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Frequency and Sensitivity Limited Fiber-Optic Transducers

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Modelling and experimental investigation of $U-h$ characteristics of fiber-optic reflective displacement transducer, with the aim to obtain the maximal sensitivity and high speed in the displacement and vibration measurements, are presented. Excellent agreement between theory and experiment was obtained, therefore the limiting sensitivity of transducers can be predicted by modelling. Configurations of non-contact fiber optical transducers of the maximal possible sensitivity and speed were found, the metrological parameters which do not depend either on the degradation of the light source intensity or on elements used in the measurements, as well as on the value of the mirror reflection coefficient and changes due to aging. All that increases the reliability of measurement system, which is of utmost importance for process monitoring.

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1. Introduction

Fiber-optic non-contact reflection sensors and transducers are frequently used for precise measurements of slight displacements. The sensors based on a single multimode fiber-optic pair have been created and investigated in detail [1–9].

New fiber-optic sensors and transducers have been constructed that consist of two fiber pairs [8]. The sensitivity of these sensors is higher by an order [5] than that of one-pair sensors [3]. In this work it is shown that useful signal U dependences of one-fiber optopair reflection sensors on the distance h ($U-h$ characteristics) can be approximated to a high degree by formula presented in [9]. The aim of this paper is a simulation of a two-fibre optopair displacement transducer by using of one-fibre optopair experimental $U-h$ characteristic results, employing laser diode (LD), and to appreciate limit of sensitivity and frequency.

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2. Experimental setup, modeling, and experimental results

Experimental setup and fiber optopairs were the same as in [9] where artificial crossing of the $U-h$ characteristics of identical fiber pairs having common light source was employed.

Using the expressions from Refs. [8, 9], the calculations of signal $A(h)$ (curve 1) are presented in Fig. 1, where values $C_0 = 1.69\times10^7$, $k = 0.12$ were used. These values differ from those obtained with the light diode (SLD) [8]. Calculated values (curve 1, Fig. 1) are in good agreement with the obtained experimental results.

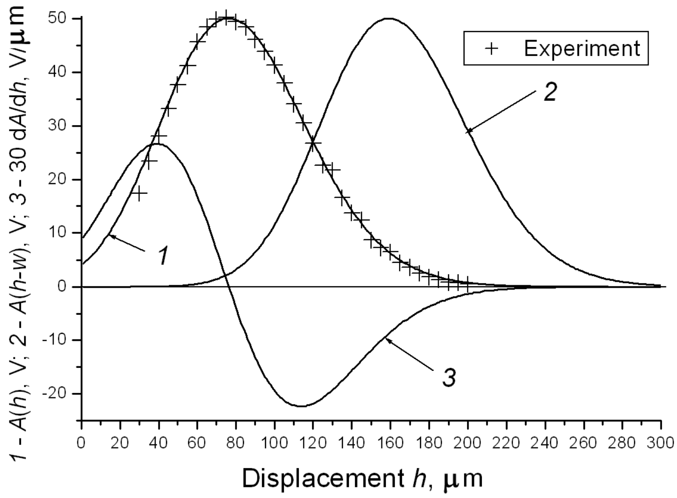

Fig. 1. Modelling (lines) and experimental results (points): 1 — signal $A(h)$, 2 — signal $A(h-w)$, 3 — signal $30\mathrm{d}A(h)/\mathrm{d}h$.

Curves 1 and 2 have a rising part of higher sensitivity, reach maximum, and then descend, where the sensitivity is lower. In the vicinity of inflection points the signal is linear, i.e., its sensitivity $\mathrm{d}A/\mathrm{d}h$ does not depend on h. The maximal value of $\mathrm{d}A/\mathrm{d}h$ for one-fiber optopair sensor is 0.978 mV/μm in the ascending part of the curve, and 0.859 mV/μm in the descending part. The resolution of such a sensor is determined by $p-i-n$ photodiode noise which is 10^{-14} W $\sqrt{\mathrm{Hz}}$. The current at operation point is 9.8×10^{-5} A, therefore, the signal-to-noise ratio is $\approx 10^{10}$. From this we conclude that the resolution of such a one-fiber optopair sensor may be better than 1 nm.

Now the advantages of two-fiber optopair transducers will be considered. The modeling shows that in this case we have two signal curves, $A(h)$ and $A'(h) = A(h-w)$ ($w = 83$ μm [8, 9]. These curves intersect each other at a single point (Fig. 1), the abscissa of which is $h_0 = 123$ μm, and the ordinate is $U_0 = 24.0$ V.

The dependence of signals $U_{\mathrm{sub}}(h)$ and $\mathrm{d}U_{\mathrm{sub}}/\mathrm{d}h$ on h is presented in Fig. 2, curves 1 and 3, respectively. The value of signal $U_{\mathrm{sub}}(h)$ changes its sign, which helps us to define the direction of movement of the two-fiber optopair sensor, i.e., to find whether the sensor is approaching the mirror or moving away from it. The sensitivity $dU_{\rm sub}/dh = 1732$ mV/μm of such a sensor is approximately twice higher than that of one-fiber optopair. As usual, the signal $U_{\rm sub}^{(h)}$ is amplified more than 30 times, i.e., three times less amplitied than in Ref. [3], whereas the sensitivity increases up to $dU_{\rm sub}/dh = 41160$ mV/μm. However, with increase in the amplification, the noise increases as well. The sensitivity can be increased by use of brighter light source at the same fiber cross- section. The reduction of the cross-section is undesirable since light intensity in the fiber decreases. The sensitivity is limited only by distance $b_{\rm min}$ [8, 9]. The value $dU_{\rm div}/dh$ of the signal is usually lower than 1 and equals 0.724 a.u./μm. This result almost does not differ from the case when SLD is using [9], more exactly, the difference for LD makes up only 2.5% of SLD parameter values, therefore, the sensitivity is the same and constant for this type transducer.

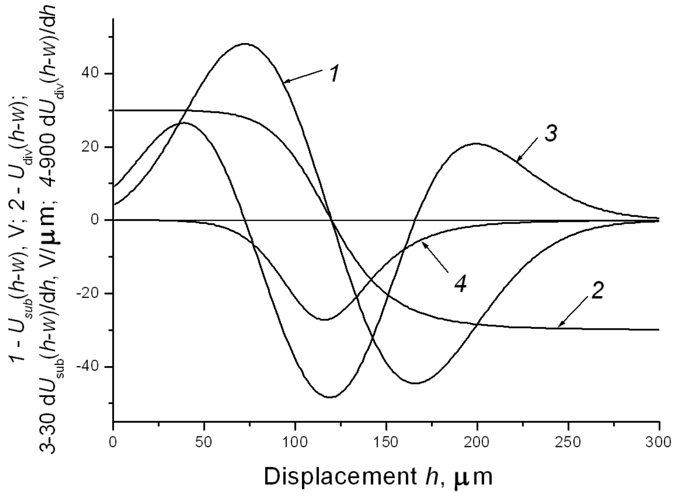

Fig. 2. Modelling results: 1 — signal $U_{\rm sub}(h-w)$, 2 — signal $U_{\rm div}(h-w)$, 3 — signal $30dU_{\rm sub}(h-w)/dh$, 4 — signal $900dU_{\rm div}(h-w)/dh$.

The electronic elements that operate at frequencies up to 200 kHz are suitable for axial displacement, pressure and acoustic wave sensors. However, there is a need for electronic elements that operate at higher frequencies, especially for sensors of orthogonal displacements that work with gratings and diffraction gratings. The investigations showed that making use of up-to-date electronic elements, such as FET transistors, microstrip transmission lines as well as the advantages of single mode fibers, one can create converters operating up to 5 GHz.

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