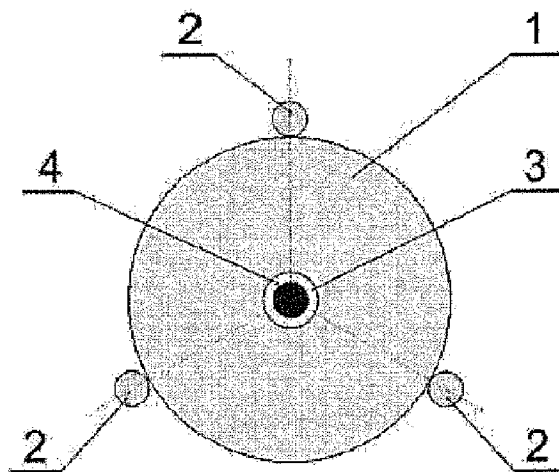




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(54) Title: METHOD FOR MEASURING THE DISPLACEMENT PROFILE OF BUILDINGS AND SENSOR THEREFOR



(57) **Abrégé/Abstract:**

The present invention provides a method for continuous measurement of displacements profile of building structures and a sensor for implementation of this method for repeated, automatic displacements profile measurements of the medium by means of optical fiber elements, especially in engineering structures, engineering structure elements, geotechnical structures, and an apparatus for implementation of this method, characterized in that the measurement involves a measuring sensor, which is constructed of the a core with coupled optical fiber sensing elements for determining the core strains and an optical fiber sensing element for determining temperature, placed freely in an axial channel of the core, making possible to perform measurements in such a way, which allows for compensation of the influence of ambient temperature.



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(54) Title: METHOD FOR MEASURING THE DISPLACEMENT PROFILE OF BUILDINGS AND SENSOR THEREFOR

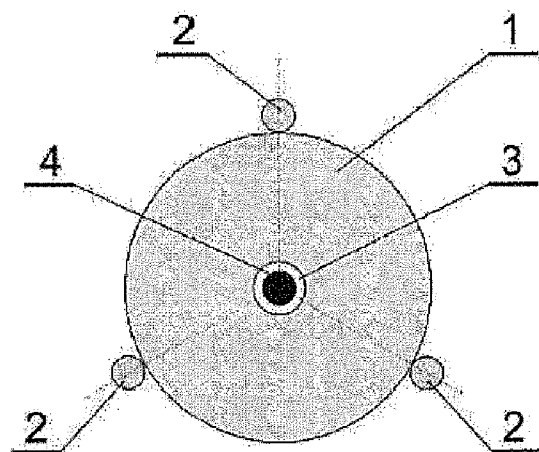


fig. 1

(57) Abstract: The present invention provides a method for continuous measurement of displacements profile of building structures and a sensor for implementation of this method for repeated, automatic displacements profile measurements of the medium by means of optical fiber elements, especially in engineering structures, engineering structure elements, geo-technical structures, and an apparatus for implementation of this method, characterized in that the measurement involves a measuring sensor, which is constructed of the a core with coupled optical fiber sensing elements for determining the core strains and an optical fiber sensing element for determining temperature, placed freely in an axial channel of the core, making possible to perform measurements in such a way, which allows for compensation of the influence of ambient temperature.

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METHOD FOR MEASURING THE DISPLACEMENT PROFILE OF BUILDINGS AND SENSOR THEREFOR

The present invention provides a method for continuous measurement of displacements profile of building structures and a sensor for implementation of this method for repeated, automatic displacements profile measurements of the medium by means of optical fiber elements, especially in engineering structures, engineering structure elements, geotechnical structures, and an apparatus for implementation of this method. The method and the sensor according to the invention allow for repeated, automatic and maintenance-free determination of a time-varying displacements profile of various types of mediums, in particular ground, structures (eg. bridges) or selected structural elements of buildings (eg. determination of beams deflection shape). The method and the sensor according to the invention allow for performing measurements for both small and large displacements. The method and the sensor according to the invention allow for determination of displacements from both effects of bending and tensile or compressive longitudinal force as well as for automatic compensation of influences caused by temperature varying over the length of the measuring apparatus.

From the US patent application No. US2007 / 0065077 A1 a method is known for determining position and shape, and an apparatus for implementation of this method. The solution is used to determine displacements profile (shape) of a monitored structure, relative position of objects, modal analysis of mechanical systems, as well as minimally invasive surgical techniques and biometric monitoring. The known device is based on optical fiber measurement technology using fiber Bragg

gratings arranged in a number of at least one hundred along the individual optical fiber cores. For two-dimensional analysis suitable is an optical fiber with two cores and for three-dimensional with at least three (in the case of three-core fiber uniform distribution of cores around the system axis at 120° is assumed). Device attached to a monitored member (or embedded within it) determines its deformations on the basis of local strain measurements resulting from bending of the monitored member comprising optical fiber cores, so that it is possible, by summing, to reconstruct the actual curvature of the monitored member. Analysis is performed in a discrete way basing on quasi-continuous measurements (fiber Bragg gratings arranged in specific intervals over the length of fiber optic core) and does not account for the effects caused by temperature. It is also not possible to analyze displacements profile caused by both bending and axial force loading.

From US patent application No. US 2010/0215311 A1 a method and apparatus are known for determining the position and shape using the multi-core optical fiber applied primarily for determining the relative position. Presented solution uses three cores arranged uniformly within optical fiber cross section, passing parallel along its length. Inside optical fiber line there are used variety of single strain sensors based on principles of Bragg gratings, Rayleigh scattering or other. The method and apparatus allow with a suitable package of functions for determination of curves, bending surfaces directions and twisting of optical fiber placed freely in a protective outer jacket. This jacket is in no way connected with the optical fiber, and therefore deformations of optical fiber in the form of twisting or unscrewing are not limited along its length. Procedure for determining displacements profiles of optical fiber in three dimensional space (the shape) is performed under the assumption that one end has fixed (known) position, while the other moves freely. From this assumption directly results the fact that displacements of optical fiber are not affected by axial force. Furthermore,

the solution allows to determine the shape only in a discrete way (quasi-continuous) over the length of the optical fiber and does not consider compensation of results due to temperature influence.

It is also known from US patent application No. US 2014/0320846 A1 a device is also known for determination of the position and/or shape of the object in three dimensions space, applied in the construction industry, space and medical. Average strains along the length of optical fiber are determined based on registered, total changes of optical length. The device uses multi-core optical fiber: in a cross-section of optical fiber there are three cores intertwined together in the form of helix and arranged in the outer part at 120° , while one core is located in the axis of cross section. Measurement data from the central core are related to the averaged values from external cores. The central core is susceptible to the effects of temperature and changes in the axial force (tension changes), but in contrast to the outer core, does not experience the change in length resulting from the influence of torque around the axis of the profile. This fact allows for measurement compensation due to the influence of either a longitudinal force and temperature, or torque, or all of these above effects. Performing measurement is done using laws of Rayleigh scattering, thus the need of Bragg gratings application is eliminated and it enables for continuous analysis of displacements profile over the entire length of specified measuring segment with high resolution.

All known solutions are based on the assumption that the sensing element, which is a multi-core fiber optic element, is a free element. This means that only one end of the sensing element can be immobilized while the whole sensing element is free. With this assumption, sensing element with optical fibers located inside can freely change its length under the influence of temperature. The known solutions, however, do not include the influence of temperature changes in the case when the sensing element

movement is limited, constrained by the medium in which it is placed, and which displacements have to be determined. The medium limiting the movement of a fiber optic sensing element can be eg. soil or concrete. Despite the change in temperature of the medium, fiber optic sensing element cannot freely change its length. Since the measurement signal obtained from the optical fiber sensors is just as sensitive to both the temperature and strains, it precludes in this case correct interpretation of measurement data, and thereby correct determination of the examined medium profile.

Technical issue to be solved is to provide a new method for determining displacements profile of the medium with time-varying temperature, i.e. displacements of building structures, and a sensor for implementation of this method. Such medium is eg. the ground or concrete, which are subjected to daily, monthly and yearly temperature changes. The solution must provide a possibility for determining the temperature effect using the free, unloaded by medium strains, a fiber optic sensor.

Optical fiber sensing elements are optical fibers designed to measure strain and temperature. Within discrete measurements this is optical fiber with applied Bragg grating, within continuous measurements (approximately at every point of the fiber) there are eg. conventional telecommunications optical fibers, which are analyzed using, in particular, the phenomenon of Rayleigh, Raman or Brillouin scattering.

The present invention provides a method for continuous displacements profile measurement of building structures characterized in that the measurement involves a measuring sensor, which is constructed of a core with coupled optical fiber sensing elements for determining the core strains and an optical fiber sensing element for determining temperature, placed freely in an axial channel of the core, making possible to perform measurements in a way that allows for compensation of the influence of

ambient temperature. The essence of the invention is to perform continuous displacements profile measurement of building structures through measurement of strains of the measuring sensor, placed in the examined medium. Optical fiber sensing element is responsible for determining the temperature, and due to of its location within the neutral axis of the sensor core cross section, it is not susceptible to strains resulting from sensor bending or twisting. Measurement signals from the optical fiber sensing elements are read using an appropriate well-known electronic device and are converted into displacements profile of examined medium.

The present invention also includes a sensor for measuring displacements profile of buildings structures characterized in that it consists of a core and coupled with it optical fiber sensing elements for determining the core strains, wherein the core in its neutral axis has formed a channel in which optical fiber sensing element for determining temperature is freely placed. Preferably, the core is a rod of a length appropriately chosen to the length of the examined medium, made of deformable material, in particular fiberglass, metal or plastic. Preferably, the channel is filled with a friction reducing substance to minimize friction between the optical fiber sensing element for determining temperature and the walls of the channel. Preferably, the cross-section of the core is a circular. Preferably, the cross-section of the core is a rectangular. Preferably, the cross-section of the core is triangular. Preferably, the core is symmetric about the axes passing through the points of attachment of optical fibers. Preferably, measuring sensor has on its surface the geometric elements for gluing optical fiber sensing elements.

The sensor implementing the method according to the invention is illustrated in an embodiment drawing, in which Fig. 1 shows a sensor having a circular cross-section, Fig. 2 shows a sensor with a square cross-section and Fig. 3 shows a sensor core with different cross-sections.

The measuring sensor consists of a core (1) and, appropriately arranged and coupled with the core (1), optical fiber sensing elements (2) for determining the core (1) strains. Core (1) within its neutral axis has a channel (3), in which optical fiber sensing element for determining temperature (4) is freely placed.

The method according to invention is that it uses the fact that the measuring sensor according to the invention adopts the shape of medium displacements profile, in which it has been placed. By determination of measuring sensor shape the displacements profile shape of examined medium is determined.

Claims

1. A method for continuous measurement of a displacement profile of a building, engineering structure, or geotechnical structure using a fiber optic measurement technology based on measurement of strain on a measuring apparatus placed into an examined medium, comprising
 - placing the measuring apparatus into the examined medium, wherein the measuring apparatus has
 - a core (1),
 - optical fiber sensing elements (2) arranged on an outer periphery of a cross section of the core (1), and thereby coupled with the core (1); and
 - a further optical fiber sensing element for determining temperature (4); wherein the core (1) has a channel (3) in which said further optical fiber sensing element for determining temperature (4) is freely placed, wherein the channel (3) is coaxial with the core (1) and placed in a neutral axis of the core (1);
 - measuring of strains of the measuring apparatus, wherein the optical fiber sensing elements (2) determine core strains and the optical fiber sensing element for determining temperature (4) is responsible for determining temperature;
 - reading signals from optical fiber sensing elements (2) and from the optical fiber sensing element for determining temperature (4); and

- converting the signals into displacements which together comprise the displacement profile.

2. A sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure using a fiber optic measurement technology, comprising

- a core (1),
- optical fiber sensing elements (2) for determining strains on the core, arranged on an outer periphery of a cross section of the core (1), and thereby coupled with the core (1) and
- a further optical fiber sensing element for determining temperature (4); wherein the core (1) has a channel (3) wherein said further optical fiber sensing element for determining temperature (4) is freely placed, wherein the channel (3) is coaxial with the core and placed in a neutral axis of the core (1).

3. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to claim 2, characterized in that said sensor has on the outer periphery of the cross section of the core (1), geometric elements for attachment of said optical fiber sensing elements (2).

4. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to any one of claims 2-3, said building, engineering structure or geotechnical structure being partially embedded in a medium, characterized in that the core (1) is a rod of a length corresponding to a length of an embedded part of said building, engineering structure, or geotechnical structure to be examined, said rod being made of a deformable material.

5. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to any one of claims 2-4, characterized in that the channel (3) contains a friction reducing substance to minimize friction between the optical fiber sensing element for determining temperature (4) and walls of the channel (3).

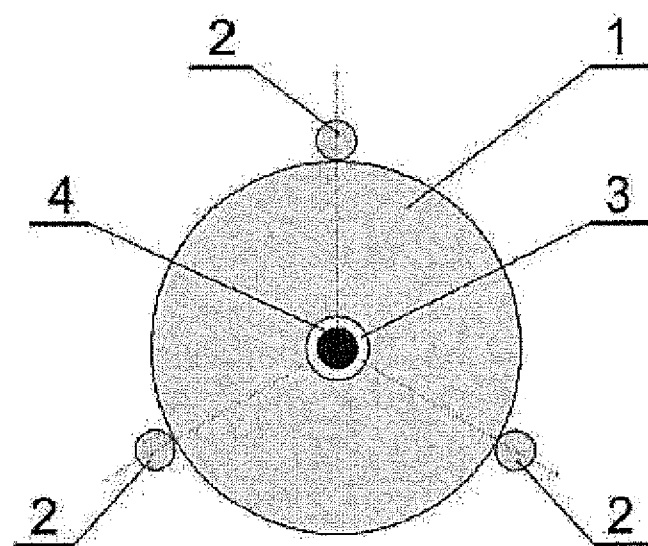
6. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to any one of claims 2-5, characterized in that said cross-section of the core (1) is circular.

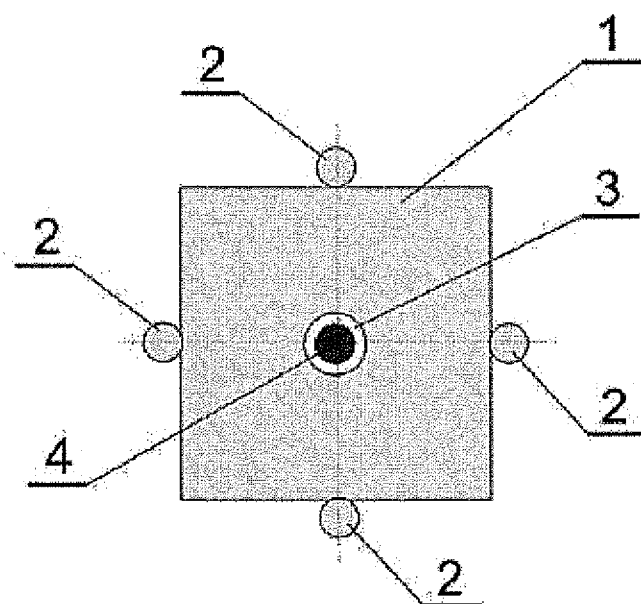
7. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to any one of claims 2-5, characterized in that said cross-section of the core (1) is rectangular.

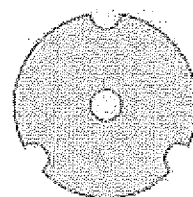
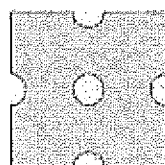
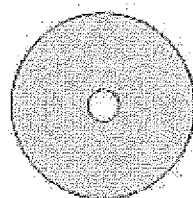
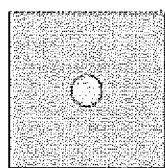
8. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to any one of claims 2-5, characterized in that said cross-section of the core (1) is triangular.

9. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to any one of claims 2-8, characterized in that the core (1) has a neutral axis, and is symmetric about said neutral axis.

10. The sensor for measuring a displacement profile of a building, engineering structure, or geotechnical structure according to any one of claims 2-9, characterized in that said sensor has on the outer periphery of said cross section of the core (1), has geometric elements to which the outer optical fiber sensing elements (2) are in attached engagement.

*fig.1*

*fig. 2*

*fig.3*

