Weight Measurements Using Microbending Optical Fibre Sensor and OTDR

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Abstract. *The paper gives a report of the design and creation of microbending optical fiber weight sensor created for teaching purposes, designed and constructed in the Laboratory of the Department of High-frequency Techniques and Optoelectronics for student's laboratory experiments. In our laboratory we deal with optical time domain reflectometry and with optical fibers as a part of sensor systems. This sensor was built to be used in a chain of laboratory experiments in teaching of optical waveguides properties and principles of sensor technology. The experiment serves not only as an actual example of sensor, but also for an explanation of sensing as a principle. From the point of view of measurement theory we can highlight sensitivity, accuracy, dynamical range, linearity and nonlinearity of various types of sensors.*

Keywords: OTDR, Optical Fiber, Sensor, Microbending

1. Introduction

In our institute in the Department of High-frequency Techniques and Optoelectronics we deal with optical fibers as transmission media and also as sensors. In teaching practice we teach several subjects dealing with optical fibers from mentioned points of view. Usage of optical fiber sensors allows to perform measurements over long distances. [1] We created several measuring experiments for laboratory work, one of them includes optical microbending sensor for weight measurement. The apparatus uses as a detection system optical reflectometer working in time domain. In this case the optical fiber serves as a sensor element itself. We would like to mention the properties of the built sensor and the possibilities of its usage in teaching.

2. OTDR

In the first step of this experiment we explain students Optical Time Domain Reflectometry (OTDR) as a non-destructive measurement method for determining the properties of optical fibers. We show that it is based on the principle of detecting back-scattered Rayleigh scattering and reflected optical radiation. OTDR as a non-destructive method for testing needs the access only to one end of an optical fiber. OTDR allows measurements at several points on the optical path [2]. Short optical pulse is coupled into the input fiber end and is propagating with the group velocity v_g like a lit area along the fiber. The impulse power which was bound into the fiber input end decreases exponentially with the distance. When the failure of fiber properties appears, it appears a sharp change on a reflectogram [3].

3. Microbending Sensor

An optical microbending sensor is built to create periodical microbendings of optical fiber at a short part of it [4]. The sensor structure can be simple; can be created by a pair of deformation plates which cause bends of fiber in a regular pattern (see Fig. 1). These sensors

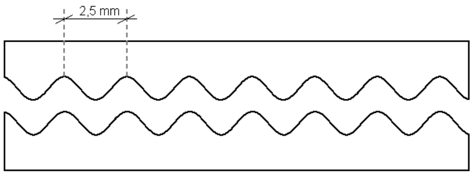

Fig. 1. Geometry of microbending sensor.

are mainly used for temperature and pressure measurements [5]. The explanation to students is given, that when the measurand acts on the fiber, inhomogenities in the fiber index profile are created. By microbendings the fiber is bent to critical angle and some modes escape from the core to the cladding. It leads to changes in the intensity of back-scattered radiation from the place of effect. The plates in response to a change of physical quantity ΔE act by force ΔF on the fiber, creating microbendings of the fiber. The change of transfer coefficient dT according to the applied force can be described by relationship

$$\Delta T = \left(\frac{\Delta T}{\Delta X}\right)\Delta F\left(K_f + \frac{A_S Y_S}{l_S}\right)^{-1} \tag{1}$$

where $\Delta T/\Delta X$ is a coefficient expressing the rate of change in transmission distortions to change of amplitude deformation ΔX, K_f is force constant of bent fiber, l_S is the distance of deformation plates and $A_S Y_S/l_S$ is a force constant with included change of plates distance [5].

The change in transmission rate will be reflected as a change in optical power detected by the photodetector (placed in OTDR reflectometer). This change of the output is therefore used to detect changes in physical quantity ΔE. The attenuation in the place of measurement depends by the force acting to the sensor and by the length of the modulator. The local decreasing of backscattered power for 3 measured weights is shown in Fig. 2. The scheme of measuring workplace is given in Fig. 3.

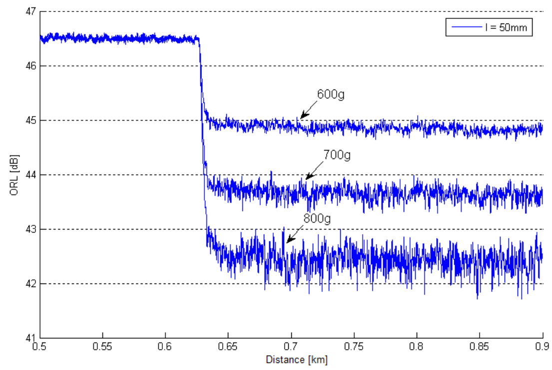

Fig. 2. Attenuation of backscattered signal as a weight dependence.

The properties of the microbending sensor (see Fig. 4) are in Table 1. The force which acts to the optical fiber depends on the weight of the load and also on the mutual position of the load and the fiber. We explain the role of the force or load placement at the upper plate of the sensor by measurements, as it is schematically given in Fig. 5. The length of the microbending modulator has an influence to the measurement range and sensitivity. Deformation plates are made with a groove. It allows to use the sensor in two lengths 60 mm and 115 mm. Input and output part of the optical fiber is fixed in foam peaces preventing the damage. Mutual position of plates is fixed. Minimum used load weight was chosen with respect to the accuracy, maximum load weight was chosen to prevent damage of the fiber and to have the measured backscattered signal not in the noise.

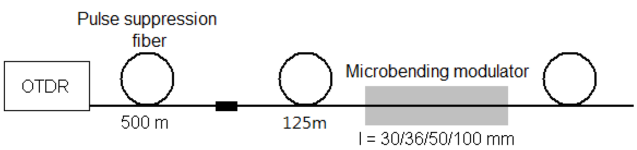

Fig. 3 Measuring workplace with microbending modulator and OTDR reflectometer.

By measurements we use the reflectometer MTS/T-BERD 6000L. Reflectometer settings are in Table 2. Optical fibers PS-9-500-FC/PC/200-FC/PC/200 are used, pulse suppression fiber 500 m long, and second, SMF 28E corning 9/125 2650 m long, with placed modulator. The fibers are connected by a connector SAA-4 JAPAN SII.

The approximation of measured attenuation as a function of weight is nonlinear with the best fit function: $f(x) = b_1 + b_2 e^{b_3 x}$ where b_1, b_2, b_3 are parameters.

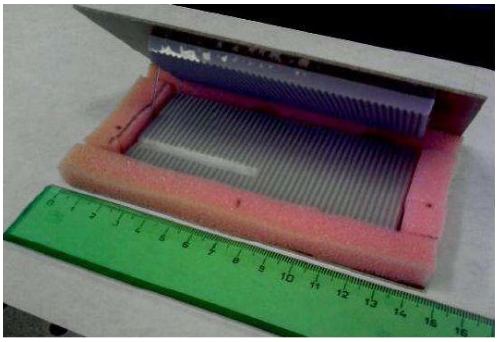

Fig. 4 Realized microbending sensor.

The sensor sensitivity is seen in Fig. 6. The dependence of the sensor accuracy for range of weights is in Fig. 7. The upper and lower weight limit is not the same for different loads. In sensor accuracy in (m±Δm)g, will be Δm maximum limit. We can teach students to construct two functions: recalculation function: the input is measured attenuation function and the output is load weight and accuracy function: the input is measured attenuation function and the output is the accuracy of weight determination [6]. We measure with two fiber places in the sensor and with the load acting in two places as it is shown in Fig. 5. Nonlinearity of the measured functions for the sensor is in Fig. 8.

Table 1. Sensor parameters

	Shorter sensor	Longer sensor
modulator length	60mm	115mm
deformation plate	115mm x 50mm	
novodur cover	145mm x 80mm	
number of tines	24	46

Table 2. Reflectometer settings.

wavelength	1550 nm
impulse duration	10 ns
range	2 km
resolution	4 cm
time of one measurement	120 s

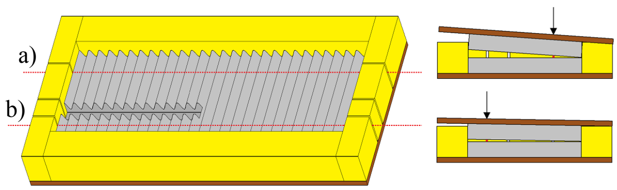

Fig. 5 The position of the fiber in the sensor and the place of the acting force.

The attenuation of these sensors is small and it allows measurements at big distances [2]. The OTDR principle offers the possibility of quasi-distributed measurement. When the sensors are placed in several places of the route (see Fig. 8) the measured signal achieved from reflectometer shows more attenuation steps (see Fig. 9). The condition for dynamic range of every sensor must be fulfilled. By maximum load of all sensors should be the measured backscattered power measurable also in the place of the most distant sensor.

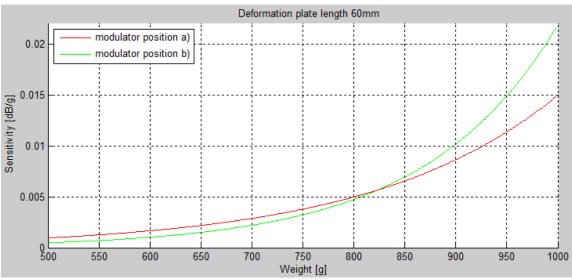

Fig. 6 Sensitivity of the sensor.

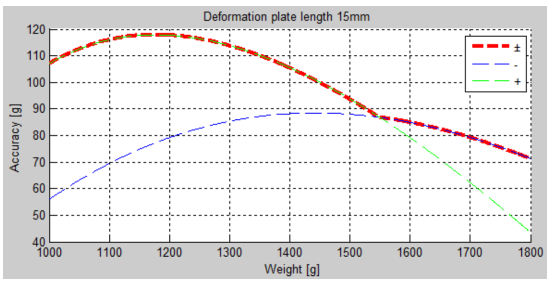

Fig. 7 The sensor accuracy as function of weight.

Conclusions

We created microbending sensor for weight measurements, dynamic range of the sensor for the length of plates 60 mm is from 500 to 1000 g, for the length of plates 115 mm is from 1000 to 1800 g. The sensor was included to students' laboratory experiments.

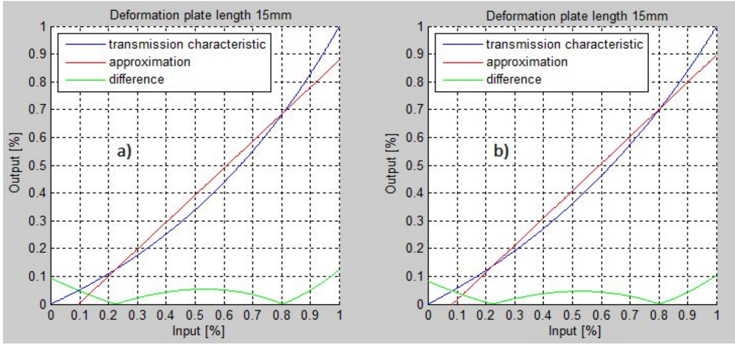

Fig. 8 Nonlinearity of the sensor

We explain theoretical principles and practical measurements with OTDR apparatus we explain principles of sensoric systems based on optical fibers.
We can show by using this experiment the methodology of nonelectrical variables measurements. One more added feature of the experiment is in the teaching possibility in the field of measurement theory: in evaluation of measured curves. We can highlight accuracy, sensitivity, dynamical range, linearity and nonlinearity of various types of sensors.

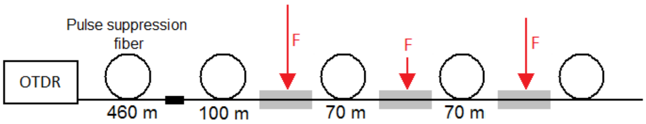

Fig. 9 Optical route for quasi-distributed measurements.

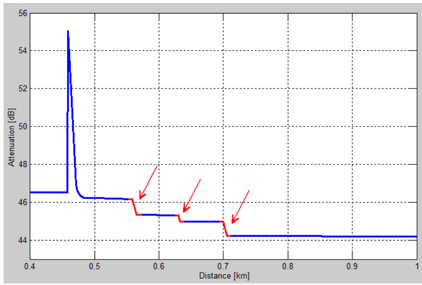

Fig. 10 Quasi-distributed measurement.

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