356. The fiber-optic non-contact piezomechanical nano-micro positioning, manipulating and measurement system

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Abstract. A non-contact fiber-optical piezomechanical (FOP) nano-micropositioning, manipulating and measuring system has been developed and investigated. The system consists of a non-contact fiber one optopair reflection sensor with a semiconductor light source (light diode), a reflected light receiver with a p-i-n photo diode, an amplifier of electronic signals, and a positioning device, the resolution of which is 0.5 μm. The diameter of the fiber sensor measuring head is 3 mm and its length is 10 mm. The positioning device is fixed in front of a mirror. The diameter of fiber core is 100 μm and the external diameter is 125 μm (WF100/110/125P22). Fiber length may reach up to 200 m. The FOP system also has a piezoceramics positioning and manipulating system with a mirror. The piezoceramics system is fastened to the positioning device. The dependence of the fiber sensor signal *U* on the distance *h* to the mirror, located on piezoceramics, has been measured. The obtained *U*-*h* characteristic has a peak on two parts of linear dependence of an increasing and decreasing signal. Sensitivity of the *U*-*h* linear part in front of the peak is higher and equal to 1.6725 nW/nm, and that of the decreasing signal part is 1.388 nW/nm. These parts can be used for displacement indication and measurement.

Keywords: Fiber-optic sensor, nanometric displacement measurement, piezoelectric actuator, experiment.

1. Introduction

Piezoceramic-piezoelecric actuators are wide used in precise positioning systems that demand a high resolution such as scanning microscopy, vibration suppression, cell manipulation, etc. [1]. Optical and fiber-optic sensors are used for noncontact precise nanometric displacement measurements [1, 2]. Interferometric [1] displacement measurements are cumbersome and expensive. Therefore fiber-optical sensors are superior for this purpose [3]. In this paper, there is a particular interest in the development of high sensitivity, nanometric resolution fiber sensors, and application of piezoelectric actuators to this advancement, and vice versa.

2. Fiber-optic sensor

Several configurations of the fiber-optic noncontact reflection sensors are created for displacement measurement [4]. The fiber-optical sensor typically has two fibers, the active tips of which at the mirror are parallel or create the angle θ (Fig. 1b). The experiment results (Fig. 1a) show that sensitivity of the sensor having fiber tips parallel (θ =0º) is 3.011 a.u./μm at the rising part of the *U*-*h* characteristic and 0.734 a.u./μm at the decreasing part of the curve. If the active tips of the fibers create the angle θ=27.5º, the sensitivity is 98.4 a.u./μm and 62.9 a.u./μm, respectively (Fig. 1a). These values of sensitivity are much higher in both regions, sensitivity increases as the angle θ increases. There is no reason to increase θ more, because that increases the diameter of the sensor head and decreases sensitivity of the sensor to bending losses [5]. Moreover, as shown in Fig. 1a, by increasing the angle θ, due to the fact that fiber-optic tips lean on the mirror, we lose part of points of the curve in the domain of small *h*, where sensitivity is highest.

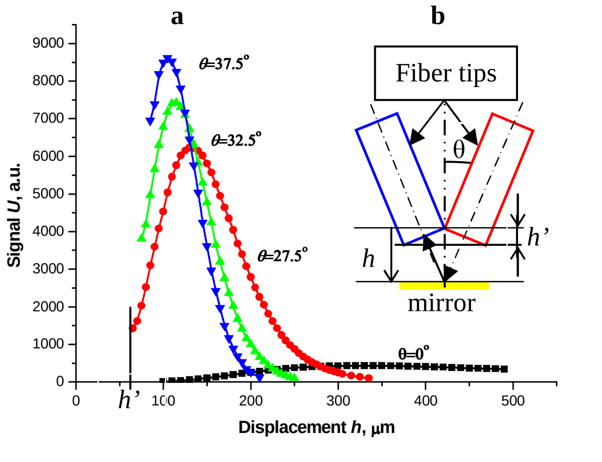

Fig. 1. Dependences of the signal *U* a. u. on the distance *h* from the fiber tips that create angle 2θ

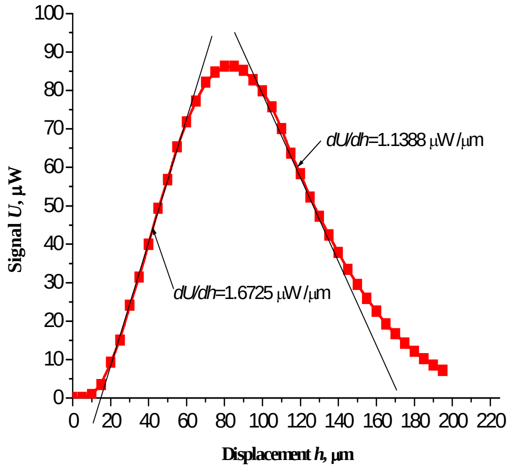

Fig. 2. Dependence of the new sensor signal U on the distance h to the mirror on piezoceramics. The arrows show the centers of a linear part of the signal

Therefore optimal angle θ was defined to be 25º.

We succeeded in creating the sensor with the *U-h* characteristic from h=0 µm. The *U-h* characteristic of the sensor is represented in Fig. 2. The output signal U of the fiber-optic sensor was measured as the dependence of reflected light intensity in µW on the distance of fiber tips h from the mirror. This parameter can be easily transferred to current or voltage [2]. Sensitivities of the sensor are 1.67 µW in the increasing part of the curve and 1.39 µW in the decreasing one. Those values corresponded to slopes of *U-h* characteristic linear parts (see Fig. 2).

3. The fiber-optic non-contact piezomechanical manipulating and measurement system

The fiber-optic non-contact piezomechanical manipulating and measurement system is presented in Fig. 3 and Fig. 4. The system has a translator 7T173-10 on which the fiber-optic sensor head, mechanical translation meter (with resolution 0.5 µm), and piezoceramic actuator with a holder were fastened. One end of the piezoceramics was tightly fastened to the holder and electrically isolated from it. The second end of piezoceramics has a mirror surface to reflect the light emitted from the fiber head and is able to freely move according to voltage V_p applied to the piezoceramics. Applied voltage was generated by a pulse generator Г6-27 (serrated, triangular, rectangular pulse) or a stabilized voltage source.

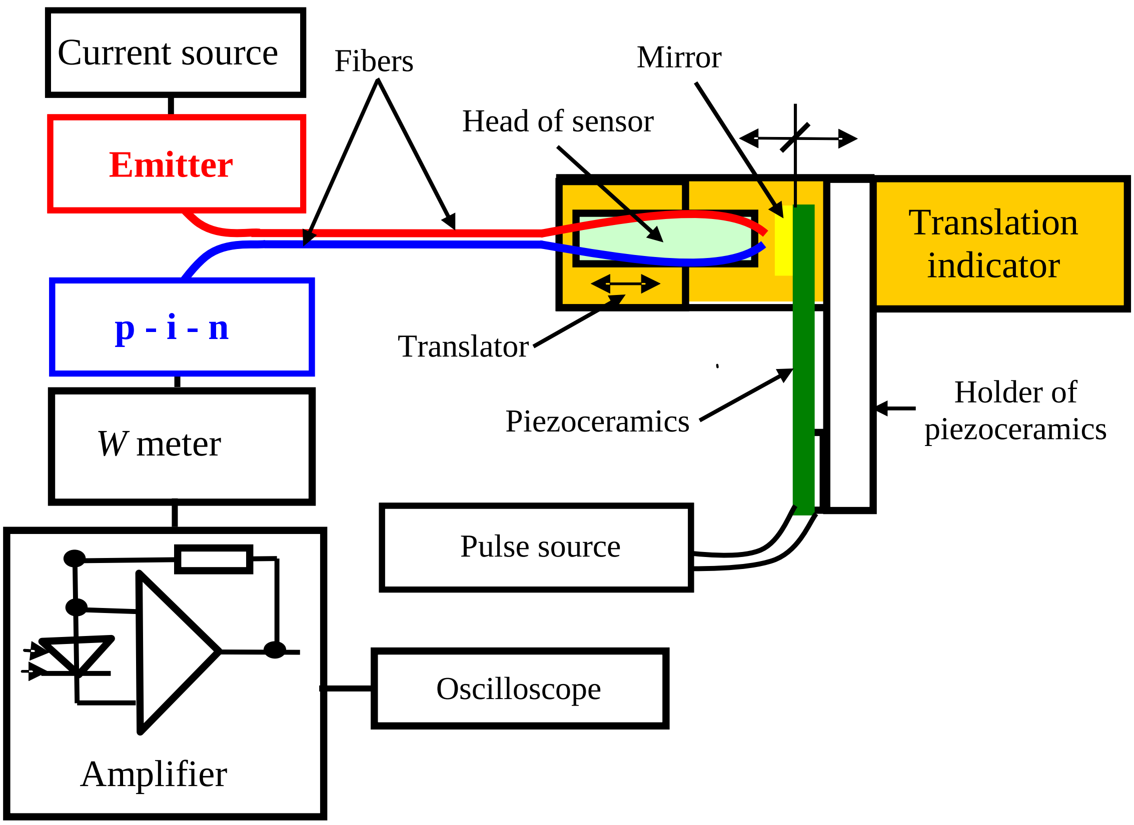

Fig. 3. The fiber-optic non-contact piezomechanical nano-micro positioning, manipulating and measurement system

A fiber-optic sensor consists of a head, with the diameter 4 mm and it is 10 mm long. The fiber WF100/125P22 tips were installed in the head precisely by special installation equipment [6] to obtain a maximum output signal.

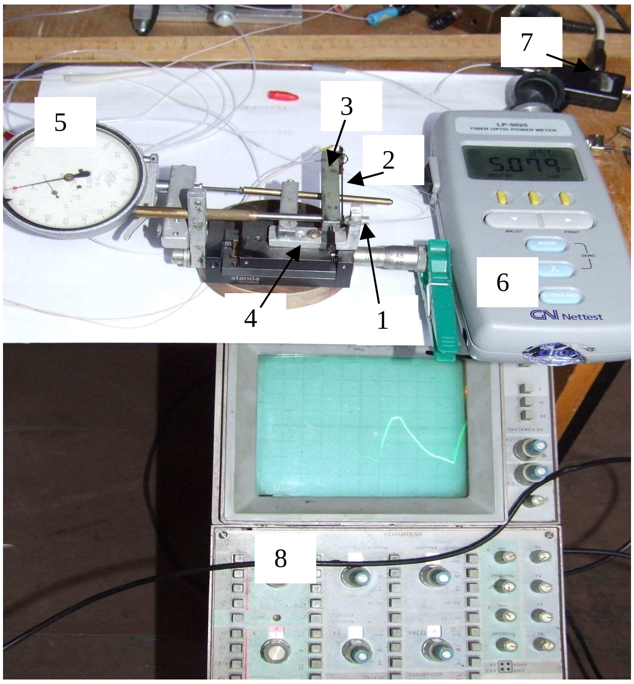

Fig. 4. Research stand of piezoceramics response kinetics. 1 - a fiber-optic nano displacement sensor (the diameter of the head is 5 mm, it is 10 mm long); 2 - piezoceramics drive; 3 - holder; 4 - translator; 5 - mechanic translation measuring device (±0,5 µm); 6 - measuring device of power of the sensor output signal; 7 - transformation block of the sensor feeding signal (12 V); 8 - oscilloscope for investigating piezoceramics motion kinetics

The other ends of fibers were installed in SMA 905 connectors. The photodiode (p-i-n) H22R880IR with the compatible connector was applied to light signal conversion to electric current. Sensitivity of the diode is 0.45 A/W, λ=850 nm. A compatible emitter H22E4020IR was applied as a light source the power of which was -15 dBm when the stabilized current 80 mA was supplied. The sensor output power was also measured by a precise fiber radiation meter LP-5025-8 or converted to voltage by a current-voltage converter and displayed on the oscilloscope.

4. Measurement

At first the *U-h* characteristic of the fiber optic sensor was measured by the translator 7T173-10, measuring the distance *h* from the tips of the fibers to the mirror and simultaneously measuring the output signal of the sensor by a precise light power meter. The results are shown in Fig. 2. In a contact with the mirror no light is emitted or received by the fiber, giving a zero output signal. As the distance of fiber tips to the mirror increases, an increasing amount of light is proportionally captured by the receiving

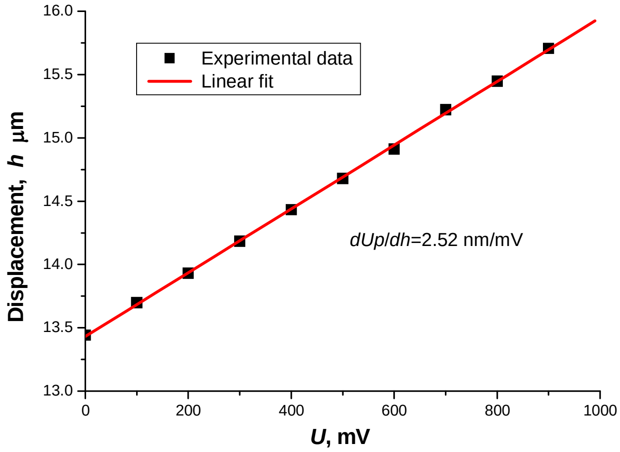

Fig. 5. Dependence of piezoceramics mirror displacement on the applied voltage

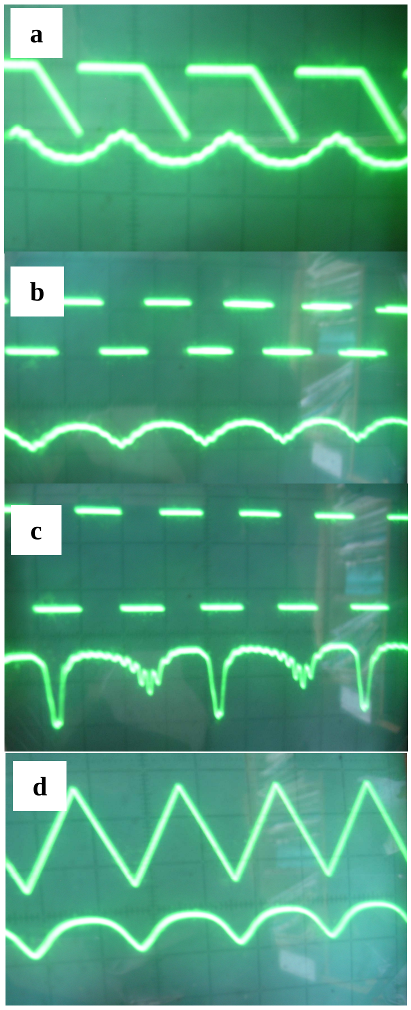

Fig. 6. Oscillograms of input (upper curves) and output (lower curves) signals. The input signal oscillation frequency is 100 Hz

fiber. The result is a very sensitive and linear signal ($dU/dh = 1.673$ µW/µm). As the distance increases further, the amount of light received approaches the maximum. After the maximum has been reached, a continued increase of the gap will proportionally reduce to the amount of light received. In the decreasing linear part, the *U-h* characteristic sensitivity is lower (Fig. 2) ($dU/dh = 1.139$ μW/μm).

By the *U-h* characteristic we can pick up the distance *h* of the mirror on piezoceramics to the fiber active tips by the translator to obtain the signal *U* value being at the middle point of the linear interval of the curve (*U*=45 μW, *h*=42 μm). Mirror displacement can be performed by applying voltage to piezoceramics. The displacement of the mirror under this voltage *V* can be measured by the fiber sensor by the *U-h* characteristic. The measurement results are represented in Fig. 5. This figure shows a linear dependence of the mirror in the whole all interval of small voltage changes. The sensitivity of the displacement *dh/dUp* of piezoceramics-mirror to voltage was determined ($dh/dUp = 2520$ nm/V). Vice versa, we can investigate the sensitivity of the fiber-optic sensor in a wide interval of the distances *h*. If we have a piezoelectrical ceramic transducer providing the displacement 250 μm at our disposal, we are able to obtain the *U-h* characteristic of the fiber-optic sensor by computer. Applying different pulses to piezoelectrical ceramic transducer, we can investigate dynamic characteristics of a piezoelectric transducer in a fixed frequency interval (Fig. 6).

Fig. 6 presents oscillograms of the output signal *U* that were obtained with the input signal 100 Hz of different shapes (a - serrated, b and c – rectangular, d - triangular). As we see from Fig. 6c, as the frequency is 100 Hz, there emerges a resonance. It has been established that in the case of rectangular pulse, the resonance also emerges even under the frequency of 20, 43, 100, 150 and 950 Hz.

5. Conclusions

The fiber-optic non-contact piezomechanical nano-micro positioning, manipulating and measurement system has been developed.

A new type of a fiber-optic sensor of maximum sensitivity was designed, prototyped, and investigated.

The FOP system allows us to investigate the kinetics of piezoceramic nano-micro positioning and manipulating systems in a non-contact way in the wide interval of frequency (up to 1 MHz), voltage, and displacement. Sensitivity of the system to voltage is 2.52 nm/mV. The diameter of the scanned ray is 50 μm.

The FOP system makes it possible to measure and automatically write down the *U-h* characteristics of the fiber-optic reflection sensor in the media of different light refraction indices.

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