MONITORING OF UILDING STRUCTURES BY SENSORS

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Abstract
The modern construction is characterized by the high rate of introduction of new materials, analysis methods, constructive solutions, and methods of works performance. Experimental studies of building structures play an important role in such conditions. Recently is revealed the tendency to use more automated systems to evaluate the current technical state of building structures and buildings itself. These systems are called as monitoring systems and are mainly used for the evaluation of the technical state of the facilities for the field of aerospace and aviation equipment, railway, building [1,2,3].

The research aims is to develop complex system of monitoring for evaluation of building structures state based on the experimental-theoretical analysis and its implementation during the construction or operation of buildings and its implementation at construction or to provide safety of buildings during the operational process.

1. Introduction

The modern construction is characterized by the high rate of introduction of new materials, analysis methods, constructive solutions, and methods of works performance. Experimental studies of building structures play an important role in such conditions. Recently is revealed the tendency to use more automated systems to evaluate the current technical state of building structures and buildings itself. These systems are called as monitoring systems and are mainly used for the evaluation of the technical state of the facilities for the field of aerospace and aviation equipment, railway, building [1,2,3].

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2. Methodology

Principal modification schemes for research, diagnosis, control and fault forecasting optical fiber systems of dynamic processes in building structures are mainly based on the principle of work of fiber-optic light waveguides, photodetectors, transmitters and other components of optical schemes.

The fiber-optical light waveguide represents transparent cylinder, composed of the core and casing. The light is spread from core. The light waveguide may currently have an external layer-coating that protects the fiber surface, increase its strength and facilitate operation. The core refraction index n_1 is slightly larger than the casing refraction index n_2, so the light from cores is reflected from the cored-casing border and fully is propagated in cor. For the full internal refraction in the light fiber the aperture angle will equal to

$$\theta_{\max} = \sqrt{n_1^2 - n_2^2}$$

$$\sin Q_{\max} = \sqrt{n_1^2 + n_2^2}$$

where the $\theta_{\max}$ is calculated in radians. Because $n_1 - n_2 = \Delta n \ll n_1$, then θ_{max} and for aperture angle we will have:

$$Q_{\max} \approx \sqrt{n_1^2 + n_2^2} \quad (1)$$

Let's consider that physical properties of the optical fiber, which is more important for uits application as a sensitive element. More precisely, let's consider the character of change of propagated along along the fibers light phase by mechanical and heat impact.

The phase change $\beta\ell$ by presented measurement object at application of interference type fiber-optical sensor, will be revealed as the intensity change of the interference. Therefore, for the determining of sensitivity of fiber-optic sensor due increased pressure, temperature and other influence, it is necessary to know the phase change $\beta\ell$ with the respect of these values. Let's determine the light phase ψ of sensory fibers, at a relatively small difference in the fibers refraction index:

$$\psi = \beta l \approx kn\ell \quad (2)$$

where, n - is the refraction index of core.

Then the relative change of phases die impact objects under measurement (sensitivity) will be equal to: $\Delta\psi / \psi = \Delta\ell / \ell + \Delta n / n$ (3)

Accordingly of the formula (3) is possible to apply relatively sensitive sensor for measurement of pressure, temperature and other values.

Fiber optic light waveguides and light energy receivers that are used to record the parameters in real time scales are characterized by hybridity and flexibility.

Scheme of monitoring systems - equipment for different levels of monitoring systems

Technical means

In the course of the work, a number of measuring instruments were used, a brief description of which is given below.

Accelerometer RefTek 131B-01/1

This single-component accelerometer has a measurement range of ±4g, self-noise 2 μg2/Hz, sensitivity about 1.6 B/g. The transmitter has an aluminum housing, which is attached to the structure with two bolts.

figs. 1. Accelerometer RefTek 131 V-01/1

Accelerometer RefTek 131B-01/3

This three-component accelerometer has a range of ±4g, a self-noise of 2 μg2/Hz, and a sensitivity of about 1.6 B/g. The transmitter has an aluminum housing that is attached to the structure with a single bolt, which is aligned with three mounting screws.

figs. 2. Accelerometer RefTek 131V-01/1

Seismic receiver six-channel RefTek 130-01

The accelerometer signals were recorded using a RefTek 130-01 six-channel digital recorder (see Fig. 5). This recorder has an Ethernet and Serial PP connector for network access, a connector for connecting to a 12V power supply, a connector for connecting to GPS. Also inside the recorder there are two flash memory of 2 GB

figs. 3. Six-channel recorder Reftek 130-01

Electronic level LS160 S-Digit mini

An electronic level was used to position the accelerometer in the horizontal plane:

figs. 4. Electronic scales LS160 S-Digit mini

Fiber Optic Sensors

Measurement of stress and strain on a metal surface.

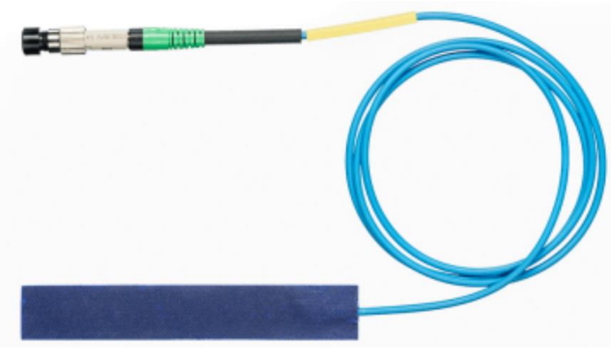
VBR voltage and/or temperature sensor

- • Sensor embedded in protective laminate
- • Zero power, EMI shielded, intrinsically safe
- • Metal, concrete, mixed materials, etc. designed by Smart Fibers. by attaching to the surface.
- • The installation includes a wind turbine,

- ship hull, yacht masts and concrete structures.

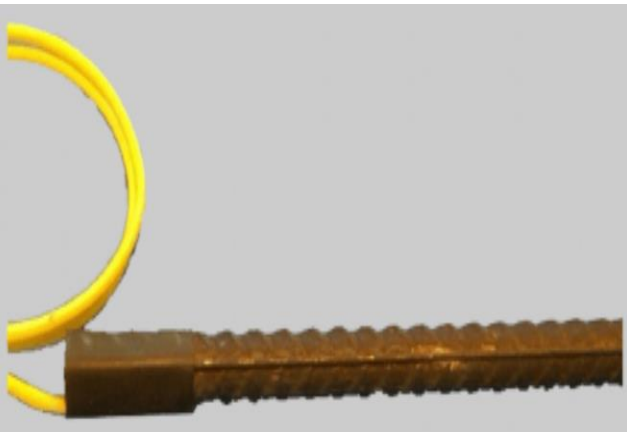
• Suitable for long term SGM

• Signal integrity over several kilometers (possibility)



figs. 5. Fiber optic sensor smart patch

SmartPatch is a rugged and easy-to-handle FBG voltage sensor in which the FBG is embedded in a flexible, fibrous polymer plastic. It can be attached very easily to difficult materials including metal, composites and concrete. SmartPatch can come in many forms: as a single axis voltage sensor, a multi-axis switch, or in massive multi-sensor configurations. Integrated temperature compensation is available on request. Applications include transferring surface tension to wind and moving turbine blades or concrete structures.



figs. 6. Fiber optic sensor

Measurement of stress and strain on a metal surface.

• Powerful voltage and/or temperature sensor FBG

• Can be welded to a metal pole, pipe, etc.

• Zero power, EMI shielded, intrinsically safe

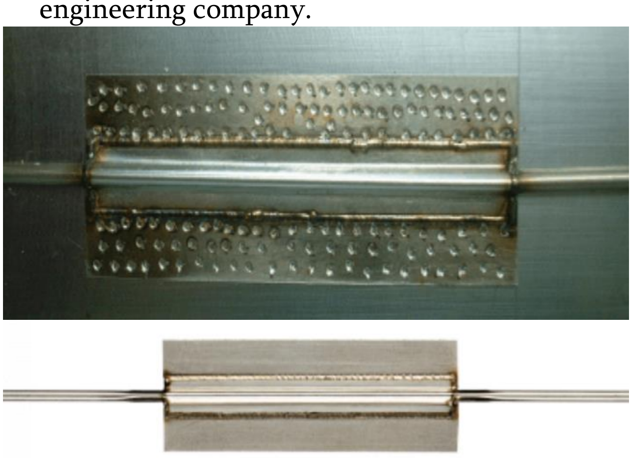
• Signal integrity over several kilometers (possibility)

• Suitable for long-term use SHM

• Sealed, welded, non-corrosive construction available even in harsh environments.

• Durability (6 million revolutions (cycles) ± 500 μs of deformation) confirmed in the UKAS laboratory.

• Improved and approved by a world class engineering company.



figs. 7. Fiber optic sensor

N The functional diagram of the fiber-optical diagnostic system is presented in Fig. 8 [1].

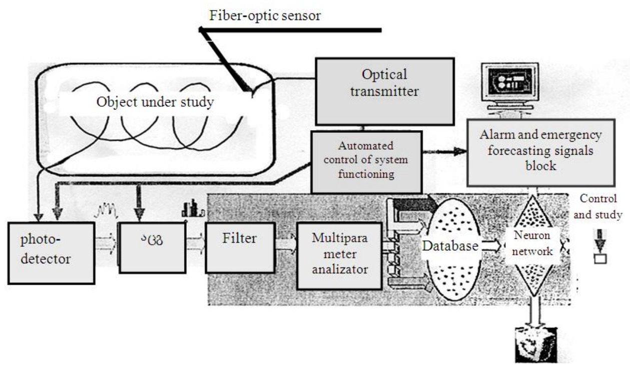


Fig. 8. Functional Scheme of Fiber-Optical Diagnostic System

It consists from the following components: object under study, fiber-optic sensor, automatic control of functional systems, photodetectors block, analog-digital transformer, filter, multi-parameter analyzer, database, neuron network, alarm and emergency signal formation block and monitor.

The present system operates as follows: light impulse from optical transmitter is supplied to the fiber-optical sensor located on the object under study. After passing the sensor, the impulse will enter into the photodetectors block. The synchronization of the optical transmitter and photodetector operation is carried out by automatic control functional systems, from photodetector the signal will pass the filter, multi-parameter analyzer and get into the database where data processing is carried out by mathematical models of Fourier spectrum analysis. Then the neuron network chooses the data, which is nothing goes to the trash in the trash, and those gives the prognosis send to alarm and emergency forecasting signals formation block, results will be displayed on the monitor. Fourier and Vievlent spectrum analyzes are used for the processing of signals, and the results are comparable with the results obtained by the finite elements method. O

Physical effects, which are considered in engineering tasks, are described as a rule by the time functions, which are called realization of processes. The realization of process implies an echo that has been registered in the building structure point due the acting on it load. It is also meant that the load is dynamic, and therefore the echoing of the structure also is dynamic.

We consider the frame of building as a system and a combination of the appropriately interconnected elements of the structures (columns, girders, slabs, etc). The important feature of the system is the hierarchy. The system is hierarchical according to its nature, if each part of it can be considered as a system, and the initial system itself is the only one element of the larger systems.

Are considered all the structures included in the system that changes its physical-mechanical characteristics as a result of various impacts and also form potentially measurable signals that pass through the arranged in the system optical fiber as light impulses. Significant signals for a specific task are called as output signal. It should also be noted that the system is subject to the external impact. The passed through fiber-optical light waveguide signal that can be manipulated by observer is called as input signals. There are also other signals, they are called as noise (disturbances) that can be divided into two groups. The noise can be directly measured (measurable noise), and if it is impossible, noise would be included in the output signal (no-measurable noise). The distinctive characteristic between the input signals and measurable noise lies in the fact that measurable noise has less importance for modeling of the processes. Many tasks of modern science are solved by using a system-oriented approach. On the Fig. 2 is presented the system with signals designation.

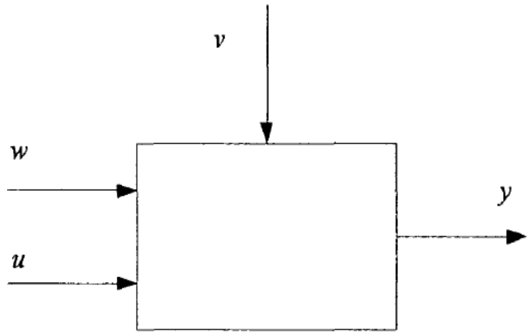


Fig. 9. Block-diagram of system with signals designation

On the Fig. 9. is presented the output signal y, input signal u, measurable noise w and non-measurable noise v.

As an example let's state dynamical system of damped and supported on spring body with one degree of freedom that is presented in Fig. 3. If the body experiences a variable in time load, then the body movement (reaction) will also be a time function. In addition, the system reaction $y(t)$ will be defined by the input impact $u(t)$ and the system's frequency characteristic (f). The frequency characteristic (f) depends only on the system's properties, such as: body mass m, spring stiffness k, damping constant c. The mentioned frequency characteristic is determined as a system reaction on the delta-function effect.

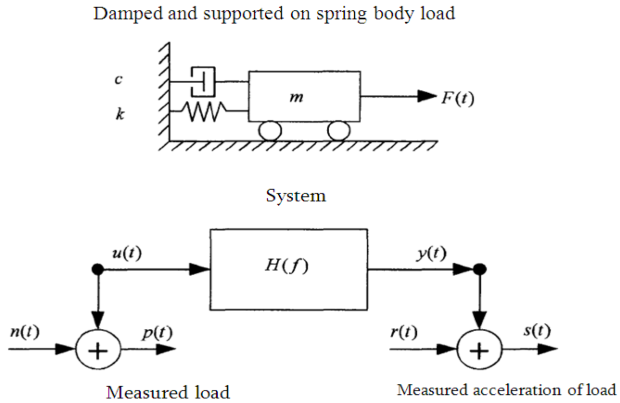


Fig. 10. Block diagram of damped and supported on spring body

The Presented on the Fig.10. block diagram has one input $u(t)$ and one output $y(t)$, and if in the obstacles are registered at the input $n(t)$ and the output $r(t)$, then the being under observation input and output processes will be as:

$$p(t)=u(t)+n(t);\\ s(t)=y(t)+r(t), \quad (4)$$

where $p(t)$ – is the measured load; $u(t)$ – is the input impact on the system; $n(t)$ – is non-measurable noise at the input; $s(t)$ – is the measured acceleration of the body (speed of movement and so on); $y(t)$ – is the system reaction; $r(t)$ - is non-measurable noise at the output.

In the given case, by measurement of $p(t)$ the system reaction $y(t)$ with taking into account of noises $n(t)$ and $r(t)$, or without their consideration, may be determine the system transmission function as $y(t)/u(t)$ and simultaneously some of the function parameters (for example, the own frequency of oscillations and corresponding damping coefficient).

Since loads, and consequently reactions are changing in time, the dynamic task does not have the unique solution (in movements, stresses and other values), in contrary of static tasks. It is therefore necessary to draw a sequence of solutions that correspond to all the interesting moments in determining of the reaction of structure. From this point of view, the dynamic analysis is more complex than static. The described difference of dynamics tasks is important to take into account the at experimental studies - is necessary to apply for dynamics a device that can perform measurement of a fixed frequency in the range 0 - 1000 Hz, the implementation of that with significant reserve of is possible in experiments with developed by us fiber-optic systems [3].

Significant difference between static and dynamic tasks is that in the dynamic tasks there are inertia forces. If the hinged supported rod which is shown on Fig.11. is loaded with a static load p, then its internal forces as well as the shape of bending will be determined only by the specified load, accordingly the mentioned values would be defined from equilibrium equations. In case of dynamic load impact $p(t)$, the movement of rod will be determined by accelerations that are cause by the inertia forces. Thus, internal forces generated in the rod must be balanced not only by external forces but also inertia forces that arise during the acceleration of rod.

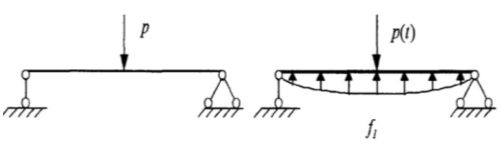


Fig. 11. Basic difference between static and dynamic tasks

If the inert forces constitute an important part of the total load that is balanced by internal forces, at solution of task should be taken into account the dynamic nature of the load. If the loading change is insignificant in time, then would be used a static analysis method.

The most common method of solving partial derivative differential equations in the structures analysis in dynamics is the method of finite elements (FEM). This method is used for any shape structures - rod, column, shell and other. The idea of FEM is in representation of structure as a finite elements system (FE) whose size can be arbitrary. At the same time, the FE are interconnected with each other in nodes, which have a finite degree of freedom.

FEM's advantage is the following:

- In the FEM models can be used different types of FE designated for modeling of rods, girders, shells, spatial bodies, etc.;
- The method is realized in many computer complex programs such as ANSYS, Lira, NASTRAN, ABAQUS and others;

-The FEM data can be easily used for applied tasks, for example by comparison of spectrum received in experimental and design models.

3. Conclusion

The developed in the paper monitoring system ensures permanent monitoring of buildings throughout the entire operation period and provides assessment of the technical state of load bearing structures, including the load bearing capability and before failure state assessment in real time.

4. References

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