Figure 2. Realisation of the EO sensor.

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Sensitivity curves for different surfaces are shown in figure 3. These curves were obtained by feeding the difference photo-signal and the displacement signal through an inductive gauge to an X–Y recorder. Curves 1 and 2 are for optical mirror and slip gauge surfaces. These curves lie very close to each other except at the saturation values. As the reflectivity of these surfaces approaches the ideal value the system exhibits maximum sensitivity which is 0.3 mV/μm. Zero signal repeatability has been practically obtained by using the laser interferometer as positional read out system. A set of positional readings of the test object surface for zero photo-signal has been taken. The standard deviation calculated from these readings is 0.01 μm in case of polished flat surfaces. The curves are linear in the ± 75 μm range, ensuring good measurement capabilities in this range after calibration. The linear range can be increased if the reflected light patch falls on the photo-diode surfaces unobstructed throughout the displacement range. It could be obtained by choosing the proper values of slit width, photo-diode width and pick-up optics (L_2). Curves 3, 4, 5 and 6 are for plane milled aluminium surface, polished cylinder of diameter 20 mm, unpolished cylinder diameter 30 mm and polished steel ball diameter 20 mm respectively. Curves 7 and 8 are for unconventional optically gauged surfaces and show that the system is quite sensitive to pressed wood and polished granite surfaces also. With the increase in roughness of target surface, the size and intensity of the light fleck falling on photo-diodes gets reduced thereby resulting in the decrease of linear range and sensitivity. The tilt of the test object surface may cause serious positioning errors. However, it has been observed that by positioning the photo-diode pair exactly in the detection optics image plane, a tilt of $\pm 0.5°$ has no effect on the photo-signal.

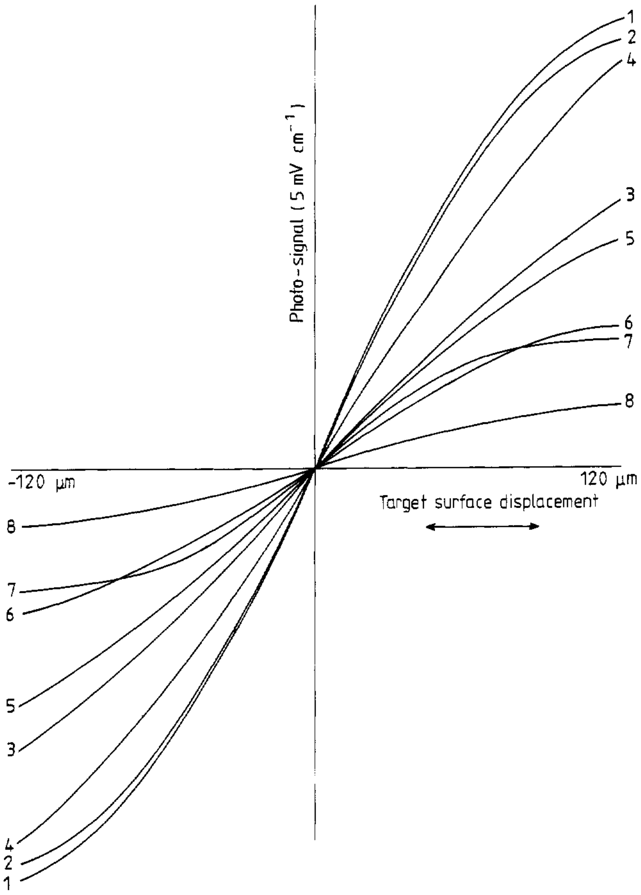

Figure 3. Sensitivity curves for different surfaces: 1, plane optical mirror; 2, slip gauge; 3, aluminium (milled surface); 4, polished aluminium cylinder (diam. = 20 mm); 5, unpolished aluminium cylinder (diam. = 30 mm); 6, polished steel ball (diam. = 12 mm); 7, pressed wood; 8, polished granite surface.

4. Comparison with other commercial systems

A comparison of the developed system with two other (Buecken 1981 and Hockley 1980) optical triangulation principle based commercially available systems is given in table 1. The discussed system has several advantages including the higher resolution and sensitivity to polished and rough surfaces.

5. Conclusions

The sensitivity curves show that a sensor can be employed for the measurement of plane and curved surfaces of polished and rough surface texture. Measurement could be performed either in null-position detector or deviation detector mode. Non-zero signal after calibration can be used for on-line quality and production control.

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Table 1.

System	Resolution	Light source	Surface requirement	Technique to achieve linearity	Applications
Optocator	± 2.0 μm	Laser	Rough	Electronic	Industry
Diffractor	± 0.5 μm	Laser	Rough	Electronic	Industry
Described system	± 0.01 μm	Filament or laser or LED	Polished or rough	Self contained in the system	Industry and precision laboratory

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Soft x-ray (0.1–4.5 nm) fluorescence of tetraphenyl-butadiene and sodium salicylate

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Abstract. The soft x-ray fluorescence of tetraphenyl-butadiene (TPB) shows an increasing advantage over sodium salicylate (SS) at longer wavelengths. At 0.15 nm, $\eta_{max} \simeq 0.25$ photons sterad^{-1} per x-ray photon for both TPB and SS; at 4.5 nm, $\eta_{max} \simeq 4.4$ for TPB and $\eta_{max} \simeq 1.7$ for SS (η_{max} is the apparent fluorescent efficiency, for optimum phosphor thickness).

1. Introduction

Measurements have been made of the soft x-ray (0.1–4.5 nm) fluorescent efficiencies of two phosphors, TPB (1,1,4,4-tetraphenyl-1,3-butadiene $C_{28}H_{22}$) and SS (sodium salicylate $NaC_7H_5O_3$), during development of a single-photon detector for the soft x-ray extreme ultraviolet band ($\simeq 0.1$–100 nm). The apparent fluorescent efficiency was determined, that is the photon conversion efficiency at near normal incidence to and emergence from a laminar phosphor layer, per steradian assuming isotropic fluorescent emission. The maximum η at a given λ corresponds to a phosphor layer whose thickness best compromises between maximum absorption of x-ray photons and minimum absorption of fluorescent photons, since η is a practical parameter that takes no account of such losses. We have tested TPB alongside SS since it is often customary to evaluate phosphors relative to SS. TPB shows the following properties:

(i) Good fluorescent efficiency relative to SS. At 4.5 nm, TPB is more efficient than SS by a factor of $\simeq 2.5$ (and $\eta_{max} =$ 4.4 ph ph^{-1} sr^{-1}).

(ii) Long term stability in storage and under vacuum.

(iii) The ability to be prepared with a 'polished' surface onto which optically opaque thin metallic films may be directly evaporated.

2. Measurements and results

Phosphor samples were prepared on glass microscope slides in a range of thicknesses. The SS samples were prepared by spraying a saturated solution in methyl alcohol, and were evaluated within a few hours to ensure reproducible efficiencies (Samson and Haddad 1974, Horton and Ilyas 1977). Both fresh and stored TPB samples were tested, after preparation by vacuum evaporation. Neither storage for several months in a filtered-air cabinet nor exposure to vacuum for 60 hours caused detectable aging of TPB (Burton and Powell (1973) reported no degradation in the vacuum ultraviolet efficiency after repeated exposure to vacuum over a period of one year). Thin film metallic filters, of thickness $\leqslant 100$ nm, were evaporated directly onto the surface of TPB samples by conventional techniques. Specularly reflecting metallic films were achieved by lightly buffing the TPB surface with surgical cotton wool prior to evaporation of the film. Films

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