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New System of Monitoring of a Condition of Cracks of Small Reinforced Concrete Bridge Constructions

T.A. Krakhmal'ny, S.I. Evtushenko, M.P. Krakhmal'naya*

Platov South-Russian State Polytechnic University (NPI), 132, St. Prosvescheniya, Rostov region, Novocherkassk, 346428, Russia

Abstract

The paper deals with the monitoring of the technical condition of bridges and description of the authors' remote system for monitoring crack opening in bridges allowing to take real-time measurements and to automate process of data transmission by means of a wireless communication. The short review and the analysis of the available devices for monitoring of the technical condition of building constructions is given. This system offered by authors is based on the crack-width- growth sensor which is protected by an invention patent. The paper presents a diagram of this device and its operation principle and conditions as well as technical parameters. Details of the processing system and the analysis of the obtained data on the inspection object are provided. The scope of the remote supervision system for the disclosure of cracks in bridge constructions is described.

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Keywords: reinforced concrete bridge structures; technical condition monitoring; crack, movement sensor; reliability and durability of a structure

1. Introduction

The issue of improving the reliability and durability of roads and roadworks is of immediate interest in the vast majority of European countries as well as in Russia, as indicated by the materials of recent international conferences [1-4]. The issue of obtaining objective information on the technical condition of facilities and implementation of the specific decisions taken is of vital importance today, while creating advanced methods and tools for inspecting the technical condition of bridges under construction is a critical task.

* Corresponding author. Tel.: +7-951-511-2390.
E-mail address: marischka_86@mail.ru

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It is worth mentioning that the term "monitoring" appeared and started being actively used in the scientific literature in the late 1960s. Initially, this term was understood as the observation of the environment, its changes and the impacts of hazard factors on nature [5].

Over time, the meaning of the term has changed, and the term "monitoring" began to mean a system of monitoring of construction projects in order to prevent their demolition.

In most cases, it is unique or especially important structures that are monitored when it is necessary to ensure their safety and smooth operation, such as nuclear power plants, dams, underground structures, bridges, high-rise buildings, and others.

Small reinforced concrete bridges are monitored in rare and exceptional cases. However, deterioration of concrete bridges on the regional roads can at least equally adversely affect the national economy due their large number [6].

In monitoring bridge load-bearing structures, detecting cracks and establishing why they have developed is the most important objective. When cracks on building members are detected, it is essential that their state and growth activity be monitored and the nature of the deformation of the structures and the risk for further operation of the entire facility are identified [7].

In most cases, the crack growth activity is determined visually, with the help of gypsum and glass tell-tale strips or plate slit-metering devices of different designs [8]. The indication of crack growth in this case is a fissure of the strips or displacement of the plates relative to each other. However, the disadvantage of these devices is that they are time-consuming and labor-intensive to employ and do not allow automated measurement. Besides, the fissure and the displacement have to be detected visually by a supervising individual. Especially difficult it is to use these devices if the crack to be monitored is in a hard-to-get-at place. A crack located in the middle of a reinforced concrete bridge beam can be cited as an example: it can be reached only by boat when the canal is in service and with the help of a five-to-eight meters-long ladder when the water from the canal is discharged.

There is a method for monitoring cracks in building structures [9], comprising rigidly installed, with the help of a mounting template, supports for an inventory measuring base on the surface of the building structure on different sides of the crack. The distance between the supports is measured, and the increment of the crack parameters is simultaneously determined, with a dial indicator, the distance between the supports being measured in orthogonal directions. However, this technique is difficult to use in bridgeworks, since the dial indicator readings need to be seen, but if the crack is located on the underside of the bridge girder, it is almost impossible.

To monitor crack states, there are movement sensors LVDT [10], which are connected via an interface to a computer or microprocessor that allows for continuous monitoring of the crack opening process in real time.

This measurement system consists of the following devices:

- Hall-effect movement sensor. The measuring range is ± 3 mm with an accuracy of 0,01 mm;
- unit of amplifying signals and converting them to digital form;
- cable network;
- «Geotek-SHM» program computer.

The weakness of this measuring system is the process of taking measurements from these sensors that eliminates the possibility of wireless data transfer to a computer, which significantly reduces the area of its application. This system can be applied only to large-span bridges under constant guard and surveillance.

At present, a wide variety of issues relating to the methods and means of inspection of buildings and structures have been considered. But still technical ideas continue developing. Today, thanks to the development of telecommunication technologies, there are opportunities of creating completely new inspection and monitoring methods on the basis of available technology.

2. Flow chart and principle of operation of the system of monitoring crack state

The system of monitoring the state of cracks in bridges [11, 12] enables real-time measurements and automated wireless transmission of data.

The technical result of this invention is enabling automation of measuring opening widths of a large number of cracks, which is especially important in those cases where the monitored cracks are in hard-to-reach places.

The monitoring system includes one or more movement sensors and a recording device, for which a computer or portable laptop can be used.

The movement sensors consist of, see Fig. 1: slide-wire (2) and current collector (3), analog-to-digital converter (5), the microcontroller (6) radio transmitter (7), protocol Zigbee supported chemical source of supply voltage (8) "alarm clock" module (9).

The sensor works in the following way. When the monitored crack opens, the distance between the sensor and the stop of the retractable rod (11) increases. As a result, the retractable rod (4) of the dial indicator follows the stop, and dial indicator (1) shows the displacement. The movement is conditioned by the spring mounted in the dial indicator design.

The device can use a standard dial indicator, such as ICH-10 (-25, -50). Slide-wire current collector (3) is mechanically connected to retractable rod (4) of the dial indicator; it receives a signal proportional to the displacement of the retractable rod. From the current collector, the signal arrives at analog-to-digital converter (5) which converts the input analog signal into a digital code. From the analog-to-digital converter output, the digital code is supplied to microcontroller input (6). The microcontroller then via transmitting radio module (7) transmits the displacement value to receiving radio module (12) and recording device (13). This eliminates the need to run a wire link.

The sensors are mounted on the proper inspection points which can be in different parts of the bridge structure or on different bridgeworks in the region. And the radio receiver module connected to the recording device communicates by radio with each transmitting radio module which is part of the sensors, see Fig. 2.

Supply voltage for all modules in the sensor is generated by a self-contained chemical source of supply voltage (8); therefore there is no need to draw supply voltage wire to the sensor. "Alarm clock" module (9) is configured such that the alarm signal is sent regularly to microcontroller (6), for example one or two times a day. Only after the microcontroller does receive an alarm signal from "alarm clock" module (9) all the sensor modules enter performance mode.

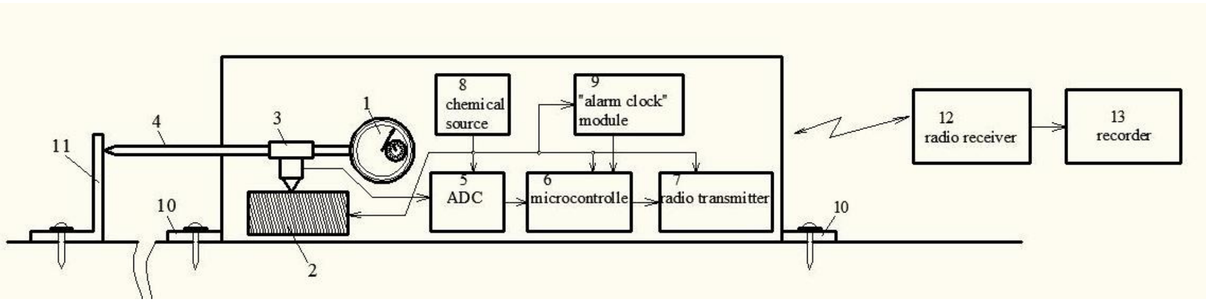

Fig. 1. Block diagram of movement sensor device: 1 dial indicator; 2 slide-wire; 3 movable slide-wire current collector; 4 retractable rod; 5 analog-to-digital converter; 6 microcontroller; 7 radio transmitter; 8 chemical source of supply voltage; 9 "alarm clock" module; 10 sensor supports; 11 stop of the retractable rod; 12 radio receiver; 13 recorder.

The entire measurement cycle is done once, then the sensor goes again into "sleep" mode. The time during which the entire measuring cycle takes place is not more than 1 second. Thus, significant energy savings are achieved; the chemical source of supply voltage lasts for a long period of time estimated in years.

Technical specifications of the sensor:

- measurement accuracy is 0,01 mm;
- measurement range depending on the dial indicator is 10, 25 and 50 mm.

When there is a need to monitor several cracks in different parts of a structure, several sensors need to be used, in accordance with the number of monitored points. In this case, radio receiver module (12) communicates in turn with radio transmitter modules (7) forming part of each sensor. Each of them has its own number and transmits the information via radio to recording device (13).

Before installing the sensor on the crack to be monitored, it is necessary to calibrate the device. To do this, the sensor housing has a specially built-in dial indicator. When switching the microcontroller to the "calibration" mode, the sensor is always in working order and the readings are not taken only one time a day, but at each request of the recording unit. When the retractable rod is set to move, the indicator defines this movement with an accuracy of 0,01 mm, and the user takes readings visually from the indicator and the recording device. Calibration is performed in the entire range of the movement of the retractable rod, and, based on the sensor readings, a calibration graph is plotted that reflects which microcontroller reading corresponds to what expansion of the crack. This graph will be required later to interpret the readings received from the sensor. In addition, the user can periodically visually monitor the sensor readings by the dial indicator and make sure of its sanity.

Data obtained on the facility are automatically entered in the data processing center for further analysis. Thus, the technical result is achieved, which is to enable automated measurement of opening width of a large number of cracks and joint gaps.

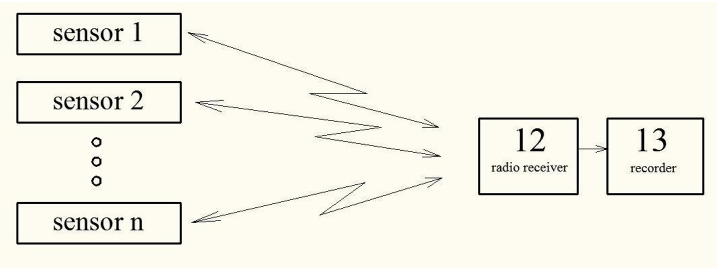

Fig. 2. System of monitoring crack opening in buildings and structures

The data processing center is supplied with a broadband Internet-access device connected to a computer. The Internet is used as a link channel between the system of gathering and transferring data and the data processing center. The supervisor scans the sensors and transfers the collected data to the data processing center. The computer, which is part of the center, stores and processes the information collected, see Fig. 3.

Fig. 3. Structure of small concrete bridge monitoring system

The information from the monitored facility is analyzed and processed, see Fig. 4, [13] in the data processing center. "Main Menu" block controlling the data processing center enables moving to the bridges registry, statistics block and the monitoring block. "Bridges registry "block allows moving to work with the bridges history block, block of registration of a new bridge, block of editing information on bridges and block of recording of the monitoring results. If "Registration of a new bridge " is selected, one by one are entered general information about the structure, location, technical information, information about the project and the operating organization, the dimensions of the bridge, the parameters of the piles, the parameters of all building structures, pavement, railings and foot-walks and other details . After all the data are entered, the information is transferred to the archive, and the user is returned to the "Bridges registry."

The results of the regular inspection of bridges are entered in the block "Record of inspection results." The information on established faults in buildings is found in this block. Finally additional information is entered and technical condition of the building structures is analyzed.

Special forms of bridge inspection reports presented in the system describe typical faults and structural failures for each member (totally, the system contains more than 200 types of faults and failures) [14]. Based on the input parameters of the detected faults, the system assigns technical condition category to each design member, and eventually concludes with the overall technical condition of the bridge and calculates its residual service life.

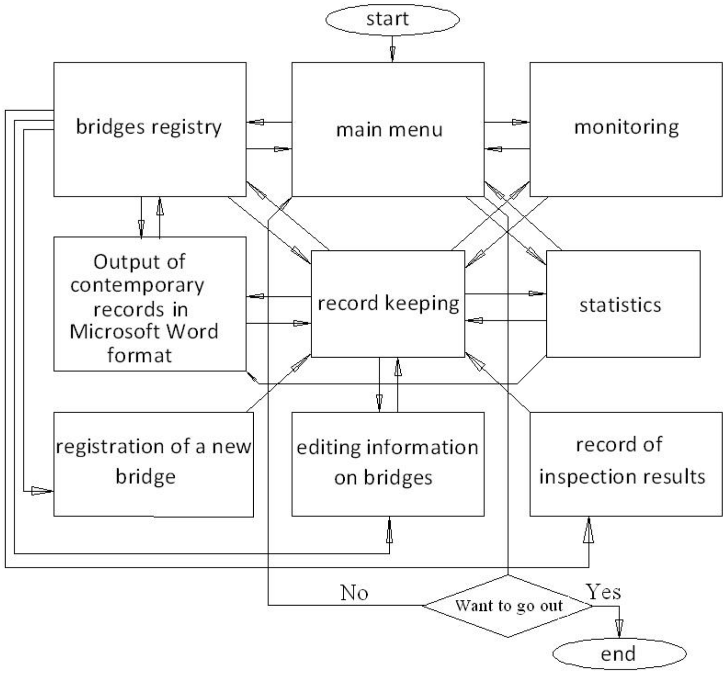

Fig. 4. Flow chart of data analysis at processing center

"Statistics" block provides data on all the bridges from the registry, hazardous, non-functional, and semi-functional bridges; bridges requiring major repairs or routine maintenance; data in accordance with the date of bridge inspection (early date, the latest date) and the least residual service life.

This monitoring system and its constituent sensors are covered by patent for an invention, useful model patent and a certificate of industry registration of the computer software.

3. Scope of the system

Upon detection of faults (cracks) in structural members of bridgework, it is advisable to install the monitoring system sensor to monitor their growth activity; the installation of several sensors will enable monitoring several bridges in the region. Thus, it is possible to monitor the faults from the office of the operating organization and in the case of intensive growth activity, block off the traffic on the bridge and take intensive measures to prevent accidents.

Another way to apply crack-status monitoring system is its use in field tests. After installing the sensor on the crack in a concrete bridge beam or a pile abutment grill, zero readings are taken. Then the bridge is loaded with a known load, for example, a light motor vehicle, and the sensor readings are taken again; then, instead of a light motor vehicle, a truck of known mass is placed, and the readings are taken again. In a third test, you can place both vehicles on the bridge and determine the crack opening under this loading. The data obtained can be used to calculate the bearing capacity of bridge building structures, to determine the maximum load on the bridge, etc.

This system of monitoring crack opening fits perfectly in monitoring long-operated bridges in the region, as the personal computer, which receives all the measurements, monitors the opening width of each crack and timely notifies operating services of an intense growth activity of a crack. This monitoring system helps prevent accidental collapse of a bridge structure.

Application of this system will lead to increased safety and durability of operation of small concrete bridge structures by providing continuous monitoring and centralized supervision of their geometrical characteristics and the status of the existing faults and damages [15].

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