

NEW DATA ACQUISITION SYSTEM FOR STRAIN GAUGE

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ABSTRACT

Two of the most difficult tasks that have to be faced when using strain gauges concern measurements in noisy environments and on moving or rotating parts. Electromagnetic noise can, in extreme cases, make the acquired signals practically unusable, while moving parts greatly affect the duration of the connecting wires; on rotating components only sliding brushes or contactless systems can be used. With these problems well in mind a new strain data acquisition system has been designed and developed, in a cooperation between AGE Scientific and Dipartimento di Meccanica e Tecnologie Industriali of Florence University. The main target has been that of performing the analog-to-digital conversion as near as possible to the strain gauges and transmit the data reliably. The present paper describes the main features of the system and shows the results obtained during the first tests carried out.

1. INTRODUCTION

The strain gauge signals data acquisition (DAQ) is usually performed using a front-end electronic for amplification and conditioning cascaded by an analog-to-digital converter (ADC). This operation requires a Wheatstone bridge balancing and a very hard noise fighting. The bridge balancing is due to the strain gauge tolerances and to the different resistance of wires and welds; the noise is due to transducer, electronics and environment. The bridge balancing can be done either adjusting the resistor value of a bridge branch or the offset voltage of the input amplifier. The balancing can be automated driving a digital-to-analog converter (DAC) by an appropriate algorithm running on a microcontroller. The noise reduction can be performed with low-noise electronics and installing the front-end electronics very close to the strain gauge. This is the most important action to obtain a low-noise data acquisition system because the most important sources of environmental noise are electromagnetic pulses produced by powerful electric motors, inverters and so on. Keeping the front-end electronics close to the sensor strongly reduces the area interested by spurious magnetic fluxes. Using the latest generation electronic components, the space occupation can be shrunk. They have small packages, low power consumption and a very powerful processing capability. This paper describes two examples of embodying a front-end electronics, an ADC converter and a microcontroller in a stamp-like surface. Each system can automatically balance the sensor bridge and transfer digital data to a personal computer for display or recording. The connection to the PC can be wired or wireless (radio link). The data are a continuous stream of 10 bit resolution samples. Actually in the wireless system a 1 kHz sampling rate can be achieved, 2 kHz in the wired system. The PC connection is via RS-232C standard. The system's main features can be summarized as follows:

- reduced dimensions allow its installation near the strain gauge, even in hard to reach positions;

- the A/D conversion takes place on board, so that the path run by analogic signals is very short, minimizing the environmental noise;
- in the wireless version it can be used on moving or rotating parts.

2. SYSTEM DESCRIPTION

Both systems, the wireless and the wired, are equipped with the same front-end electronics and the same automatic balancing algorithm. The wireless is battery powered. It can be installed on rotating shafts or in hardly accessible places. The wired is even smaller resulting in very compact integrated sensor and DAQ system. In the wired system the power supply comes from the PC adapter through the connection wires. In both systems the microcontroller performs the bridge balancing at power-up, then starts data transmission. The automatic balancing system uses a microcontroller driven DAC. The algorithm assumes that the strain gauge is initially unloaded or statically loaded, setting the DAC output until a half scale readout occurs. Later on it starts the data conversion sending each sample value on a pair of properly encoded data bytes. The PC acquisition software decodes the incoming data bytes and produces a real time display and data recording. The acquisition software runs under W9x, NT, and XP. The wireless system sends via radio a continuous stream of 10 bit resolution samples at 1 kHz rate, the wired one can do it at 2 kHz rate.

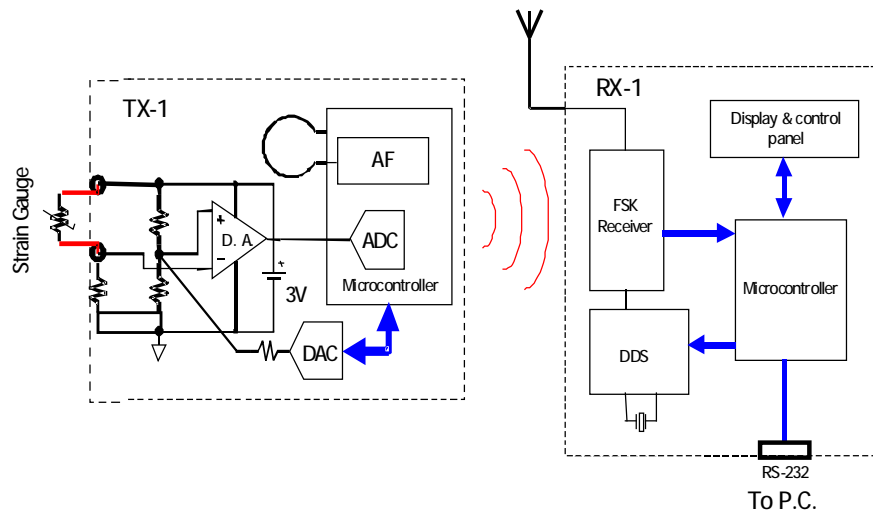


Fig. 1. Wireless system block diagram: radio equipped front-end electronics and radio-receiver PC adapter.

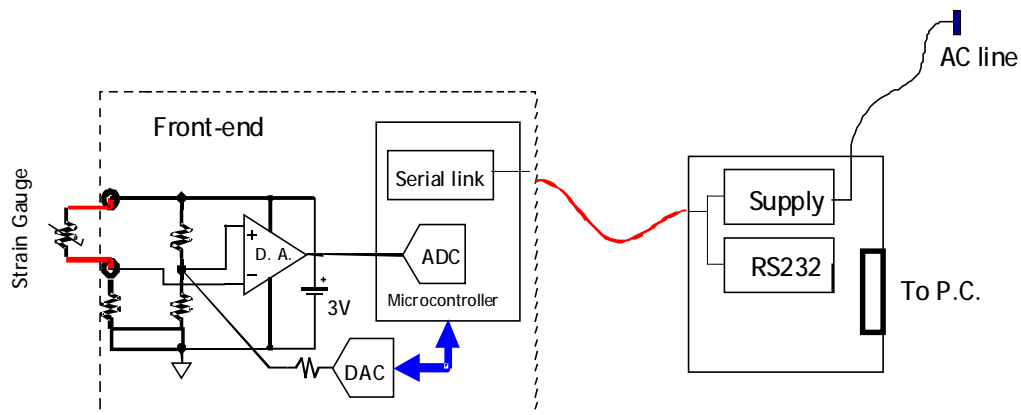


Fig. 2. Wired system block diagram: front-end electronics wired to the PC adapter.

The sensitivity can be adjusted on demand from 0.4 to 200 $\mu\epsilon$ /count changing two resistors in the circuit. The wired system differs from the wireless one in three aspects:

- the power supply is now coming from the PC interface via an AC adapter;
- the dimensions are smaller;
- possibility of faster data rate due to the radio-link absence.

Figures 1 and 2 schematically describe the layout of the two systems, both in quarter bridge configuration. In fig. 3 is shown the wired system in half bridge configuration, which can be easily obtained removing a resistor from the board.

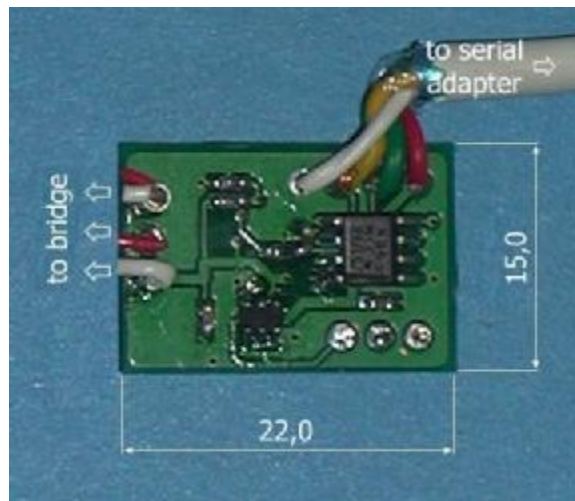


Fig. 3. The wired system and its connections (dimensions in mm).



Fig. 4. Example of application of the wireless system: Ducati 996 wheel.

In fig. 4 is shown the application of the system in a typical case in which a wireless system is needed: the wheel of a Ducati 996 motorbike. In fig. 5 is described how the components are

disposed; silicone has been used to protect the strain gauge and to fix the electronics and the battery holder. The transmitting antenna is arranged all along the rim. If necessary a much smaller battery pack can be used.

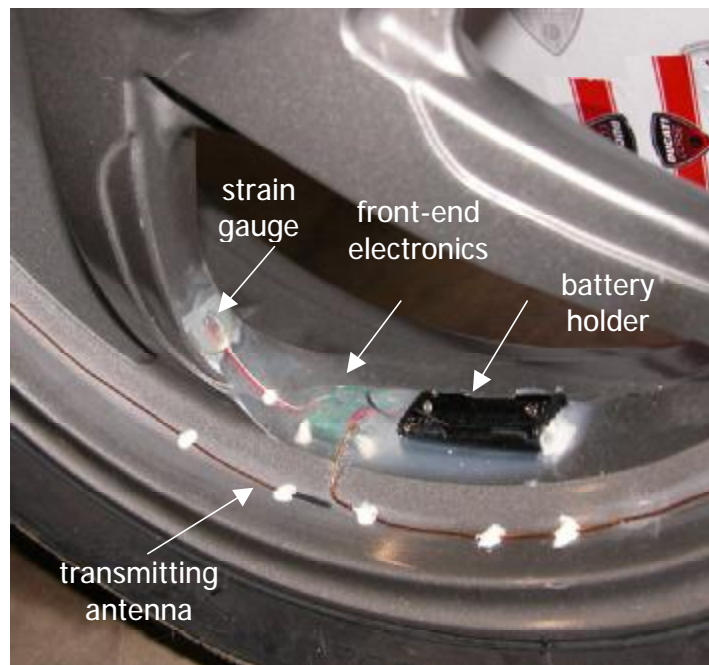


Fig. 5. Layout of the components of the wireless system on the wheel.

3. SYSTEM CHARACTERISTICS

A full characterization of the two systems was performed in many mechanical tests, resulting in the following:

- Sensitivity 0.4 to 200 $\mu\epsilon$ /count;
- Full range $\pm 200 \mu\epsilon$ to $\pm 100 m\epsilon$;
- Battery duration 3 hours (wireless system);
- Radio-link range 1 m;
- Dimensions 25x23x6 mm (wireless system); 15x22x6 mm (wired system);
- Weight 6 g.

4. TESTS

To appraise its features the system has undergone characterization sessions and has been compared to other strain indicators. The tests have been carried out in a hardware configuration resulting in a sensitivity of 3.854 $\mu\epsilon$ /count. Among others, the following tests have been performed:

- static tests on cantilever beams;
- dynamic tests on cantilever beams;
- dynamic tests on rotating shafts.

4.1 Static tests

In static tests a cantilever aluminium beam was loaded at an extremity. Two strain gauges were applied at the same distance from the clamp, on opposite sides. One has been acquired with the wireless system and the other with a commercial strain indicator, both in quarter

bridge configuration. The results always show a good agreement (fig. 6) and correspond to theory. The theoretical values were calculated using the usual equations from the theory of elasticity; the product EI of the elastic modulus of the beam and the area moment of inertia of the cross section was exactly calculated through measurements of deflection.

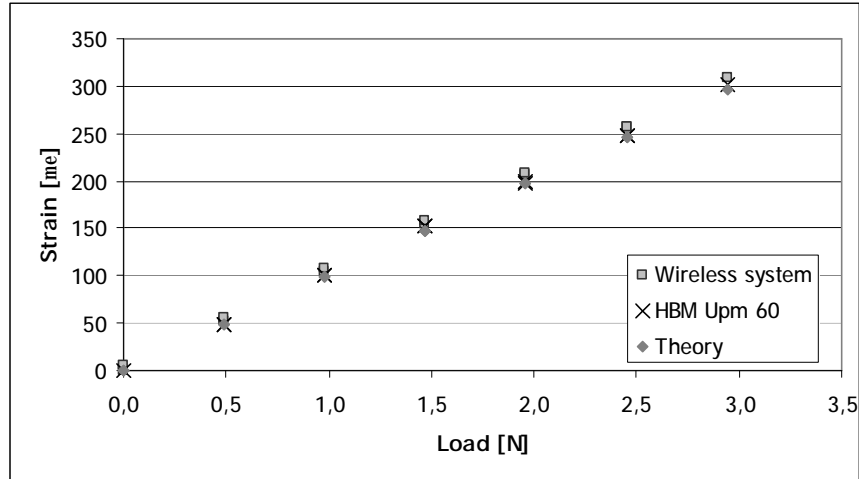


Fig. 6. Strain measured with the wireless system compared to a commercial unit and to theory.

In fig. 7 the wired system and a commercial system are compared, this time acquiring both strain gauges in half bridge configuration.

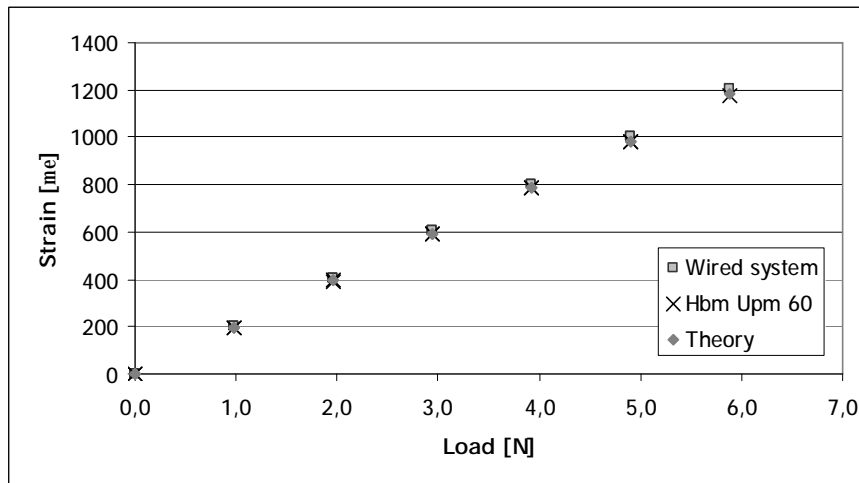


Fig. 7. Strain measured with the wired system compared to a commercial unit and to theory.

Some of the overall static performances of the two systems can be expressed as follows:

- zero shift over 1 hour: < 0.8 % of full-scale output;
- drift over 1 hour, at 20 % of full load: < 1.0 % of full-scale output;
- output noise (no load): < 0.5 count rms;
- repeatability at 10 % of full load, 10 applications: < 0.4 % of full-scale output.

The maximum difference in sensitivity, in comparison with the other instruments tested, has always been under 1.5 %.

4.2 Dynamic tests

Dynamic tests have also been carried out. In fig. 8 and 9 are shown the spectra obtained from strain gauges applied on a cantilever aluminium beam, freely vibrating at about 80 Hz. In the first chart, concerning a commercial strain indicator, a 50 Hz noise produced by the power grid is clearly visible.

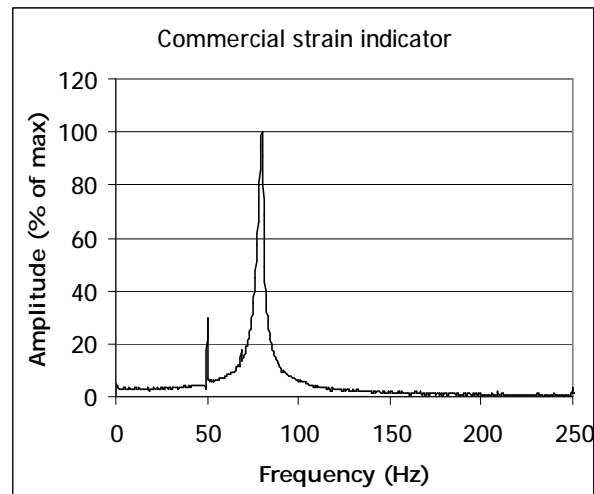


Fig. 8. Spectrum obtained from a free vibrating clamped bar (commercial strain indicator).

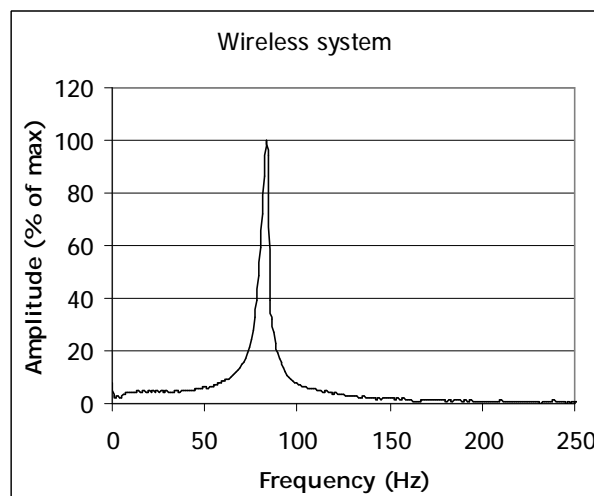


Fig. 9. Spectrum obtained from a free vibrating clamped bar (wireless system).

To test the influence of the environment, the wireless system was also used within the distance of about 1 m from an inverter driving a 4 kW three-phase electrical engine. In fig. 10 is shown the effect of the noise produced by the inverter on a commercial strain indicator during a test on a freely vibrating cantilever steel beam. Superimposed to the signal many spikes caused by the electromagnetic pulses are visible.

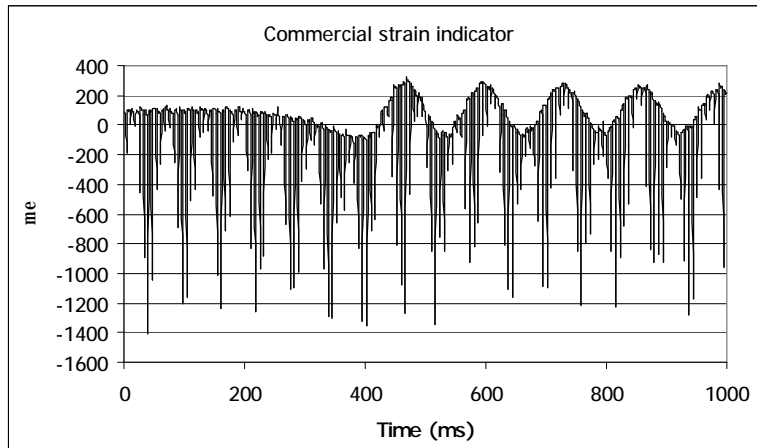


Fig 10. Effect of a noisy environment using a commercial strain indicator

The same noisy environment does not seem to affect the test carried out with the wireless system, as shown in fig. 11.

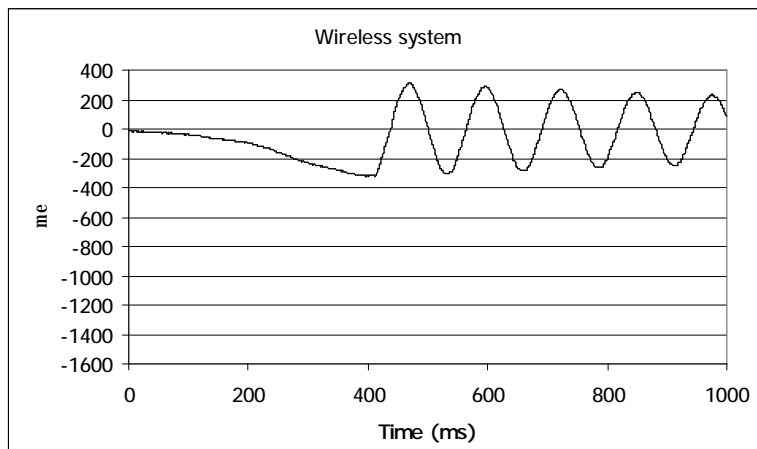


Fig 11. The noisy environment doesn't affect the output obtained with the wireless system.

The system has also shown a good behaviour during the tests on rotating shafts. It has been mounted on a shaft at a distance of about 5 cm from the axis; the transmitting antenna was arranged along a circumference and the receiving one at the distance of about 30 cm parallel to the axis; the test has been carried out up to a speed of about 3000 rpm without loss of data.

BIBLIOGRAPHY

- [1] D. H. Sheingold, Transducer interfacing handbook: a guide to analog signal conditioning, Analog Devices Inc, 1981