Contributed paper

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Hybrid optical fibre binary sensors

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Examples of hybrid optical fibre binary sensors with amplitude modulation of light for measurement of mechanical load and temperature are presented. A structure of such sensors allows selecting of the measured quantity and gauge parameters only by changing the mechanical structure and without any change of the optical processing of data. This multi-purpose feature of hybrid optical binary sensors increases their technical advantages and competitiveness on the market for in measurement and control systems.

Keywords: binary optical fibre sensor, load sensor, temperature sensor.

1. Introduction

Optical fibre sensors are applied in industry at a steadily increasing degree [1–7]. Still existing limitations are caused mainly by their high cost of manufacturing and operation, despite of their many interesting features. In a dominating number of such sensors perform analogue measurements and in various applications have more or less complex optical structure. Such structure is responsible for relatively high technological costs in case of higher technical parameters the costs also increase relatively [8,9].

Industrial applications of fibre sensors virtually are limited to binary gauges for sensing of exceeding state [9,10]. This is due to safety requirements for industrial installations. Therefore, the proposition of construction simple and cheap binary optical fibre optics [11–14] with possibility of easy adaptation to measurement and protection circuits.

In the presented paper several manufactured and tested versions of hybrid binary optics gauges with amplitude modulation of light for measurement of force and temperature are described. The hybrid layout of these sensors is based on application of standard industrial binary sensors and a simple structure of the optical fibre intensity type sensor [15–16]. In such a way, it is possible to select the measured quantities as well as the parameters of the gauge only by adaptation the structure, for example of the usual traditional measurement and simultaneously preserving the homogenous simple and cheap fibre optics interface. The optical uniformity of optical fibre gauges allows for its easy application to digital network control circuits with digital data processing on the level of optical network [10,17,18].

Presented solutions of hybrid binary optical fibre sensors are based on with current research projects carried out at the University of Technology of Opole, Institute of Electrical Engineering, and directed by the author [10,15–20].

2. Basics of the hybrid binary optical fibre sensor

The hybrid circuit of the sensor is based on the coupling of the executing unit of the conventional (e.g., mechanical, electrical or chemical) binary measurement circuit with an optical fibre gauge (Fig. 1). In such way various types of measurement circuits can operate with the same interface circuit of the optical fibre sensor with the standard optical signal. There is no necessity to introduce any significant changes in traditional technological measurements (the same bodies of gauges, the same system of installation in the measurement environment, the same parameters of gauges and methods of setting measurement values).

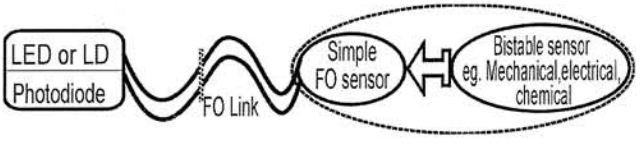

Fig. 1. Full scheme of binary hybrid optical fibre sensor.

Binary sensors allow for detection of exceeding of characteristic values of the measured physical quantity W_1 and/or W_2 (Fig. 2). In this case the form of changes of optical intensity (if it is treated as output signals of the gauge) from the one level, e.g., low T_1 to high T_2 is important. Taking into account listed assumptions we can list the following cases:

- Ideal binary gauge (switch, relay) with variation of the optical power level $T_1 \rightarrow T_2$ with the increasing value W at parameter W_1 (Fig. 2a). The inverted version is presented in Fig. 2b.

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- Binary gauge (switch, relay) with hysteresis and a change of the optical power level $T_1 \rightarrow T_2$, with the increasing values of W at the level W_2, and with a change of theoptical power level $T_2 \rightarrow T_1$, with the decreasing values of W at level W_1 (Fig. 2c). The inverted version is presented in Fig. 2d.
- Binary gauge (switch) with properties of a fuse, a shift from the power level $T_1 \rightarrow T_2$ with the fixed parameter W_1 and the fixed high optical power T_2 (Fig. 2e). Inverted version is shown in Fig. 2f.

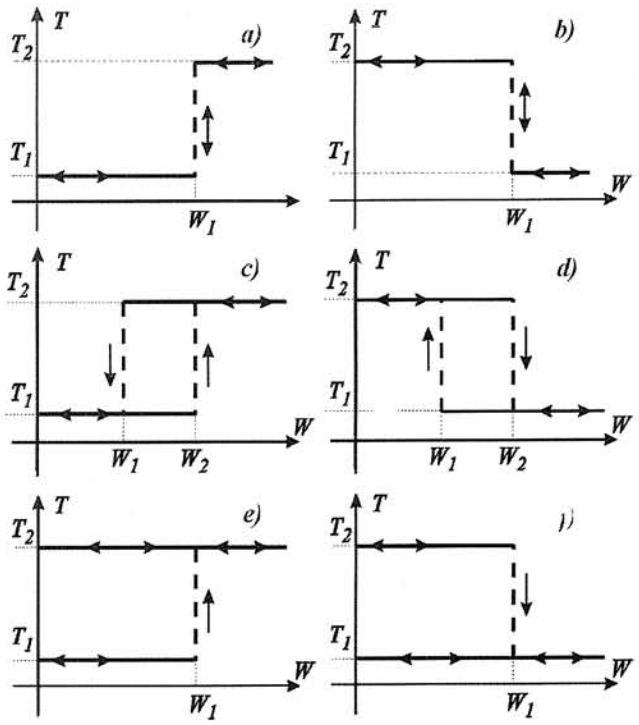

Fig. 2. Typical characteristic of binary sensors: (a) and (b) ideal sensor (relay), (c) and (d) real sensor (relay) with hysteresis, (e) and (f) fuse.

The transmission characteristic of pass of binary optical fibre gauge as a function of W is often formed on the mechanical arrangement of conventional measurement gauge, but the output levels of optical signals T are set in the interface unit of the fibre optics gauge. It is relatively easy to obtain the standard optical levels T_1 and T_2, for example optical fibre attenuating sensors providing the stable changes on the optical fibre, which is proved below.

3. Binary load sensors

Binary load sensors are widely used as limit switches or failure load relays in control systems. They usually operate in extreme environments and therefore should exhibit a high reliability, especially in the case of explosive media (chemical and mining industries).

A first example of hybrid binary optical fibre load sensor having properties of binary switch is shown in Fig. 3 [15]. The attenuation of optical fibre gauge is coupled with

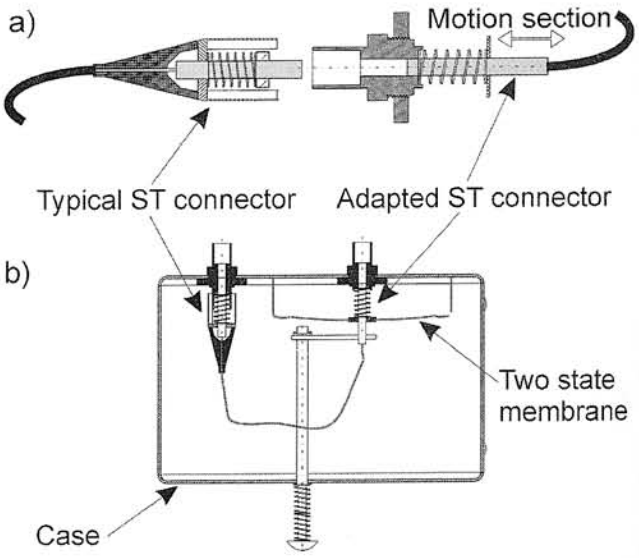

Fig. 3. Binary optical fibre mechanical load sensor: (a) adapted ST connection, and (b) mechanical structure of the sensor.

a mechanical lever and a membrane with binary characteristics. The optical gauge itself is based on the layout of the ST connection (Fig. 3a) where one part is located loose in a sleeve and fixed to a membrane. Using the standard ST connection and standard 50/125 μm telecommunication optical fibre the 8 dB attenuation was achieved for 3 mm displacement of the connection. The change of attenuation from the "on" state to "off" state depends mainly on the displacement of the membrane and in the model circuit it has been assumed as equal to 3 dB. The measurement scale in the range from 40 N to 60 N is selected by the level of tension of the spring on the main knob. The versatility of the gauge is based on its mechanical part the change of the measurement range requires only replacement or adjustment of the spring of the main knob, without any change in the optical circuit. Binary feature of gauge on the mechanical level of the system allows for application of simple opto-mechanical arrangement that is shown together with the gauge in Fig. 4.

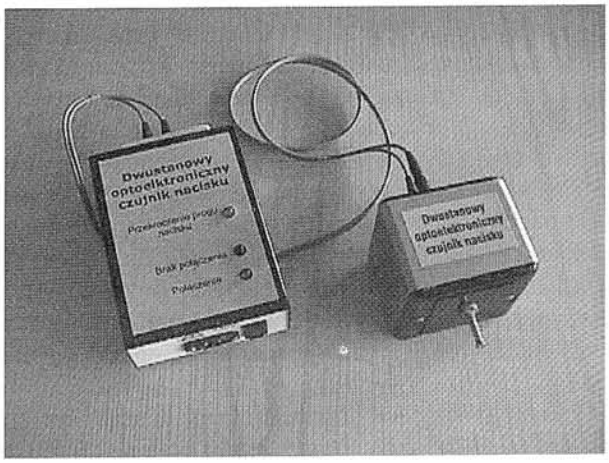

Fig. 4. Binary optical fibre load sensor (right) with transmitting/receiving circuit (left).

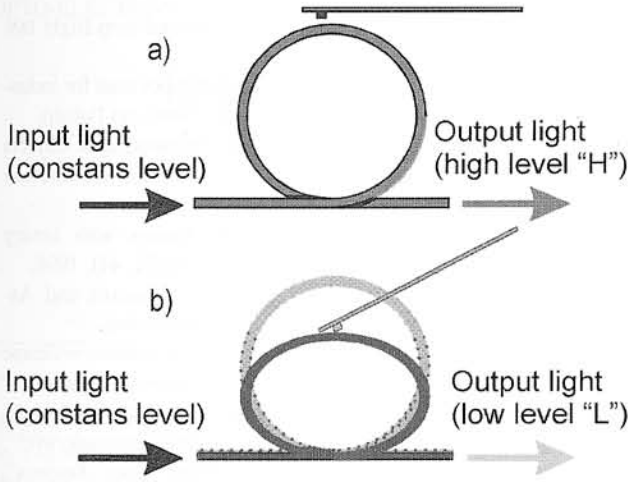

Fig. 5. Optical fibre loop as microbending sensor: (a) bright state "on", (b) dark state "off".

The second example of a binary optical fibre load gauge for measurement circuits is based in its optical part on the microbending sensor using optical fibre loop (Fig. 5) [16,18]. The mechanical lever changes the shape of the loop and therefore two levels of attenuation are achieved. In the model circuit (PCS optical fibre 200/280 μm, red light) the changes of attenuation were from 0.1 dB to 3 dB and the relevant changes of the diameter of the loop were from 5 mm to 25 mm, with the lever displacements changing from 2.2 mm to 15 mm, at the starting attenuation from 0.1 dB to 0.5 dB. Easy setting of attenuation parameters of the gauge allowed for application of simple and cheap optical transmitter and receiver circuits, and the starting low attenuation of the gauge recommends it for applications in binary measurement networks (Fig. 6b).

4. Binary temperature sensors

Binary electric or electronic temperature sensors are often used in industry in order to protect installations against critical temperatures. They usually operate as the last protection or control barrier protecting against catastrophic damages or failures. Therefore, they must exhibit high reliability of operation in extreme industrial environment. The structure of a hybrid optical fibre sensor serving as a temperature fuse with manual reset is shown in Fig. 7a [17]. A mechanical device of temperature switch connected with bimetallic gauge operates, as microbending sensor, is located at the switching lever. Changes of attenuation from the state "on" to "off" depend on the type of the optical fibre, the basic single or multiply diameter and variations of its dimensions (see Fig. 5) and on the wavelength of light. In the model circuit the elastic PCS optical fibre was used with red and infrared light. The optical properties of the gauge with optical fibre loop as microbending sensor are similar to the described earlier mechanical load sensor, but the temperature range of the gauge (set at its mechanical part) is between 40°C and 90°C due to its bimetallic nature.

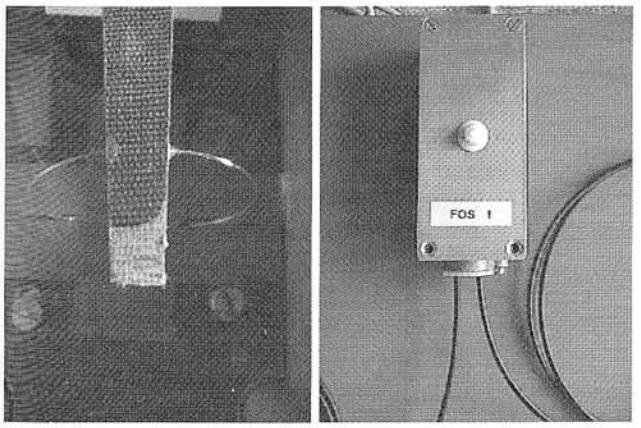

Fig. 6. Optical fibre loop in the load sensor (left) and the sensor in the industrial body (right).

Cross-section of binary optical fibre temperature sensor in industrial version (a standard body and system) is shown in Fig. 7b [17]. The circuit has properties of a temperature switch with hysteresis (approximately 20°C). The thermal and optic properties and parameters of this sensor are similar to those which temperature gauge described above. The changes are introduced only to the mechanical part of the switch.

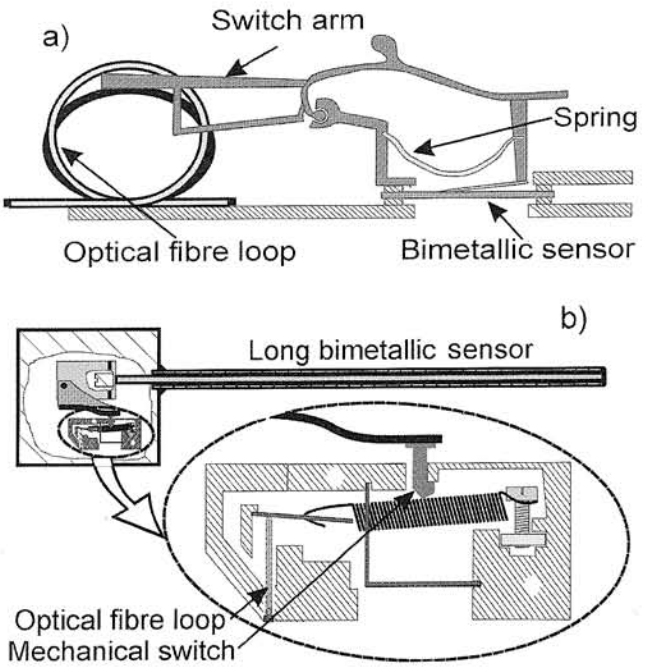

Fig. 7. Optical fibre binary temperature sensor: (a) as a temperature fuse, (b) as thermal relay with hysteresis.

5. Conclusions

Optical fibre technology permits to solve many difficult problems of monitoring and measurement in large objects and technical installations. Especially hybrid optical fibre binary sensors contributed significantly to improvement in measuring process and to increase safety of monitored installations. The advantages of such sensors are based on

their simplicity and high resistance to hostile environments [18–20]. Improvement in reliability of the sensors is achieved, and by adaptation of existing mechanical binary sensors, the cost of the upgrade and operation is significantly reduced. The hybrid sensors can be used in locations of traditional sensors without any modifications in existing installations.

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