Application of industrial communication network in structure testing

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Summary

This paper describes digital measurement system based on PROFIBUS industrial communication network. Digital system was design and built for large structure testing. The comparison this new digital measurement system with analogue measurement system that has been used before will be also presented.

Keywords: structure, testing, industrial communication network

1. Introduction

Structure testing completes the process of design and structure building. It is also used in further exploitation and monitoring of the structure. Therefore it is important to approach to the testing with great studiousness. Since we performed lots of structure testing, especially with arc bridge testing, in further text, large structure testing will be discussed on the example of the arc bridge testing.

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. In dynamic test, dynamic strains, structural displacement and structure natural frequencies are measured. Frequency spectrum and dynamic factor can be determined from those measurements. During the whole bridge testing some other necessary quantities could also be 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.

3. Digital measurement system

We used to performed bridge testing measurements with analogue measurement system. Since this system shows lots of weaknesses we designed and build new digital measurement system.
Digital measurement system is based on PROFIBUS industrial communication network.
PROFIBUS (PROcess FIeld BUS) is leading European communication protocol for industrial communication networks. As communication protocol, PROFIBUS is standardized as German national standard (DIN 19 245) and in European standard (EN 50170). PROFIBUS devices are offered by a wide range of qualified vendors. That is the reason that PROFIBUS communicates between more than 2 000 000 devices in various industries all around the world. We tried to explore and use its advantages in order to create better measurement system for bridge testing.
The new measurement system is built from several different devices, all communicating on PROFIBUS protocol network for data transfer and acquisition. The following devices are used in this system: computer (PC and PCI communication processor card for PROFIBUS), PLC (programmable logic controller – the hart of the system) and distributed analogue input modules. All devices are connected via PROFIBUS cable.
The analogue input modules collect data from sensors (accelerometers, strain gauges, displacement measurement sensors, etc.) Each module has 4 analogue inputs. Sensors, mostly give ±5V DC signals so amplifiers were made to convert and amplify such signals to 4-20 mA signals. Those signals are, in analogue input modules, transferred into digital signals and sent through PROFIBUS cable to measurement station. PLC (in fact small industrial computer) ensures that data are collected and record in constant time intervals (sample rate). PC shows recorded data and, with additional software, enables data analysis.
This system was built from standard equipment, but modified for outdoor measurement. In order to reduce cabling, connection box with analogue input module and independent 24 VDC power supply was designed and build. So far our measurement system has 4 connection boxes (16 signals).
Figure 1 shows block diagram of PROFIBUS measurement system.

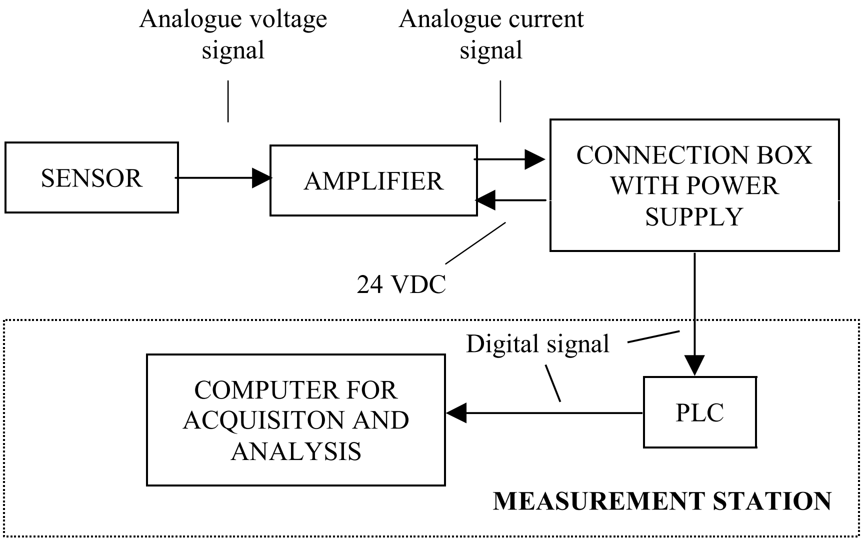

Fig 1 Block diagram of PROFIBUS measurement system

The new digital measurement system was tested and commissioned during the Pag bridge testing. The Pag bridge is a 280m long and 28m high arc concrete bridge placed between land and the island Pag. Figure 2 shows longitudinal section of the Pag bridge. Figure 3 shows the picture of that same bridge. Figure 4 shows its position in Adriatic sea, and in Croatia.

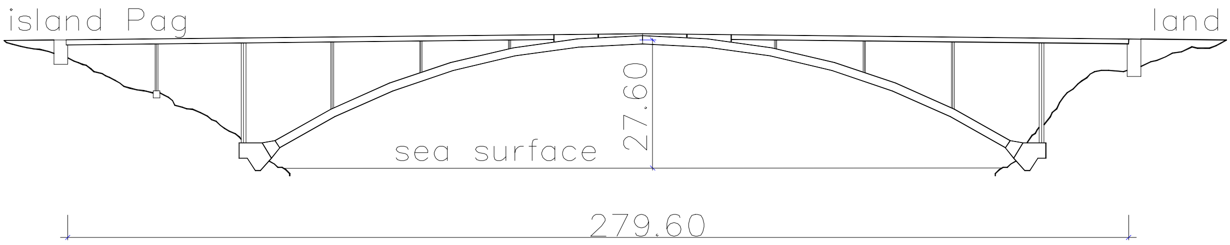

Fig 2 Longitudinal section of the Pag bridge

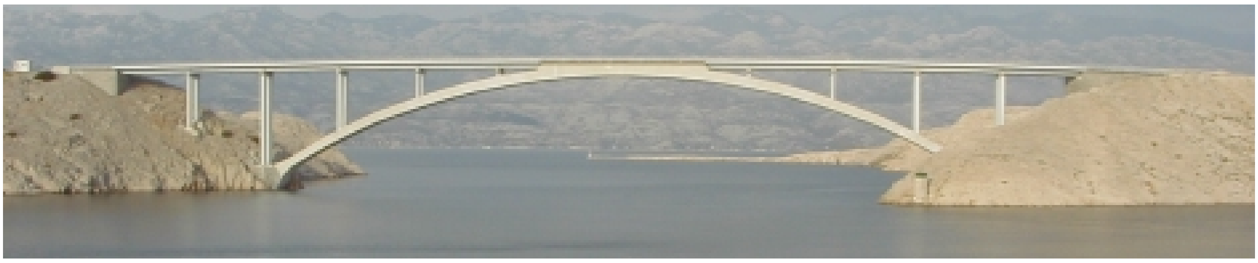

Fig 3 Picture of the Pag bridge

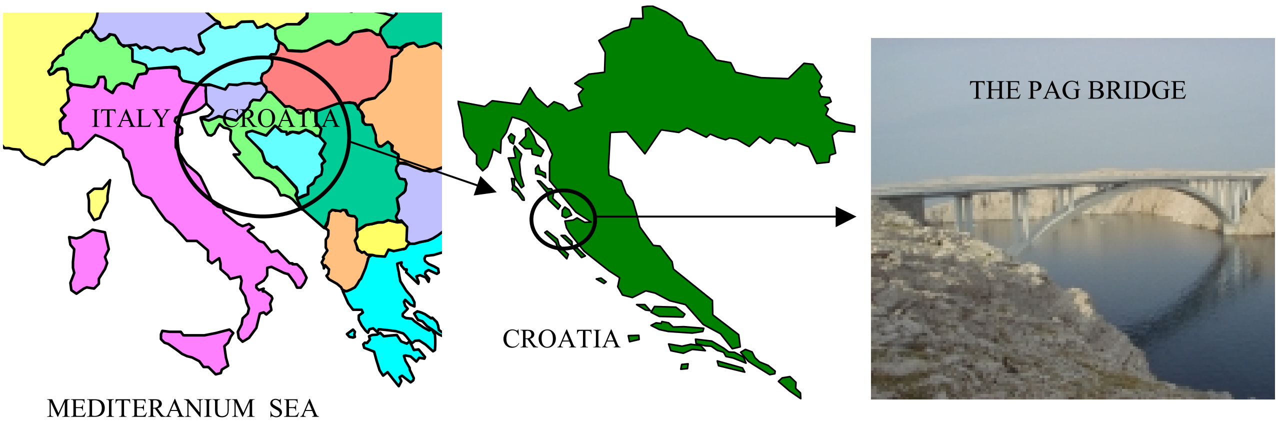

Fig 4 Map with the Pag bridge position in Croatia

There can be up to 128 analogue input modules connected with PROFIBUS to one PLC, therefore this system can record 512 signals. If additional PLC is used, the number of signals increases accordingly. All connection boxes, and PLC are connected with digital signals (PROFIBUS).

3.1 Comparison with analogue measurement system

The major disadvantage of the analogue measurement system is analogue signal transfer (for large structures distances are 200-500 m). Therefore this system is highly sensitive on electromagnetic disturbances. All signals have their own line from sensors to measurement unit. That results in large cabling. Additional problem lies in system enhancement. The configuration of the analogue system is not easily changeable.

In all those aspects new digital measurement system based on PROFIBUS is in advantage.

Digital signal transfer from analogue input modules (connection boxes) to measurement station ensures almost total insensitivity to electromagnetic disturbances. This is shown on Fig 5 and Fig 6 where the same signal is transferred through analogue and digital system. After FFT digital system signal has only one dominant frequency in spectrum and analogue has also frequency of

electromagnetic disturbance. If those two frequencies are close in spectrum, the measurement is not accurate and the results are not reliable because the disturbance frequency can not be filtered without losing the real signal frequency.
Since all devices are connected with one PROFIBUS cable, there is a lot less cabling in digital measurement system.
If there is need for new signal to be recorded, digital measurement system allows simple addition of a new connection box (4 new analogue signals) without additional cabling.
All of those aspects result that digital measurement system is much more reliable, faster to become operable, easier for maintenance and more accurate.

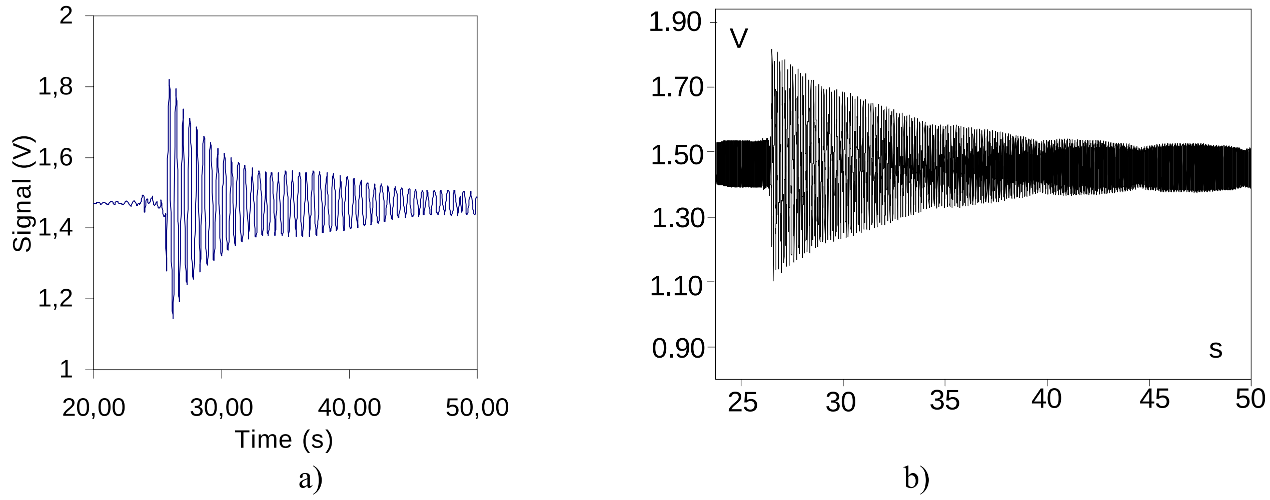

Figure 5: Accelerometer signal measured with: a) PROFIBUS system; b) analogue system

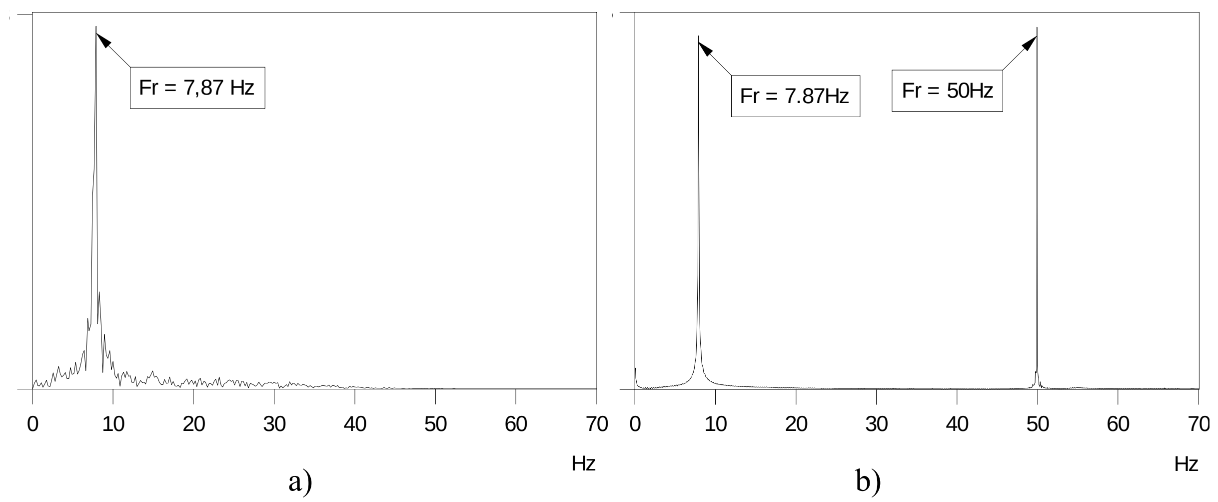

Figure 6: Frequency analysis of signal measured with: a) PROFIBUS system; b) analogue system

4. Bridge test results

After measurement during bridge test process acquisition data were analyzed and in Table 1 some results are presented.

Table 1 Some results of Pag bridge test

STATIC TEST			
ASYMMETRICAL LOAD		SYMMETRICAL LOAD	
Span	Deflection [mm]	Span	Deflection [mm]
1	12,25	1	10,45
5	10,85	5	10,30
8	10,10	8	9,95
10	10,15	10	9,65
ASYMMETRICAL LOAD		SYMMETRICAL LOAD	
Span	Strain [Mpa]	Span	Strain [Mpa]
1	37,68	1	42,32
5	39,80	5	44,44
10	33,96	10	41,29
DYNAMIC TEST			
Mode shape		Frequency [Hz]	
3		1,4	
8		2,5	
10		3,86	
18		5,48	

5. Conclusion

Presented measurement system was tested during the Pag bridge testing, and functioned perfectly. Software improvements should be made and then this system is ready for market. But the main purpose for designing and building of this system was to improve our own bridge testing process. This intention was completely fulfilled.

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.

6. References

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