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EXPERIENCES IN BRIDGE TESTING WITH PROFIBUS-DP NETWORK

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Abstract: This paper shows our experiences in implementation of PROFIBUS-DP based industrial communication network in large structure (bridge) testing. Measurement process and equipment, data acquisition and analysis of measured data will be presented.
Keywords: measurement system, PROFIBUS-DP, bridge testing

1 INTRODUCTION

Static and dynamic parameters of large structure (bridge) are necessary for evaluation of structure state. Therefore those parameters should be measured when construction is finished and before the bridge is open for traffic. Control and measurement of relevant parameter fluctuation should be performed periodically during whole lifetime of the bridge or permanently monitoring.

Our common praxis was to use analogue measurement system. It was consisting of sensors, special signal amplifiers, 128 channels acquisition device (Musycs) and PC. Due to problems with large cabling, disturbances and complex data analysis new digital measurement system has been designed based on PROFIBUS-DP industrial communication network. Also analogue system needed power cable for powering amplifiers and sensors. This cable (or cables) is long and their installation is very time consuming.

This paper is continuation of our work described in previous paper [4] so all relevant details can be found in that paper.

2 BRIDGE TESTING PROCESS

There are two major categories of bridge test: static and dynamic test [1]. In static test strain and deformation in structure critical locations are measured. From dynamic test dynamic strains, structural displacement, structure frequencies, frequency spectrum and dynamic factor can be determined. During the whole bridge testing some other relevant quantities are measured (temperature, humidity, wind speed, wind direction and if possible corrosion state in long term monitoring). All of those parameters are used for full analysis of bridge condition.

Static test is performed during test load, which is realized with loaded trucks positioned on different locations in order to induce specific strains in structure parts. Test is performed for every span. Between two span tests, bridge is unloaded in order to determine possible irreversible structure deformations. In static tests strain gauges are used as sensors for strains and potentiometers for displacement.

Dynamic test is also realized with loaded trucks, but they are driving over the bridge with constant speed. During that drive they have to cross over the obstacle (wooden board). That induces step shock, which results in dynamic strains, displacement and vibrations of the bridge. Such tests are performed for every span and pear. Longitudinal displacements and vibrations are induced with fully loaded truck that has to brake on the bridge. In dynamic test strain gauges, linear potentiometers and accelerometers are used as sensors.

If permanent on-line monitoring is required, signal from all of those sensors can be combined in one system and used for bridge’s state long period monitoring during regular traffic.

3 BRIDGE TESTING MEASUREMENT SYSTEM

Analog measurement system (our pervious) [2] was used for described bridge test measurements and showed some weaknesses. Lots of cabling was one of weaknesses due to need to connect each sensor with amplifier and acquisition unit with separate shielded cable. Each sensor-amplifier couple needed power (24 VDC) which results with additional cabling. Due to bridge length and large distances between sensors and acquisition unit, significant cable lengths were required. Because of that, lot of time was needed to put the measurement system in operation. Another weakness was electromagnetic disturbances. They appear due to analogue signal transfer (4-20mA) and great cable length inspite of shielding. Complex data analysis was also a major time consumer. Data acquisition software did not allow us to automate the analysis process and reporting.

PROFIBUS-DP measurement system was designed to overcome analogue measurement system problems [3]. Standard Siemens equipment for PROFIBUS was used [4]. Cabling was significantly reduced because PROFIBUS based industrial communication network connects sensors, PLC (programmable logical controller) and PC in serial connection. So only one cable is necessary for data transfer. Powering the sensor-amplifier couple is designed locally within portable connection boxes with batteries so there are no cables needed for powering.

In December 1999 there was testing of bridge connecting island Pag with the main land. There was huge reconstruction on bridge and serious testing took place. During this testing PROFIBUS measurement system was functionally tested. Weather conditions were poor and there was lots of rain and wind. Since the see is present, lots of salt was in the air. Under all those circumstances system work properly and no malfunction was detected.

Figure 1 and 2 show signals of same structural part recorded on that bridge.

Electromagnetic disturbances are limited because of digital data transfer. This is very well shown on Figure 1. Signal measured with PROFIBUS is much “clearer”. That is especially obvious in first part of signal where signal recorded with analog measurement system shows lots of disturbances.

Two frequencies analysis can be seen on Figure 2. Frequency analysis of signal measured with analogue measurement system is shown Figure 2 b) and frequency analysis of signal measured with PROFIBUS measurement system is shown Figure 2 a). Signals DC component was removed before frequency analysis.

Distinctive frequency can be seen on both spectrums. This is frequency of 7,87 Hz (characteristic frequency of vibration acceleration of tested structure part), but signal measured with analogue system has another frequency dominant at 50 Hz.

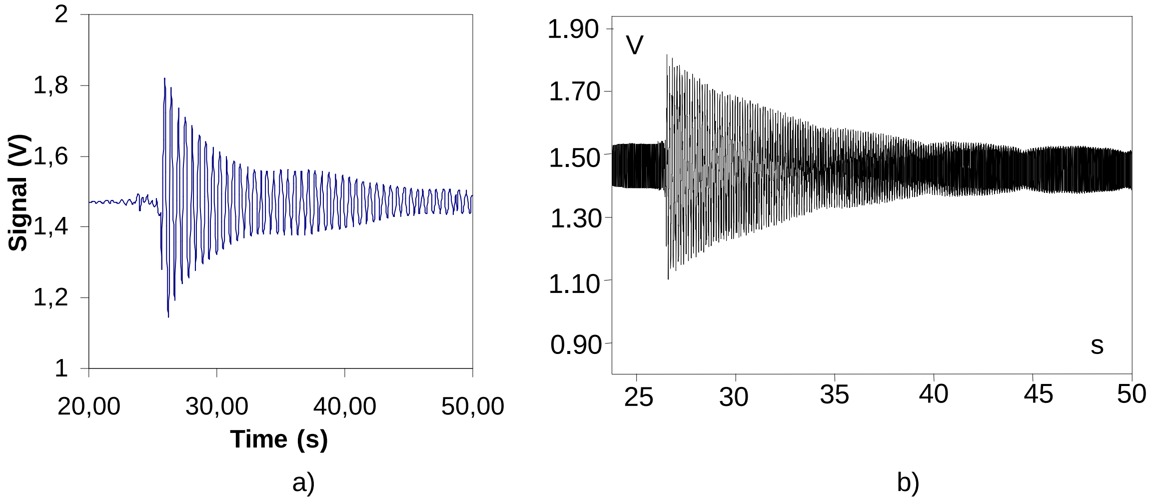

Figure 1. Accelerometer signal measured with: a) PROFIBUS system; b) analogue (old) system

This frequency corresponds with frequency of power supply (220 V, 50 Hz). Disturbances did not come from powering parts of measurement system. They entered the system on “sensor - measurement unit” cable level. Signal in that cable is current type (4-20 mA) but electromagnetic disturbances were strong enough to influence the main signal.

In analog system cable length that carries analog signal was 30 meters from sensor to amplifier and connection box and at least 100 meters form connection box to data acquisition unit. In PROFIBUS system analog signal is present only in that first part of the system (from sensor to amplifier) which is maximum 30 meters.

In PROFIBUS system data transfer from amplifier to measurement unit (acquisition unit) is digital, which prevent electromagnetic disturbances to influence measurement signal. PROFIBUS has clearer signal and as such gives as more accurate insight in the actual data.

Sampling rate of analogue measurement system was 5 ms per channel, and PROFIBUS system 10 ms. This sample rate (10 ms) enables PROFIBUS measurement system to be implemented for all big structures because the natural frequency is lower than 10 Hz. With this sample rate it is possible to measure 10 points per period in order to capture frequency of 10 Hz what is sufficient for the majority of large structures testing.

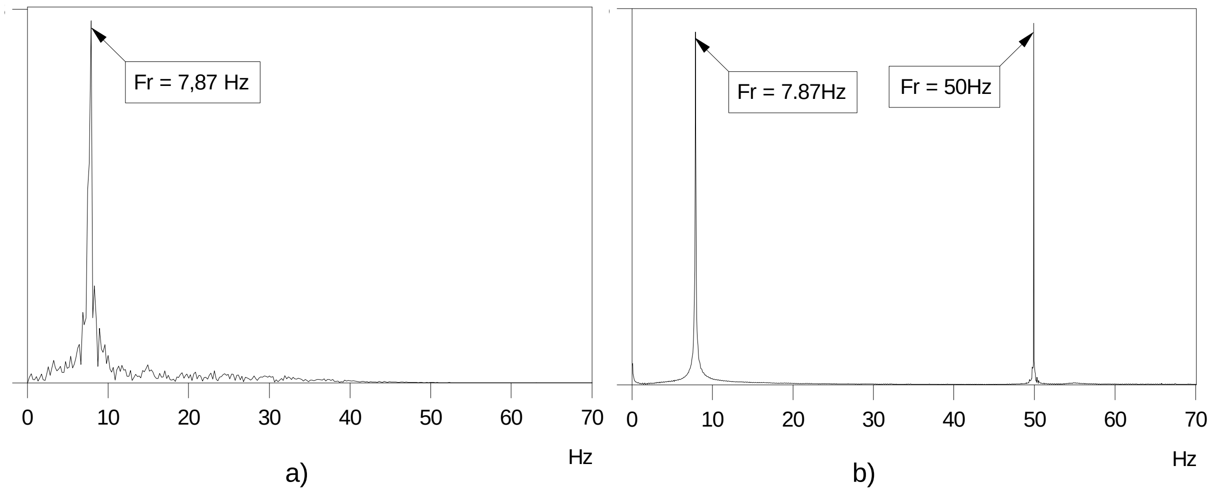

Figure 2. Frequency analysis of signal measured with: a) PROFIBUS system; b) analogue (old) system

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4 PROFIBUS SYSTEM DESCRIPTION

PROFIBUS measurement system consists of PC, PC communication card (Siemens CP5611), PLC (Siemens S7 315-2DP), 4 channel A/D converter (Siemens ET200C) and sensors.

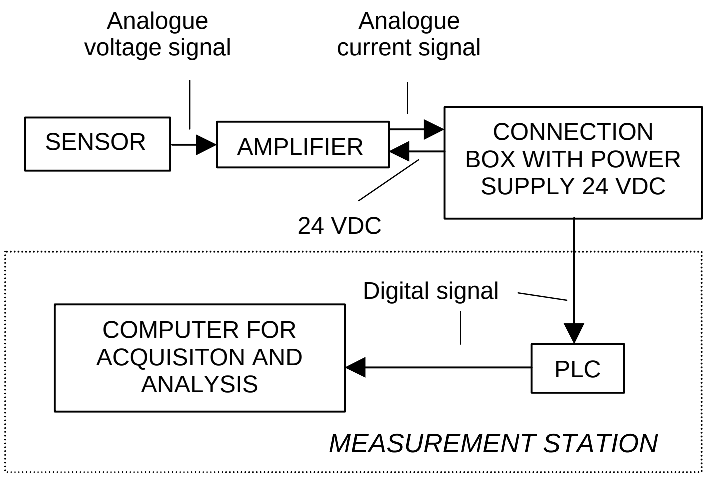

Figure 3. Block diagram of PROFIBUS measurement system

Figure 3 shows main parts of PROFIBUS measurement system as well as signal character on certain parts of the system.

All details of PROFIBUS measurement system was thoroughly presented in our previous paper [4] so no further discussion is needed.

There is great deal of software involvement in this project. Several software packages were used in order to make hardware work.

First of all there is necessary Siemens software like STEP 7, COMPROFIBUS, OLE/DDE MANAGER. With STEP 7, PLC S7 315-2DP was programmed. COMPROFIBUS enables hardware (PLC, PC communication card CP5611 and ET200C) to work together on PROFIBUS. OLE/DDE MANAGER was used to link measured data with software for data acquisition.

Microsoft Excel was used for data acquisition, storage and signal showing. Necessary macros were programmed in order to automate measurement.

Frequency analysis was made in software called FAMOS version 3.0.

It is planned to use this measurement system for large structure monitoring. In that case system will be permanently built in which is more natural use of these equipment.

Present system is highly flexible. There are several measurement configuration possible and system is very mobile. Main idea was to built the system that can easily be connected and disconnected because most of bridge teasing last for one day.

It is estimated that the installation time for the one-day bridge testing has been reduced from 5 to 2 hours.

5 CONCLUSION

Our initial interest was to build robust measurement system for outdoor use mainly in rough weather conditions. Siemens PROFIBUS communication protocol was chosen. This protocol is very used in industry and there is lots of hardware parts that work with PROFIBUS. To eliminate any additional problems, Siemens hardware was used.

With additional programming and better usage of hardware, it would be possible to achieve 5 ms sample rate with the same hardware configuration. That will give additional accuracy to measurement and measurement data will be more representative. For further reduction in sampling rate new hardware configuration would be needed.

Further programming will of course ensure faster measurement process. This is planned to be done in Microsoft Visual Basic.

So far, universal sensors are used, but with modern, PROFIBUS compatible sensors and amplifiers this system will show even better results.

One of the major advantages of PROFIBUS measurement system is lying in two qualities: it is easily expandable and it is distributed.

This measurement system needs further polishing but it has great potentials in large structure testing and monitoring what has been tested during the actual bridge testing in outdoor environment.

With PROFIBUS measurement system measurement process becomes easier and faster. Automation of measurement, analysis, data storage and test certificate producing is possible, and there is lots of space to improve that automation in future.

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