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Microarticle

A novel fiber optic distributed temperature and strain sensor for building applications

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ABSTRACT

A novel fiber optic distributed sensor for temperature and strain measurements in building constructions has been developed and studied which is a composite optical element in the form of a reinforced single-mode optical fiber placed directly in the body of a fiberglass armature. The sensor has a reasonably high sensitivity to changes in external temperature and strain and a good spatial resolution. Besides, it is characterized by a high mechanical strength as compared to conventional fiber sensor elements. The experimental results obtained on a prototype show the value of the temperature sensitivity of 0.1 MHz/deg and the sensitivity to strain of 2.7 MHz/mm.

Controlling the state of load-bearing structures and building bases of industrial facilities is an important part of a package of measures to ensure the safety of nuclear power facilities. Everyday monitoring of the state of load-bearing structures and building bases allows a quick identification and assessment of the load that occurs as a result of, for instance, placing heavy equipment, operation of powerful mechanical devices, unexpected land subsidence [1], etc.

Currently, measuring systems based on fiber optics are occupying more and more dominant positions among the monitoring technologies due to their undeniable advantages [2,3].

As a sensor element, optical fibers are used in such systems due to the mass-dimensional parameters that allow placing them in various building designs without changing the technical and operational characteristics of the structure.

Theoretical considerations show that embedded fiber optic sensors have a reduced sensitivity in strain [4] which depends on the mechanical properties of the glass core, the protective coating, and the gauge length of the optical fiber.

In reinforced concrete structures, fiber optic sensors are usually mounted on metal armatures or on special hangers inside the reinforcement cage just before pouring the concrete that imposes high demands on the staff qualifications [5,6].

Several efforts were made to embed optical fibers into more convenient casings such as polymer rods [7,8]. The effectiveness of such sensors highly depends on the technology of embedding fiber optics in fibrous composite materials [9].

We present a simple technology of embedding an optical fiber directly into the body of an armature which seems an effective solution and can be easily implemented in the industry. At the heart of this technology was the use of a composite armature. A composite fiberglass armature was a fiberglass rove impregnated with epoxy resin. The central fibers were winded round with another strand of fiber that formed a periodic profile on the surface which improved an adhesion to concrete. The armature was pulled through an oven where a rapid polymerization of resin takes place. The manufacturing process allows an implantation of an optical fiber in the body of the armature which gets rigidly associated with it during the polymerization. When passing the product line, the optical cable was going through wetting, contracting and polymerization, which ensures its firm contact with the fiberglass and protection against external mechanical damage.

The strand holding the rove compresses the fibers together significantly. Therefore an unprotected optical fiber placed into the armature gets multipoint stress that adversely affects the performance of the fiber as a sensor. To compensate for this effect, an optical fiber reinforced with a spiral metal sleeve was used. The reinforced fiber used was a part of the FO-SA-IN-9-1-LSZH-YL optical cable by Hyperline Systems Inc. Its outer shell and aramid yarn protected the fiber from moisture and tension, and the spiral metal sleeve prevented clamping.

The final product was an armature of the desired length with sealed optical couplings at the ends.

Such the armatures containing optical fibers can be used as a part of optical fiber distributed strain and temperature sensors (DSTS). DSTS systems are based on the Mandelstam-Brillouin

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scattering effect and are able to measure both temperature and mechanical strain along the entire optical fiber.

Experimental study was performed on the developed fiber optic sensor in building structures. For this purpose, the sensor was connected to a DSTS-C-01/50-1/100 Distributed Strain and Temperature Sensor by OZ Optics (Canada).

The experimental scheme is shown in Fig. 1. The system consists of a sensor element (armature) with the length of 3 m, the ends of which are connected to the DSTS by an optical patch cord. In the middle of the sensor, a heating coil was placed consisting of 10 turns of nichrome wire. The heater was connected to a regulated power supply. To control the heating, a calibrated thermocouple connected to a voltmeter was placed close to the sensor.

To minimize the impact of uncontrolled temperature effects, the sensor, the heater and the thermocouple were placed in a polyethylene foam thermal insulator. The whole structure is rigidly secured to the chassis to reduce the mechanical strains.

Before starting the experiments, the integrity of the sensor element was checked, the possibility of its use as a temperature sensor was assessed, and the spatial resolution was determined.

The initial data readings without heating (25 °C) were performed, which served as a basis value for further experiments. Then the Brillouin spectral shift was measured with the temperature being increased in increments of 10 °C. The results are shown in Fig. 2.

The measurement results have demonstrated a good sensitivity to external heating. The sensitivity was estimated to be ~0.1 MHz/°C. The sensor is capable of localizing the spot of heating with precision of up to 20 cm.

The next series of experiments was aimed at studying the possibility of measuring the deformation of reinforced beam structures and the sensitivity of the sensor element encased in concrete. Fig. 3 shows the experimental setup.

The test concrete beam was a parallelepiped with the length of 3 m and the cross section of 10 × 10 cm^2, made of M300 concrete. The beam was reinforced by two sections of the composite armature containing fiber optic sensors. The beam was rested on pivot bearings made of an 18U channel, which were attached to a supporting mainstay by M12 rods. The mainstay was also made of an 18U channel. A mechanical jack with a maximum force of 2 tons was set up between the reinforced beam and the mainstay. The deformation of the reinforced beam was controlled by a micrometer.

First, the initial data without deformation were measured. Then, guided by the micrometer readings, a deformation was made with a jack mounted in the middle of the beam. The magnitude of the deformation was set in 1 mm increments.

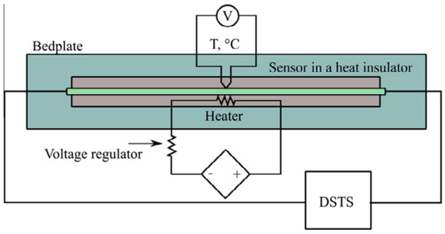

Fig. 1. Scheme of the experiment.

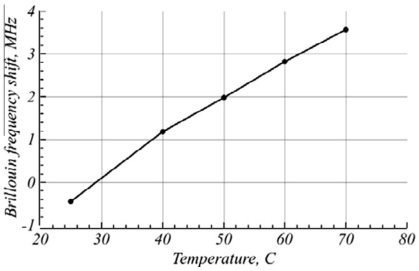

Fig. 2. Temperature dependence of the maximum Brillouin frequency shift.

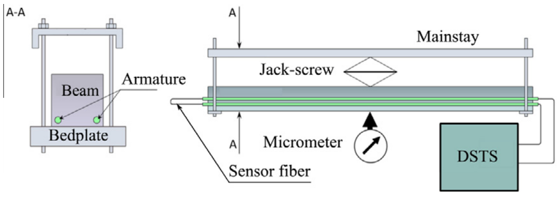

Fig. 3. Experimental scheme with a reinforced concrete beam.

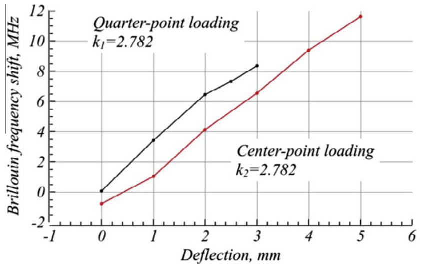

Fig. 4. Dependence of the maximum Brillouin frequency shift on the transverse deformation of the beam.

Fig. 4 shows the results of the experiments. The sensor developed demonstrated high sensitivity: for the above configuration of the setup, the sensitivity ranged from 2.5 to 2.8 MHz per 1 mm. The dependence of the frequency shift on the deformation magnitude appeared to be linear.

Thus we can conclude that the fiber optic distributed temperature and strain sensor for building structures designed in the form of an armature can be used for building facility monitoring due to its reasonably high sensitivity to changes in external temperature and strain, high resolution and high mechanical strength.

Such sensors can be of great demand in industrial and civil constructing projects, including nuclear industry.

Acknowledgement

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