Balancing Devices with Voltage and Current Excitation for the Strain Measurement

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Abstract. *The research analyzes the proposed circuits of balancing devices for the strain measurement with voltage or currents excitation. The dependence of measurement codes on strain sensor resistance variation and parameters of the circuits are presented, also, the requirements for the readjusting of power supply range are introduced. The experimental results are presented.*

Keywords: Strain Measurements, Small Resistance Change Measurement, Voltage Excitation, Current Excitation,

1. Introduction

The strain researches are often required for constructions of various materials during their design, construction and operation. This applies to the newly designed structures for carrying out tests to determine durability and resistance to applied forces identify weaknesses, and to provide means for improving or strengthening. Also it is often important to monitor different statuses of existing buildings. In these cases it can be seen that in some time deformation reaches a critical value asked; predict the onset of construction accident, and to take appropriate actions to prevent it [1, 2]. Strain gauges with balanced [1] and not balanced Wheatstone bridges [3] are often used. It is suggested to use the circuits of bridges with current excitation [4] and the current-balanced devices for automated measuring of strains [5], with a lower sensitivity to interference.

The research analyzes the new proposed balanced circuits of small resistance changes with voltage and currents excitation.

2. Analysis of Balancing Methods of Strain Measurement with Voltage and Current Excitation

At present there are many different DACs are manufactured. Multi-bit DACs with several DACs in one integrated circuit with current output are quite common. Such DACs can be successfully used in balancing devices of the strain measurement. Balancing devices embody full range of advantages as greater accuracy; avoids nonlinearities of devices and so on. The summarized circuits of balancing devices with voltage (current) excitation is composed which is shown schematically in Figure 1. It consists of two power sources S1 and S2, and four resistors $R_1 - R_4$. Two resistors of the circuit (R_1 and R_3 or R_2 and R_4) are the sensors of a strain gauge and the active one of them determine the size of deformation, and the second one is compensatory, which compensate resistance change of the active sensor due to environmental conditions. Electrical connections between point's *ab* and sources S1 and S2 can be used when the circuit is powered from the current sources. The output voltages (currents) of one or the other or both of the sources are digitally regulated by the control device CU, so that the circuit would be balanced ($U_{ab} = 0$, applying voltage excitation and $U_{12} = 0$, applying current excitation).
The voltage difference between the points *ab* of circuit, powered from the voltage sources, is equal

$$U_{ab} = \frac{U_1 R_2}{R_1 + R_2} - \frac{U_2 R_4}{R_3 + R_4} \quad (1)$$

where

U_1, U_2 excitation voltages,

$R_1 - R_4$ circuit resistances, two of witch ($R1$ and $R3$ or $R2$ and $R4$) are strain gauges.

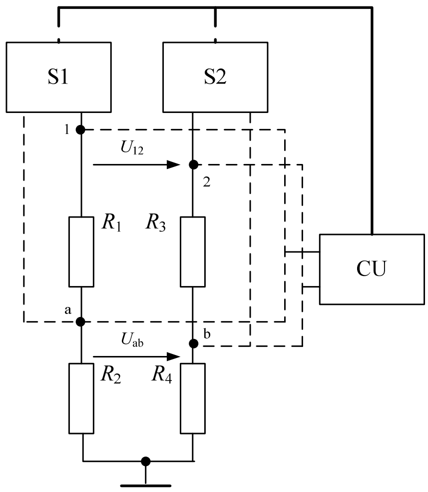

Fig 1. General circuit of balanced devices. S1, S2 – excitation sources; CU – control unit

Sizes of strain gauges, constant resistors, connecting cables resistances are different in the real device and power supply voltage sizes may also be different; installed measuring amplifiers and comparators in control unit (CU) have disbalance of the input voltage. These factors influence eliminated by two measurements – unloaded and loaded measurements. Strain is determined by the values of these two measurements.

There are several ways of realization of devices with voltage excitation:

1. R_2 – active and R_4 compensating strain gauges, $R_1 = R_3$ – constant resistors; device is balanced by changing the value of U_1 and U_2 is kept constant. When a voltage source S1 output voltage is altered digitally, the strain code is equal to

$$m_{1m} = \frac{2^n R_1}{R_1 + R_4}\left(\frac{\Delta R_{2n}}{R_4 + \Delta R_{2n}} - \frac{\Delta R_{2a}}{R_4 + \Delta R_{2a}}\right) \quad (2)$$

where

n number of DAC bytes,

$\Delta R_{ia}, \Delta R_{in}$ changes of loaded and unloaded strain gauge resistance value.

2. R_2 and R_4 – strain gauges, $R_1 = R_3$ – constant resistors; device is balanced by changing the size of U_2, and U_1 is kept constant, then strain measurement code is equal to

$$m_{2m} = \frac{2^n R_1}{R_4}\left(\frac{\Delta R_{2n}}{(R_1 + R_4 + \Delta R_{2n})} - \frac{\Delta R_{2a}}{(R_1 + R_4 + \Delta R_{2a})}\right) \quad (3)$$

3. R_1 and R_2 – strain gauges, $R_2 = R_4$ – constant resistors; device is balanced by changing the size of U_1, and U_2 is kept constant; then strain measurement code is equal to

$$m_{3m} = 2^n\left(\frac{\Delta R_{1n}}{R_3 + \Delta R_{1n} + R_2} - \frac{\Delta R_{1a}}{R_3 + \Delta R_{1a} + R_2}\right) \quad (4)$$

4. R_1 and R_2 – strain gauges, $R_2 = R_4$ – constant resistors; device is balanced by changing the size of U_2, and U_1 is kept constant; then strain measurement code is equal to

$$m_{4m} = 2^n\left(\frac{\Delta R_{1n}}{R_3 + \Delta R_{1n} + R_2} - \frac{\Delta R_{1a}}{R_3 + \Delta R_{1a} + R_2}\right) \quad (5)$$

5. During the measurement the values of U_1 and U_2 can be changed. In this case, the most convenient way to balance the strain monitoring device is to use U_2 source for the unloaded and U_1 source for loaded construction. Then the measurement result is

$$m_{5m} = \frac{-2^n R_1}{R_1 + R_4} \frac{\Delta R_{2a}}{R_4 + \Delta R_{2a}}. \quad (6)$$

Analytic review and research has shown that one of the ways to increase the range of strain measurement is to use circuits with current excitation. The code of strain gauge resistance (strain) change when adjusting the S_2 current excitation source and strain gauges are R_1 (active) and R_3 (compensative) will be equal to:

$$m_{\mathrm{Im}} = m_{\mathrm{a}} - m_{\mathrm{n}} = 2^n \frac{I_1}{I_{2\max}} \cdot \frac{\Delta R_{1a}}{R_2 + R_3}, \quad (7)$$

where

I_1, $I_{2\max}$ the current of the first current source and maximum value of the second source.

As can be seen from (7), the difference of the two codes is directly proportional to the size of the gauge resistance changes during the measurement. Analogically, the code alteration by the adjusting current I_1 is obtained, but in this case the dependence comes more complex, and therefore accepted to regulate the current I_2.

There are current sources which does not require external feedback, and $R_2 = R_4 = 0$, then (7) becomes simpler

$$m_{\mathrm{Im}} = \frac{2^n I_1}{I_{\max}} \frac{\Delta R_{1\mathrm{a}}}{R_3} = \frac{2^n I_1}{I_{\max}} \delta R_{1\mathrm{a}}. \quad (8)$$

The adjustment range of voltage or current sources depends on the maximum possible measured resistance change. This change can be up to ± 30% for steel strains, up to ± 6% for concrete products and so on. Assuming for steel strain measurement $I_1 = 5$ mA, $R_2 = R_1 = 100\ \Omega$, $\Delta R_{1\max} = 30\ \Omega$, then the monitoring devices need $n = 7$ bits, and laboratory devices – $n = 10$ bits for regulation of currents.

Voltage or current DAC may be used as excitation source. They have been formed in one microchip, using the same reference voltage, which reduces the environmental conditions on the monitoring results, as temperature changes almost equally affects both DAC output currents and drift. The DAC current ranges are determined before monitoring by the control code and it can be flexibly chosen for observable construction. The expression of dependence of code on the gauge resistance change is determined.

3. Experimental Results

An experimental model of the circuit with two current sources and one of these sources is adjustable has been made. Dependence of the device adjustable current I_2 on R_1 gauge resistance was measured, which shows that this dependence is linear, the instability of currents and their difference satisfies the requirements for laboratory equipment. During experimental study it has been also found that the proposed circuit allows covering all the required range of adjusting of the current.

The long-term performance stability and the work of the model with the gauges connected by long (10 m) twisted-pair cables and influence of industrial frequency interference has been investigated. The test results (Fig. 2) shows that the stability of current difference in time meets the requirements of laboratory and monitoring equipment in all scenarios; when simply

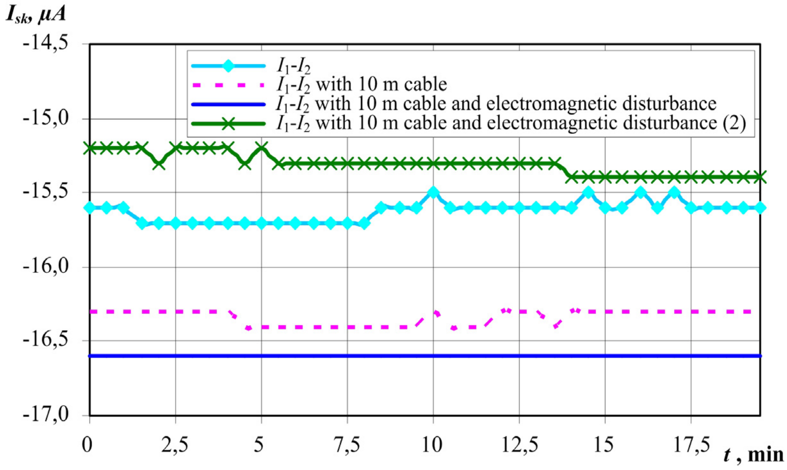

Fig. 2. Dependence of currents difference on time

connecting sensors, when connecting them with long twisted pair cables and when exposing them with an electro-magnetic interfe-rence. Measured disbalance voltage value over time has shown that the experimental circuit is suitable for deformation monito-ring and laboratory test equipment.

4. Conclusions

1. Three new circuits of balancing devices for construction strain monitoring using voltage or current excitation has been proposed designed and analyzed. The obtained results enable to define the required number of control bits for voltage or current in order to receive required resolution.
2. It was confirmed that the easiest option would be to control current of the Wheatstone bridge arm where compensated gauge is switched on which makes the dependence more simple and linear.
3. Voltage or current DACs may be used as an excitation sources. They have been formed in one microchip, using the same reference voltage, which reduces the environmental conditions on the monitoring results, as temperature changes almost equally affects both DACs' output currents and drift.
4. The test results shows that the current change is directly proportional to a change of strain gauge resistance. The stability of current difference in time meets the requirements of laboratory and monitoring equipment in all scenarios including situation with strain gauges connected using long twisted pair cables and exposing them with an electro-magnetic interference.

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