Implementation Of Digital Measurement System In Monitoring Of Structures

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Summary

Digital technologies in measurement enable better quality in monitoring of large structures than mostly analogue system that have been used at the Maslenica bridge in Croatia. This monitoring system with analogue signal transfer from sensor to the acquisition unit is presented. Because of the observed weaknesses of analogue system, new digital system for monitoring of large structures was developed. This paper compares the relevant characteristics of both systems and gives short review of further development.

Keywords: structure monitoring, industrial communication network, digital measuring system

1. Introduction

In order to achieve more reliable and economical construction and maintenance of structure through its life cycle, monitoring is becoming more and more important. The implementation of structural monitoring is being envisaged for large bridges in The Republic of Croatia.

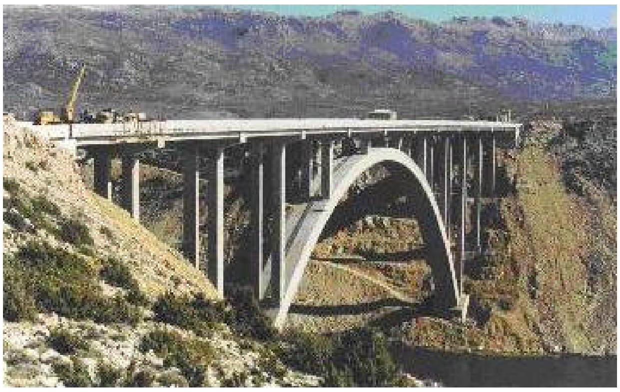


Fig 1. The Maslenica bridge

The first system of monitoring in Croatia at one large bridge is implemented at the Maslenica bridge. The Masnenica bridge was constructed in 1997. It is concrete arch bridge with 200 m span and overall length of 350 m (fig. 1) [1]. In this paper a more detailed review of monitoring principles, on the example of the Maslenica bridge monitoring system, is presented.

2. Monitoring

Open measurement systems enable a gradual development of the measuring system according to present needs, available means and new technologies. This approach to structure monitoring development has been implemented at the new Maslenica bridge where the reliability of the bridge structure is being monitored through erection phases and its whole service life [2].

The undertaken actions include a simple visual monitoring of the bridge condition, recording of the bridge environmental conditions, testing of structures and a complex testing which includes the appraisal of structural members reliability and the reliability of the overall bridge structure. On the basis of gathered data, one can make valid and timely conclusions about the present bridge condition. The collected data within a longer period of time compared with the present testing provide the solid basis for the prediction of the further development of the structure condition and correspondingly the necessary maintenance interventions. The whole procedure necessarily includes the creation of a data basis, which contains the data about the parameters of structural elements, as well as about the parameters of the global bridge structure.

Monitoring of Maslenica bridge includes:

- monitoring of static and dynamic characteristics
- corrosion monitoring

Monitoring of static and dynamic characteristics is essential factor in bringing the decisions about the condition of load carrying capacity, and the level of safety and serviceability of the bridge. Short-term records of these structural characteristics have been applied in our common practice. This way the conclusions about the temporary bridge condition were made. Permanent monitoring of bridge reliability is particularly important in the cases of heavy live loading such as passing of special vehicles and heavy loads over the bridge, and during strong winds that are often at the Maslenica bridge in winter when the access to the bridge and bridge vicinity is not possible. That way very important data for the overall evaluation of the reliability of the bridge structure are recorded. The experiences of long distance monitoring of engineering structures with a great number of data that are simultaneously registered (>100) is possible to implement in other technical fields. This research is applied for the first time in the field of civil engineering in Croatia. Monitoring of static and dynamic characteristics had been started in construction phase and has been continued through the test load and service life. [2].

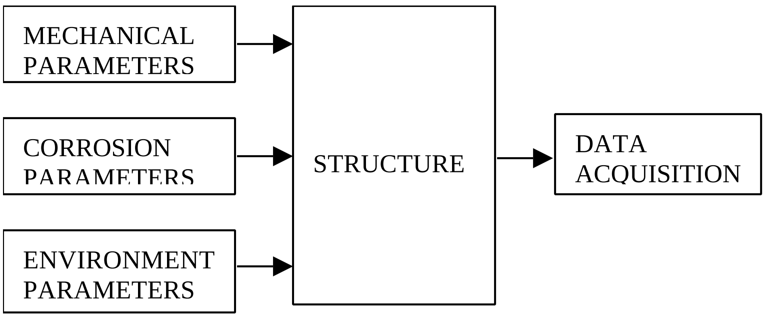


Fig 2. Schematic representation of Maslenica bridge monitoring

Corrosion monitoring is particularly important because Maslenica bridge is situated in an aggressive environment, particularly regarding the influence of sea-salt carried by wind. Therefore, corrosion condition in the reinforcement of concrete structures is being monitored. Parameters of static and dynamic characteristics, corrosion and environment (temperature, humidity, wind speed) are registered by means of central measurement and acquisition device (Fig 2).

3. Monitoring measuring system

Monitoring measuring system consists of (Fig. 3):

- sensor assembly
- signal transfer system
- acquisition system

Fig. 3. Monitoring measuring system

3.1 Sensor assembly

Sensor assembly consists of sensors that are built in the structure during or after construction and measuring amplifiers that are conditioning measuring signal. Adequate amplifiers were developed for different types of sensors with the standard current output of 4-20 mA. This characteristic simplifies and unifies signal transfer system and makes easy application of different acquisition systems. Sensors that are used are strain gauges, accelerometers, displacement sensors, structure temperature sensors, external humidity and temperature sensors, anemometer and corrosion sensors. For monitoring of Maslenica bridge 88 strain gauges, 40 structure temperature sensors, 22 accelerometers, 20 corrosion sensors, 5 displacement sensors, anemometer and external humidity and temperature sensors are used.

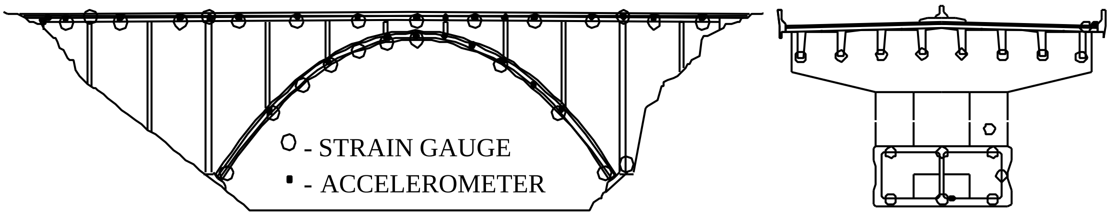


Fig.4. The position of sensors

Strain gauges are used for static and dynamic tests, and besides deformations and strains, dynamic amplification factor is determined as well. On the Maslenica bridge strain gauges were placed on the reinforcement of the main girders, arch, roadway slab and columns. It was also placed on the surface of the concrete arch. Because of the impossible subsequent access to the sensor on the reinforcement, on each place was installed redundant strain gauge. On the reinforcement strain gauges HBM 6/120LY41 are used, and on the concrete HBM 50/120LY41. Accelerometers are used for monitoring the structur vibration. Kyowa AS-2GB accelerometers with frequency 0-85 Hz are used. These accelerometers are based on strain gauges and use the same amplifiers. Displacement sensors are used for measuring displacement on the bridge supports. Linear potentiometers with measuring range 0-26 mm are used. Temperature sensors Pt-1000 are used for measuring structur temperature. They were built along with strain gauges. Anemometer Gill Solent WindMaster with range 0-60 m/s is used for measuring of wind speed and direction [3].

Corrosion sensors were installed for the monitoring of the reinforcement corrosion process. A system developed by IBAC- Institut für Bauforschung from Aachen (Germany) was applied. This method is based on the current measurement between anode and cathode, measurement of electrochemical potential between anode and cathode, temperature measurement and electrochemical concrete resistance measurement [4]. Corrosion sensors were installed on critical places of the reinforcement.

3.2 Analogue measuring system

Present measuring system is analogue - transfer of the signal from sensor assembly to the acquisition unit is analogue. Measuring signal is transferred from the sensor to central acquisition unit through signal transfer system. Conversion of measuring signal from analogue to digital is performed in the acquisition unit (Fig 5).

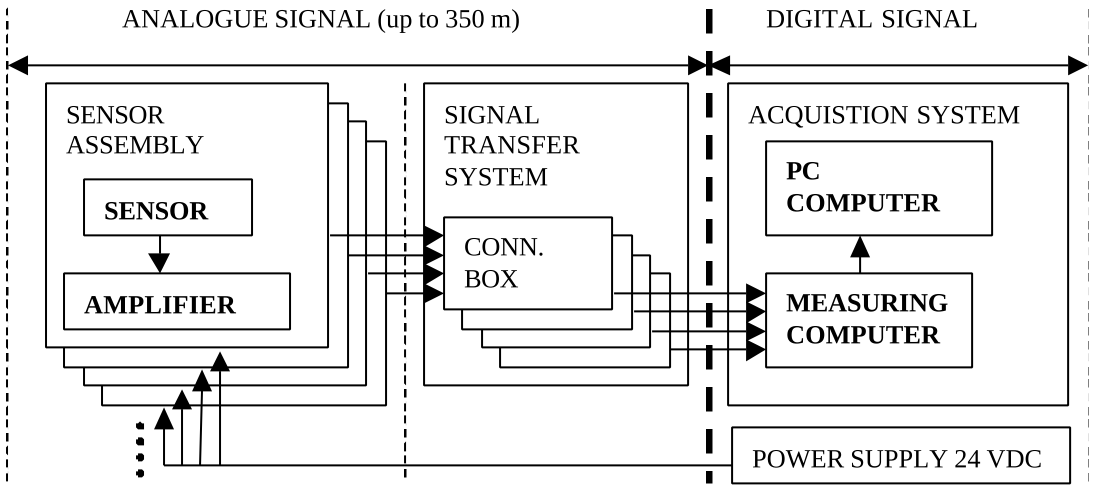
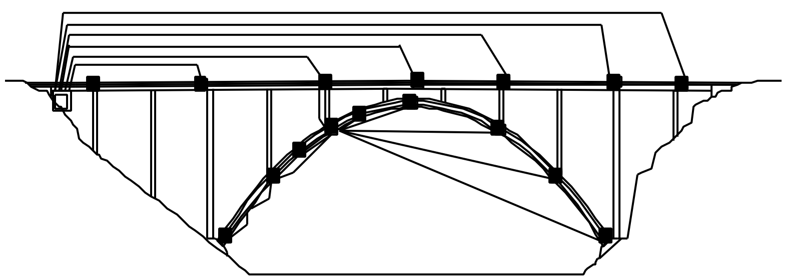


Fig 5. Analogue measurement system scheme



Present measuring system can register 128 channels. Measuring signals are collected in the connection boxes that are distributed on the bridge (Fig 6).

Each connection box can group 24 signals. All components in connection boxes are standard and exchangeable. Installation 24 V is used for powering of measuring amplifiers.

Fig 6. The arrangement of the sensor connection boxes

All cables used are shielded and connected to the point of common potential. Because of long distance (up to 350 m), significant electromagnetic disturbances occur.

System has radial configuration so each signal has its own cable connected to the acquisition unit. It results in lot of cabling and makes difficult installation, maintenance and repairing. There is possibility of adding new sensors.

3.3 Digital measuring system

Because of noticed weaknesses of the classic analogue system, list of requests for new measuring system was made:

- standard measuring system (industrial implementation)
- large number of measuring channels (over 100)
- open system (possibility of expanding and development)
- standard signals (4-20 mA)
- compatibility with sensor assembly of previous system
- larger distance between sensor assembly and acquisition unit
- reducing of cabling
- applicability in field testing

New measurement system is based on the PROFIBUS DP industrial communication network. This is new application of this equipment for the monitoring of structures. PROFIBUS DP is designed for operation in extremely difficult environment, which increase reliability of monitoring. System consists of central measuring unit (PLC – programmable Logical Controller and PC computer), four connection boxes with A/D converters (ET 200C) and communication bus (Fig. 7).

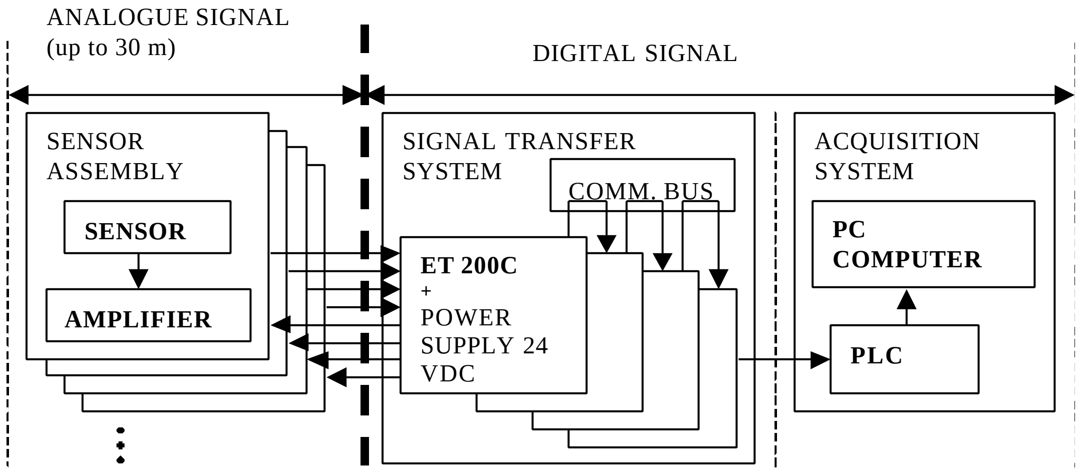
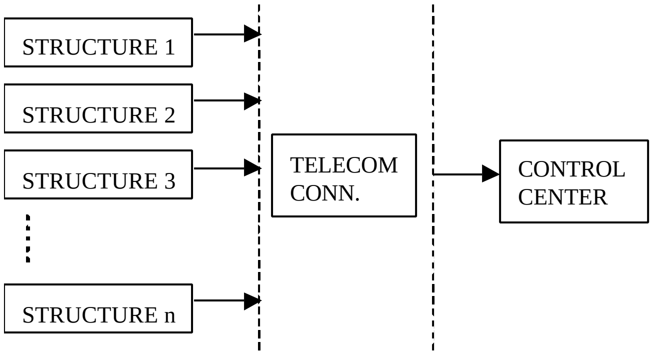


Fig 7. PROFIBUS DP measuring system

Each ET 200C unit can receive four measuring signals. At the moment, system has four ET 200C units (total of 16 channels), with possibility of expanding up to 512 channels. A/D conversion is performed in ET 200C unit. Maximum distance between sensor assembly and A/D converter unit is 30 m. From ET 200C unit signal is transferred digitally by means of PROFIBUS communication network. It connects serially ET 200C units, which significantly reduces cabling. System enables transferring of data up to 700 m with copper cable, or up to 1200 m with optical connection. That makes possible the application of the system in testing most of the existing and new structures.

Available control software is open for upgrades and development of custom user functions. Modules for displaying measured data and conversion of measurement results in format for existing post-processing software were developed, which ensures compatibility with existing software.



Since it is digital system, remote data access and control is possible. Remote control and off-line data acquisition are planned at the moment. With increase of data transfer rate, on-line monitoring will be possible. It enables monitoring of structure when the access to the bridge and bridge vicinity is not possible (strong winds are often at Maslenica bridge in winter). Distant monitoring of several structures is possible from one control center (Fig. 10).

Fig. 10. Distant monitoring of several structures

3.4 System comparison

After expected results of laboratory tests, comparison of two systems had been carried out during testing of Pag bridge. Pag bridge is concrete arch bridge with steel superstructure with 193 m arch span. It connects island of Pag with mainland. In field testing new system proved to be very reliable which was confirmed by test results. On the basis of parallel tests, comparison table of analogue (old) and digital (new) system was made (Table 1.).

Table 1. Comparison of characteristics of systems

Characteristic	**Analogue system**	**Digital system**
Number of channels	128	16 , expansible to 512
Transfer of signal	Analogue	Digital
Configuration of signal transfer system	Radial	Serial
Expansion	Difficult	Simple
Sensitivity to EM* disturbances	Significant	Low
Sensitivity to weather conditions	Significant	Low
Robustness	Complicated and delicate system	Industrial product
Structure	Complicated (difficult error trapping)	Simple
Installing	Time consuming due to complicated structure and large cabling	Fast and simple
Applicability	On large structures	On large structures
Reliability	Reduced due to EM* disturbances	Significant due to digital transfer of signals
Compatibility	Analogue systeme can be replaced with digital simple, all sensors and amplifiers remain in the system	
Technology level	Classicall design	Modern design
Perspective	It can be used till amortization	Further development of components and system is expected

*EM – electromagnetic

4. Conclusion

The aim of our research is development and design of reliable monitoring system. This system should overcome main weaknesses of existing analogue system and enable application of new digital technologies. After careful study, system based on the PROFIBUS DP industrial communication network was chosen. Tested system satisfied all requests in the laboratory and field tests. Further application of new system in monitoring of large bridges in Croatia is planned. System is digital and has modular design, and can be upgraded with development of new components.

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