WIRELESS TRANSMISSION SYSTEM FOR A RAILWAY BRIDGE SUBJECT TO STRUCTURAL HEALTH MONITORING

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Jednym z prężnie rozwijających się tematów badawczych w elektronice jest bezprzewodowa transmisja danych, na którą jest duże zapotrzebowanie w monitorowaniu stanu konstrukcji inżynierskich. W artykule opisano nowo projektowany system bezprzewodowej transmisji danych do monitorowania stanu technicznego mostu kolejowego.

Słowa kluczowe: bezprzewodowa transmisja danych, monitorowanie stanu konstrukcji

One of the fast-developing research topics in electronics is the wireless data transmission, which is a highly desirable component in health monitoring of engineering structures. The paper describes a newly-designed system of wireless data transmission for structural health monitoring of a railway bridge.

Keywords: wireless transmission of data, structural health monitoring

1. INTRODUCTION

This paper describes a wireless transmission system to be operating on a real bridge structure. The investigated bridge (Fig. 1) is a single-span, 40-meter-long, steel truss structure providing support for a single railway track. The program of monitoring of the bridge includes two major issues. First, monitoring of structural health and its potential degradation due to e.g. corrosion is planned. Second, monitoring of railway car mass and speed is of interest to the owner of the railway infrastructure. The monitoring will be performed using piezoelectric strain sensors.

Consequently, the proposed integrated monitoring system [1] will consist of two hardware parts. The first part installed nearby an investigated bridge is supposed to weigh trains in motion (Fig. 2). This way the parameters of dynamic load acting on the bridge will be known in contrast to frequently used unknown ambient excitation like wind. Information from part 1 will be transferred to a remote analysis centre using a module of wireless transmission of data. The part 2 installed directly on the bridge should record time responses of the structure induced by train passage. The time responses will be then transferred to the analysis centre (independently from part 1) using another module of wireless transmission.

Having the information both about the dynamic load and the structural response to this load, monitoring of the bridge health can be performed by solving an inverse problem in the framework of the Virtual Distortion Method [2]. Deterioration of the bridge can be interpreted as stiffness degradation and/or mass loss for every element of the truss bridge.
The undertaken in-situ monitoring campaign, started mid 2007, fits in the fast-developing research area called Structural Health Monitoring (SHM) [3]. The principal idea behind is that a structure should be subject to a permanent monitoring (performed not necessarily round the clock, but repeatedly). The main advantage of such monitoring is the ability to track changes in responses during the lifetime of a structure, raise alerts in case of significant deviations from normal behaviour and estimate the usable lifetime until demolition or general repair. The *in-situ* monitoring system consists of two major components, depicted in Fig. 3, i.e. some sensors collecting responses in time and the central data processing unit (DP), providing basic signal processing and data transfer to a remote computational centre.

The sensors may communicate with the DP unit either via cables or wirelessly. The latter way is the subject of consideration in this paper.

Fig. 1 Railway truss bridge monitored in Nieporet

Fig. 2 Excitation by train – weigh in motion (WIM)

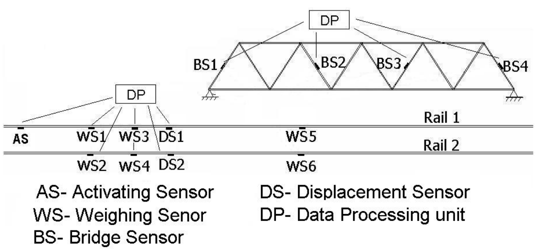

Fig. 3 A scheme of the bridge equipped with sensors and data acquisition unit

The wireless method of data transmission has been the subject of intensive research in the SHM community. The reasons of this fact are the following:

- cables may be used only for local transmission of data, far-range transmission to a remote location seem to be realizable only by wireless methods,
- installation time of standard cable connections between sensors and DP unit is very long and the process may be troublesome,
- cost of cabling for large structures is high,
- cables used for data transmission are prone to devastation.

2. THE GENERAL CONCEPT

Several types of topologies for wireless communication networks, shown in Fig. 5, are currently in use [4]. The authors plan to configure their wireless system as a set of independent sensors controlled by a central data processing unit, which corresponds to the star topology. Both hardware parts of the system will have their own autonomous DP units.

The WIM sensors is connected to the WIM DP unit with standard cables because the distances between the sensors and the unit are small. The bridge sensors communicate with the bridge DP unit via nearby-range wireless transmission, because they may be mounted far away from one another, depending on bridge size.

The far-range wireless transmission of data takes place independently for the WIM DP unit and bridge DP unit. This is due to the fact that monitoring of rail traffic should be performed on-line and monitoring of bridge health can be done off-line. Therefore the amount of data and frequency of transmission for the WIM and bridge DP units will be different. Another explanation is that the WIM point may be located too far from the bridge, so one unit for the whole monitoring system might be impractical.

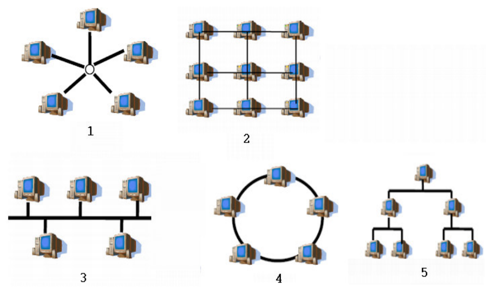

Fig. 4 Types of wireless networks: 1) star, 2) net, 3) rail, 4) circle, 5) tree

The major challenges to be faced from the electronic viewpoint are:

- equipping the system with a maintenance-free source of power,
- designing durable small-size and energy-saving components of the wireless transmission system,
- pre-processing of time signals in situ and optimizing them for far-range wireless transfer.

Fig. 5 Piezoelectric sensor for collecting strains

Piezoelectric sensors were chosen to collect strain responses in time. An example of a piezo-ceramic sensor is shown in Fig. 5.

3. TIME SIGNALS TO BE TRANSFERRED

As the integrated system consists of two blocks, there are two types of time signals recorded by piezo-sensors. These time signals need to be pre-processed in situ before starting their wireless transfer to a remote centre.

The first type of signal corresponds to the load identification block and the associated weigh in motion procedure for running trains. An example of the time signal detected by the weighing sensors (WS), is depicted in Fig. 6.

The second type of signal corresponds to the bridge health monitoring block and the associated damage identification procedure. An example of the time signal captured by bridge sensors (BS) is shown in Fig. 7.

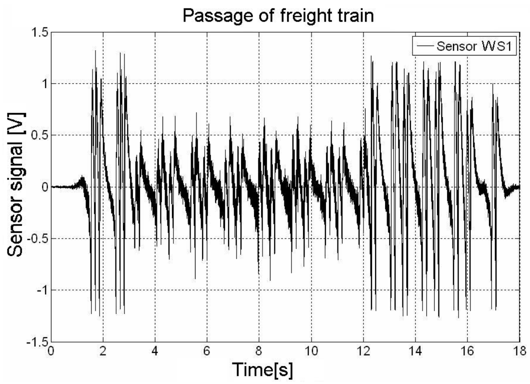

Fig. 6 Signal captured by a weighing sensor

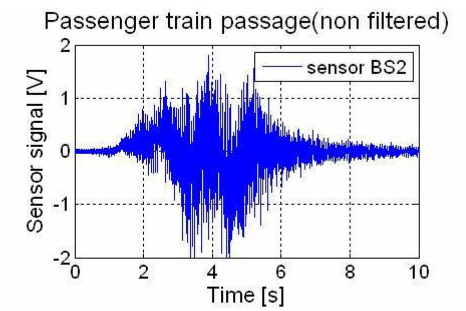

Fig. 7 Signal captured by a bridge sensor

4. WIRELESS TRANSMISSION SYSTEM

In the authors' opinion, the wireless system for SHM should be characterized by a relative simplicity, high reliability and low energy consumption.

The complete system proposed in this paper can be divided into two subsystems – for weighing trains in motion and for health monitoring of the bridge. Detailed proposition of the wireless solutions will be focused on the latter subsystem only. The reason is that both the nearby-range and far-range transmission has to be considered for the bridge.

The proposed bridge system, schematically shown in Fig. 8, consists of three major components – a number of the measuring units integrating piezoelectric sensors with associated electronics described as BS, the DP unit and two activating sensors (AS). The role of the activating sensors is to wake the system up for the time of train ride only and put it in a passive mode afterwards.

Each measuring unit collects analogue signals from the piezoelectric sensors mounted on the bridge and transfers them to the DP unit via an embedded transceiver using a local mode of wireless transmission. A scheme of the integrated bridge sensor is shown in Fig. 9.

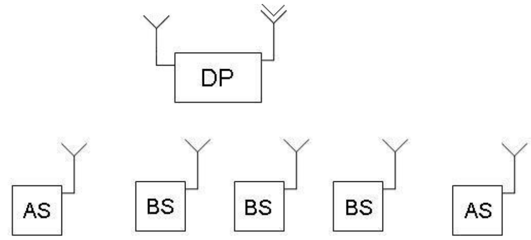

Fig. 8 Scheme of the local wireless transmission system

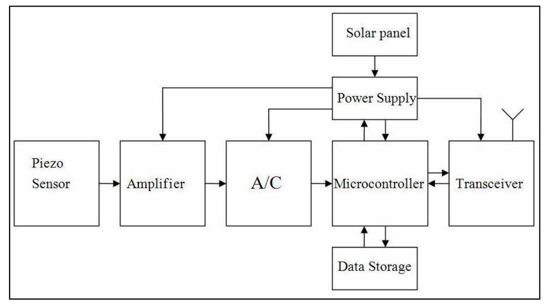

Fig. 9 Scheme of the integrated bridge sensor

The proposed electronics associated with each measuring unit is not sophisticated in order to keep the power supply at the 50 mW level. At first stage of testing, a lithium-ion battery will be used. Subsequently, a solar cell should be provided to recharge an in-built battery for long-term, maintenance-free operation. A crucial feature of the system resulting in significant energy savings will be its intermittent operation. The system will be activated by one AS from each direction. It will remain active only during the passage of a train over the bridge. Otherwise it will switch to a passive, energy-saving mode. The only sensor operating in the stand-by mode will be the two activating sensors. The difference in energy consumption is 3 order of magnitude as the microcontroller of the DP unit needs 0.4 mA when active and just 0.6 µA when passive.

The integrated bridge sensor will perform analogue to digital conversion of a signal before sending it to the DP unit. To this end, a 12-bit analogue-digital converter providing proper sampling will be used. The available nearby transmission distance is estimated to reach approx. 100 m. All measuring units are supposed to start data acquisition simultaneously thus have to be properly time-synchronized by triggering signals from the DP unit.

The tasks of the DP unit are: sequential collection of digital signals from the bridge sensors, signal compression and transfer to a remote computing centre for analysis. Thus the DP unit should consist of a transceiver to collect the signals from various measuring units, microcontroller for signal processing, sufficient memory buffer enabling storage of data and additional RS-232 port for possible *in-situ* acquisition. A scheme of the DP unit is depicted in Fig. 10. Advantage of the GSM system is taken to transfer the digital data to a remote computational centre.

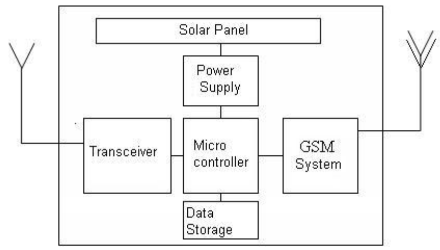

Fig. 10 Scheme of the DP unit

Several tests of the proposed system are planned, starting from a check of the performance of a single measuring unit, through the design of the DP unit, finally leading to the installation of the system *in situ* and its subsequent verification.

Currently the work is focused on development of specific modules (see Fig. 11) of the system for both the local and far-range wireless transmission. The next step is to assemble all the modules in the planned items i.e. the BS and DP units. It is planned to install and test the whole system of wireless transmission in situ in 2009. The local transmission will be checked first.

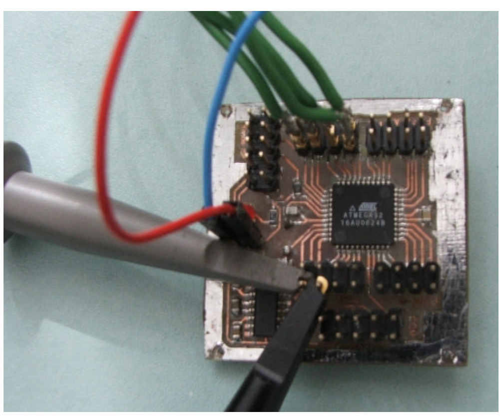

Fig. 11 Module of the wireless system ready for lab testing

5. CONCLUSIONS

High demand from the Structural Health Monitoring community is the reason for fast development of wireless transmission systems applicable to real structures. A prototype of the proposed system will be implemented and tested on a railway bridge. Further development of the system, taking into account fidelity of transmission, durability and cost-effectiveness of hardware will be the subject of future work.

General conclusions are the following:

- wireless transmission of data is very important for permanent SHM,
- it is relatively easy to adapt the wireless system to various applications e.g. structures, water networks,
- fidelity of data processing and durability of hardware should be major features of the wireless system.

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