LOW NOISE CONDITIONER FOR HIGH RESOLUTION, WIRELESS MEASUREMENT OF MECHANICAL MICRO-STRESSES

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Summary: The paper presents technologically advanced, programmable, low noise conditioner for the wireless measurements micro-stresses using strain gages. The conditioner and radio telemetric module have embedded digital filters. The filters are used for optimum frequency response of low signal level measured in the presence of high level electromagnetic interferences.

Keywords: intelligent transceiver, wireless measurement, deformation state, mechanical stress, strain gauge, telemetric module, electromagnetic disturbances

1. Introduction

Wireless communication between measurement points may be carried out by a transceiver (transmitter-receiver) which operates with strain gauge measurement circuit. The most popular electrical elements used in strain, force measurements are resistance strain gauges. Transceivers however are usually not equipped with a communication protocol suitable for network operation. They also do not contain measurement circuits. These devices contain specialised circuit of transmitter and receiver operating in VHF or VHF band. Depending on the needs the operation of the device with associated system depends on particular applications.

Many companies produce separate transmitters and receivers circuits which can be used for bi-directional communication. Despite of their sometimes attractive price, designing of transmitters for bidirectional radio communication is too complicated task and not advantageous in practice. Design problems associated with high frequency technology make it more reasonable to cooperate with experienced companies and use their products which have already been verified in practice. With this aim cooperation was commenced with some companies in the area of using several transceiver for design of own, specialised conditioners for telemetric measurement modules.
Many of such technical problems can be solved using the wireless technique coupled with computer system of data registration. The radio telemetry technique has been adopted for measurements of silo deformation states on the silos [3, 4].

In telemetry system dedicated for the measurements of mechanical stresses by using strain gages, we can not avoid all electromagnetic interferences but it is possible to avoid some of them using specialised circuit of conditioners, transmitter and receivers operating in UHF or VHF band. Also screening techniques, shields, filters, intelligent communication protocol suitable for network operation must be used.

The operation of the device can be customized according to user’s requirements. Transmission protocols must be created by a programmer with significant experience in cooperation with the equipment.

2. Description of conditioner

Conditioner (Fig. 1) consist of high frequency module and transmission controller (radio modem) cooperating with measurement module (Fig. 2). High frequency module contains a low power (10 mW) transmitter working in UHF band (433,92 MHz) with frequency modulation and a compatible super-heterodyne receiver with double frequency conversation and sensitivity of -107 dBm. The transmitter and receiver set provides bidirectional communication.

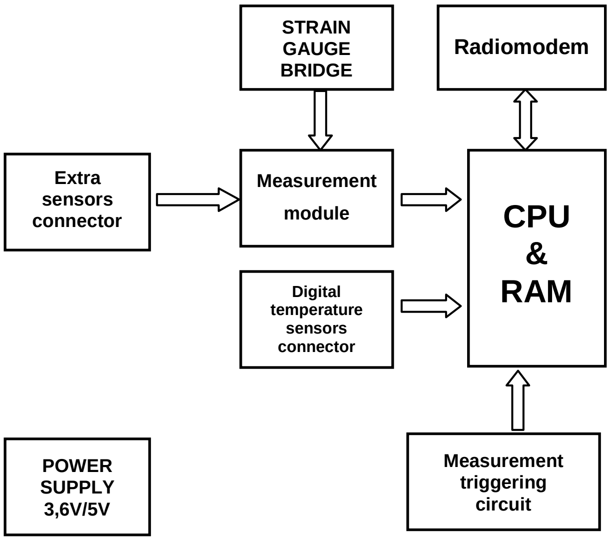

Fig. 1. Conditioner block diagram

2.1. Measurement module

Resistance strain gages are most popular electrical elements used in mechanical stresses. The resistance strain gage is a resistive element which changes in length, hence resistance, as the force applied to the base on which it is mounted causes stretching or compression. Strain gages are low-impedance devices. They require excitation power to obtain reasonable levels of output voltage.

A typical strain-gage based load cell bridge will have typically a 350 ohm resistance. Sensitivity of the strain gages is defined in terms of milivolts full scale per volt of excitation. The sensitivity (for metal strain gages) is from 1 to 5 mV/V for normal range of stresses. For lower range (for the mechanical micro-stresses) the sensitivity is below 1 mV/V (e.g. 100-300 µV/V). Because of very low sensitivity it is extremely difficult to design very accuracy conditioner. Influence of electrical noises, electromagnetic disturbances is very big and is necessary to use individually designed electronic circuits.

Described in this paper measurement module (as a part of the conditioner) is a complete system based upon circuit AD7730L by Analog Devices [1]. Its simplified block diagram is presented in Fig. 2. The circuit was specially designed for operation with very low level signals (24-bit no missing code) in strain gauge measuring mechanical micro-stresses and deformation in building objects. The circuit accepts signals from both DC and from AC bridges. Serial, digital output of the signals make easier to deliver it to the microprocessor system.
Effective resolution extends to 22 bits depending upon PGA gain, post filtering, update rate, programmed filter bandwidth, etc. Because of high resolution of the conditioner, the effects of noise must be very well interpreted how it affects the A/D converter performance.

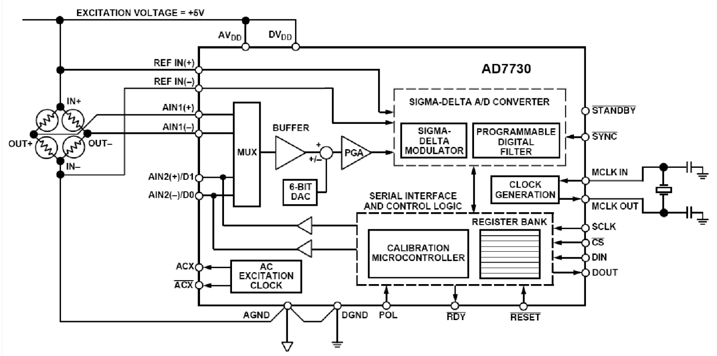

Fig. 2. Simplified block diagram of the strain gauge measurement circuit [1]

This problem also applies to A/D converters of lower resolution, but is very important when dealing with 16-bit or more sigma-delta A/D converters. The total noise in the conditioner can be considered to be an input source which is summed with the input signal from the strain gages into an ideal noiseless A/D converter (*effective input noise*).
Used in the conditioner A/D converter was specifically designed to interface directly to bridge and outputs a serial digital word (Fig. 2). The programmable gain amplifier (PGA) can be programmed for four differential unipolar and bipolar analog input ranges. Minimum range is from 0 to ±10 mV. The maximum peak-to peak, or noise free resolution achievable is 1 in 230.000 counts or approximately 18 bits.
The noise-free resolution is a function of input voltage range, filter cut off and output word rate. Noise is greater using the smaller input ranges where the PGA gain must be increased. Higher output word rates and associated higher filter cut off frequencies will also increase the noise [2].
With the strain gauge output voltage from the bridge of ±3 mV, it has noise voltage of 40 nVrms (ca. 240 nV p-p), the amplification precision 1 µV, voltage drift – below 1 µV, temperature drift of 0,5 µV approx. With ambient temperature ranging from -30°C to +85°C there is possibility of remote, automatic calibration of strain gauge bridge, correction and background bias. Parameters of the procedures are stored in measurement module memory. Built-in memory gives a possibility of performing dynamic measurements. Built-in digital filters enable shaping of the recorded signal. The first stage is low pass filter. The cut off frequency and output rate of this first stage filter is programmable. The second stage filter has three modes of operation. Reading of results is performed by means of notebook computer with radio receiver station.
The 6-bit D/A converter can remove tare values from the analog input signal range (zeroing mode). The conditioner contains self-calibration option and has an offset drift of less than 5 nV/°C and a gain drift of less than 2ppm/°C. This very low offset drift is obtained using a chop mode (similarly to a chopper-stabilized amplifier). The conditioner can be programmed to operate in either chop mode or non chop mode. The chop mode can be enabled in ac-excited or dc-excited applications; it is optional in dc-excited applications, but

chop mode must be enabled in ac-excited applications. The chop mode has the advantage of lower drift numbers and better noise immunity, but the noise is approximately 20% higher for a given –3 dB frequency and output data rate. For mechanical micro-stresses measurements the conditioner can operate in the chop mode to avail themselves of the excellent drift performance and noise immunity when chopping is enabled.
Due to difficult environmental conditions of operation (wide range of temperature changes, including below-freezing temperatures, high humidity, dust etc.) the conditioners are mounted in tight metal housing of IP67 class [Fig. 4]. Electronic circuitry is assembled in SMD technology [Fig. 5].

3. Radiomodem

Due to fact that the measurement are performed over the radio, the conditioner had to be equipped with a number of functions, which are quite troublesome in traditional stress measurements with use of strain gauge technology (zeroing, scaling, calibration etc.).
Transmission controller in the radio modem (Fig. 3) provides data exchange between the main measurement microcontroller and the high frequency module.

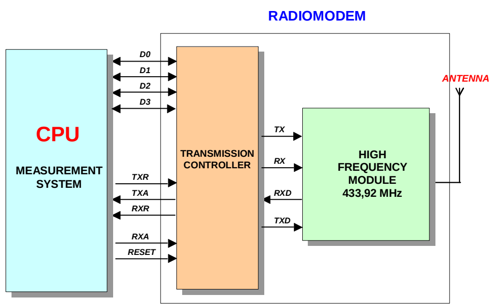

Fig. 3. Radiomodem block diagram

Data packet (1-27 bytes) from the measurement microcontroller is being sent to the buffer of transceiver operating in receiver mode. The received packed is decoded and delivered to the measurement module controller. Received block of data from measurement is preceded by data which identify the transceiver operating in transmitter mode (preamble), start byte and control sum. In order to avoid clashes in case of other transmitters operation "listen before TX" method is used. If the transceiver is not in TX mode its reception circuits are attempting to catch the identification data (preamble). After decoding such data, the transmission controller synchronises itself with subsequent input data bytes, which are then decoded and control sum is checked. In the final phase the complete packet of measurement data is received. The initial byte and the control sum are practically invisible for the user.
The conditioners are presented on Fig. 4 and Fig. 5.

Fig. 4. Radio telemetry conditioner systems

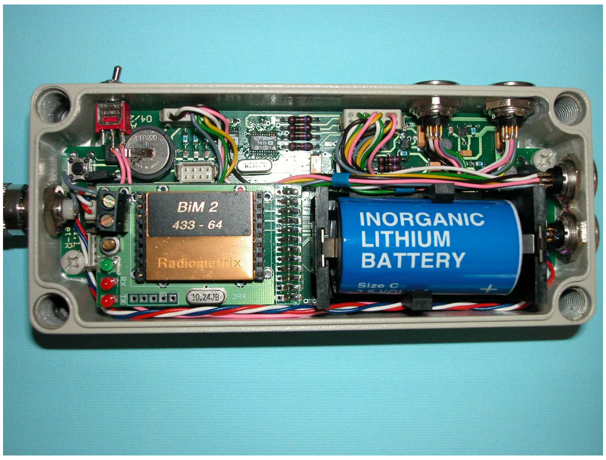

Fig. 5. Inside view of the conditioner

4. Noise reduction in the conditioner

Eliminating electrical noise is very important because it can present problems even with the best measurement equipment. Most industrial environments suffer from multiple sources of electrical noise.
Designing a completely noise-free environment for test and measurement is seldom practical. Simple techniques such as using shielded/twisted pair wires, averaging, filtering, and differential voltage measurement are available for controlling the noise in the measurements. Some techniques prevent noise from entering the system. Other techniques remove noise from the signal.
Averaging for the conditioner is done in microcontroller software after several samples have been collected. Depending on the nature of the noise and the technique used, averaging can reduce noise by the square root of the number of averaged samples, however, reducing RMS noise significantly may require averaging many samples. Figure 6 demonstrates the voltage across the shorted channel when 16 samples of data are averaged

together. Averaging is best suited to lower-speed applications.

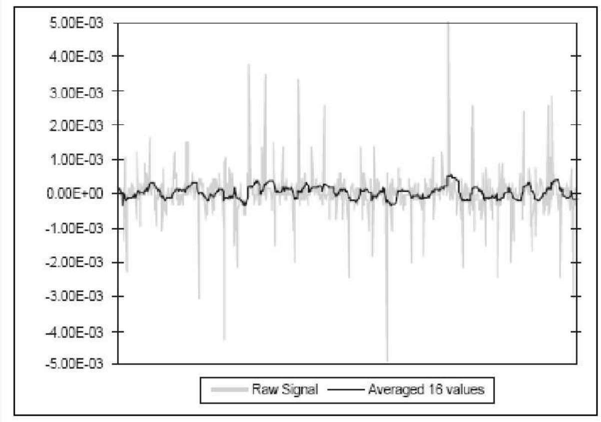

Fig. 6. Noise reduction using averaging [5]

Averaging is only suited to low-speed applications. Also, averaging only eliminates random noise. It does not necessarily eliminate many types of system - noise such as periodic noise from switching power supplies [5].

Electromagnetic disturbances from other radio transmitters and electric equipment which are installed around and within of building objects e.g. silos, requires the use of intelligent transceivers functions, particularly during creation of complex algorithms of data exchange within the data exchange in the entire measurement network. The power of electric equipment (e.g. elevators, conveyors, hammer and tumbling mills, mixers, cyclone separators, etc.) is up to 100 kVA or even more. They are sources for very large electromagnetic disturbances. Also the silos during the operation (filling phase, storing and discharging phase) generate the electrostatic fields, which are very dangerous for the electronic equipment installed on the silo walls. The electrostatic fields is a resultant movement of solids (conveying transportation, rotating, filling, discharging etc.) [6].

5. Conclusions

Built of intelligent conditioner, after its testing (with bidirectional communication), allows for measurements of mechanical micro stresses using strain gauge technology. Inherent "intelligence" features provides more credible results, which are particularly required in field conditions. The conditioner allows for long term, uninterrupted operation over 6 to 9 months. Further works will be performed to extend the batteries operation time to 24 months.

After performing of tests on selected real building objects (bridges, silos), production of telemetric measurement systems is made at AMEX Research Corporation Technologies (Poland), basing on the built prototype device.

6. References

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