Balanced Devices of Strain Measurements with Current Excitation

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Abstract. *The paper analyzes the proposed three circuits of strain measurement devices using high-output-current DACs. Operating principles and capabilities of these devices are analyzed. It has been shown that the proposed designs have an advantage of being relatively simple and flexible while ensuring high linearity and wide strain measurement range.*

Keywords: Strain Measurements, Small Resistance Change Measurement, Current Excitation, High-Output-Current DACs.

1. Introduction

The strain measurements are applied to the newly designed structures and constructions for carrying out tests in order to determine durability and resistance to applied forces, identify weaknesses, and to provide means for improvement or strengthening of these constructions. It is also important to monitor different statuses of the existing buildings. In this case it can be seen that in some time deformations reaches some critical values and gives possibility to predict construction accident, and to take appropriate actions to prevent it. Such strain measurements should be applied to number of specific points of the construction while these points can be distant one from another while measurement results should acquired to central data analysis and storage centers by using wired or wireless measurement equipment [1, 2]. In this case measurement equipment should be organized in a way that there is number of measuring units that are situated in variuos places of the construction and acquiring strain measurements and after that sending the measurement information to the data analysis center. Therefore it is necessary to design simple and relatively cheap strain measurement units that are capable to operate under various external conditions. Strain gauges with balanced [1] and not balanced Wheatstone bridges [3] are widely used for this purpose. It is proposed to use bridge circuits with current excitation [4] as these have better resistance to external noise and automated balancing circuits with current balancing [5].

Integrated circuits of DACs with current output are quite common in the market nowadays (e.g. MAX5548, MAX5550, AD5510, AD8810 and many others). These DACs are 10 to 16 bits resolution with capability to generate output currents of 20–30 mA. For some of these DACs output currents can be set by software and several DACs (up to 8) can be situated in one IC. New balancing strain measurement devices designed using DACs with current output are presented and analysed in this paper.

2. New circuits of balancing strain measurement devices

A new structural design for monitoring strains of constructions using two current DACs (Fig. 1) is proposed. Two analogous current DACs are formed in one microchip MAX5550, using the same reference voltage, which allows to reduce environmental conditions on the monitoring results, as temperature changes almost equally affects both DACs' output currents and drift. This IC is designed to be used in balancing circuits in wide temperature range. The DACs' current ranges are determined before monitoring by the control code and it can be flexibly chosen for observable construction. Values of the output currents are also set by control code to any of 12 different sub-ranges starting from 1 up to 30 mA. Therefore it is possible to set the most suitable strain gauge excitation currents according to gauge specifications. Output currents of these DACs can differ one from another up to ± 2 %. Such

difference of the currents can be eliminated together with resistance differences of strain gauges and connecting wires and disbalance of measurement amplifier by applying two strain measurements for construction without load (initial value) and measurement of the strain of construction with load applied. The strain measured is the difference between these two measurements. For the initial measurement (measurement with no load applied to the construction) microcontroller DD1 (e.g. MAXQ2000) control signals switches on MOSFET transistors VT*i*1, VT*i*2. Transistors are opened and connect pair of strain gauges R_{ji1}, R_{ji2} to the outputs A and B of the current DAC. MOSFET transistors used should have a resistance of the open channel less than 0.1 Ω and does not influence strain measurement results. Strain gauges are connected to the equipment using twisted-pair 4 wire cable. Results of the experimental investigations have shown that using cable of 10 meters length measurement results are not influenced by 50 Hz mains noises and disturbances. Therefore it is possible to connect from 16 to 32 strain gauges that are located in ± 10 m range from the measuring equipment. Differences of the component values of the measuring circuit shall result in disbalance of the circuit and input voltages of DA1 shall be different. Measuring process is started. Microcontroller DD1 generates changing control code to the B DAC and therefore output current of B DAC is changing. DD1 is reading output signal of the DA1 (logic 0 or 1) and changes control code of B DAC accordingly until the circuit is very near to the balance condition. The resulting control code is stored and sent to system database if needed. All other pairs of strain gauges are measured in the same way and measurement results are stored. Construction is exposed to the load after that and measurements with balancing circuit are repeated for the desired pairs of strain gauges. Result of the strain measurement is the difference between two measurement codes – code obtained in the initial stage with no load applied to the construction and the code obtained by measuring construction under load.
The expression of dependence of code on the gauge resistance change is determined in [5]:

$$m_{\mathrm{m}} = \frac{2^n I_1}{I_{\max}} \delta R_{\mathrm{j1a}}, \qquad (1)$$

where

$\delta R_{\mathrm{j1a}} = \Delta R_{\mathrm{j1a}} / R_{\mathrm{j2}}$ relative changes of the active strain gauge resistance of the loaded and the nominal resistance value of the gauge.

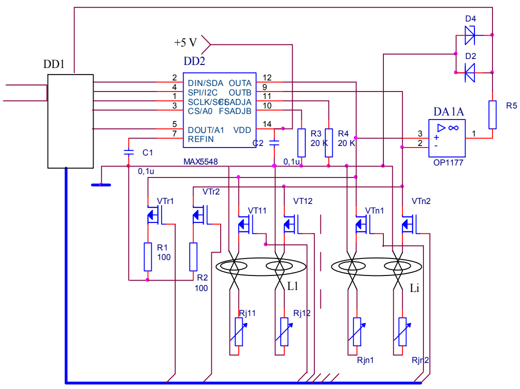

Fig. 1. Strain monitoring device using two current digital-to-analog converters.

Obtained equation indicates that the DAC control code is directly proportional to the gauge resistance change. However, the integrated current DAC (for example MAX5550) has 10 bits. In this case the full range of the strain measurement shall be

$$m_d = 2^n d$$

where

n	number of DAC bits
d	range of strain.

In case OUTB current is set to the value of the most significant bit, then for the steel constructions ($d = \pm 0.3$) $m_{\mathrm{d}} = 353$, concrete constructions ($d = \pm 0.06$) – $m_{\mathrm{d}} = 61$. Device resolution meets the requirements for monitoring equipment and does not meet the requirements for laboratory equipment. It is necessary to mention that in case of monitoring applications only one or several compensating strain gauges are used. In this case construction of the equipment is simpler and number of measurement points can be increased.

In order to avoid influences of external conditions to the measurement circuit high accuracy and thermally stable resistors $R1$ and $R2$ can be used in monitoring equipment that operates for long periods of time and in different temperature conditions for calibration.
In this case after some predefined time of operation VTr1 and VTr2 connects precision resistors $R1$ and $R2$ to the measurement circuit and performs balancing of the circuit. Code obtained is compared to the stored values and differences are calculated. These differences are subtracted from the measurement results to eliminate external influences.

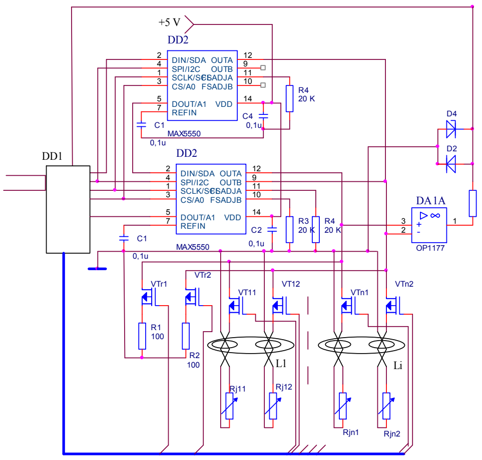

Fig. 2. Strain monitoring device using three current digital-to-analog converters.

In order to increase the resolution, structure of device with three current DACs (two MAX5550 chips) has been proposed (Fig. 2). The current of the device's second DAC output is equal to $I_B = I_A - I_d$, where I_d – the maximum readjusting current. Third current DAC (DD3) of the same type is designed to balance the current and the current output of this DAC is connected in parallel with the second DAC output. In this case, the first two DACs are constant current sources, and the third is determined by balancing the currents so that the initial and strain measurement codes is determined by the strain size and does not affect the strain measurement.

Range of the strain measurement and resolution can be changed by changing output current of A and C DACs. For instance in case concrete construction is under investigation (range $d \leq 0.06$), excitation current of DAC B is set to $I_B = 5$ mA, excitation current of DAC A is set to $I_A = 4.7$ mA and maximum output current of DAC C is set to $I_A = 1$ mA. All 10 bits of the DAC C bits are used for measurement and this setup is corresponding to the requirements of the laboratory equipment. In case steel constructions are measured with the measurement range ($d \leq 0.3$), current of DAC B is set to $I_B = 5$ mA, excitation current of DAC A is set to $I_A = 3.5$ mA and maximum output current of DAC C is set to $I_A = 3$ mA. All 10 bits of the DAC C bits are used for measurement and this setup is corresponding to the requirements of the laboratory equipment.

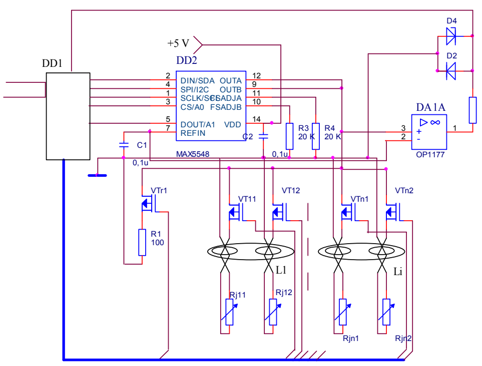

Fig. 3. Strain monitoring device using two current DAC with increased resolution.

New balancing circuit implementing two current DACs has been proposed (Fig. 3). Initial excitation current to strain gauges is generated by DAC A. Balancing of the circuit is made by the sum of the currents of DAC A and DAC B connected in parallel. Range of DAC B is set the same way as in circuit with 3 DACs. But the current is balanced in respect of constant U_a. Value of it be proportional to voltage drop on the strain gauges $U_0 \approx I_{Am} R_{jv}$ (where I_{Am} – named current value for the strain gauges, R_{jv} – named resistance value of the strain gauge).
The proposed structure is fairly universal: according to tested construction material it determines allowable excitation current for this material or gauges and it allows to eliminate the monitoring deviations caused by monitored construction properties or temperature increase of the gauge on the gauge resistance variation, it allows flexibility (software setting) to change the measurement range and resolution; it allows identification of large strains with high resolution.

Simulation using MultiSim 11 modeling software and physical model has been developed and investigated. Performing simulation of change of the strain gauge resistance R_{j11} and balancing circuit afterwards it has been found that the dependence of digital-to-analog converter control code in the decimal counting system and the change of balancing current are directly proportional to the change of the resistance of the strain gauge. Range of the measured strain (and resistance change of the strain gauge) is ± 30 %. Resistance differences of the connecting cables, open channels of MOSFET switches and gauges itself has been simulated by setting different resistance values of the compensating gauge R_{j12}. It has been found that by performing two measurements (measurement without strain applied and with strain applied) abovementioned resistance differences are eliminated from the measurement result.

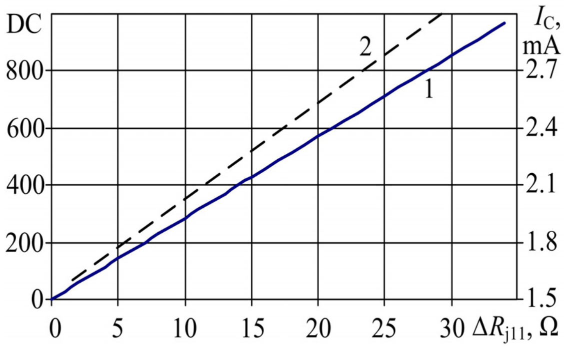

Fig.4. Dependence of control decimal code (DC) (1) and current I_C (2) on gauge resistance changes.

3. Conclusions

1. A newly designed circuit for strain measurement implementing two DACs situated in single IC and having single excitation supply is proposed. Design ensures that instabilities of two DACs are nearly identical. Resolution of the circuit and relatively simple design ensures the possibility to implement this circuit in strain monitoring applications. Strain measurement result (measurement code obtained by balancing the circuit) is directly proportional to the change of the strain gauge resistance. Differences of the DAC output current is compensated and do not influence measurement results.

2. New design of strain measurement device with three current DACs has been proposed. Third DAC is used for balancing the circuit. In this implementation it is possible to select required excitation current for the selected type of strain gauges and the material of the construction under investigation. Design allows elimination of the measurement errors caused by heating of the gauge or the construction. New design of strain measurement device implementing two current DACs connected in parallel has been proposed. The device has and advantage of simpler construction while ensuring extended resolution for laboratory type measurements. The latter two designs allows flexible (software based) change of measurement range and resolution and therefore ensures measurement of high values of strain with high resolution by setting output current of B DAC.

3. Results of computer modeling and experimental investigations have shown that the dependence of control code and balancing current on sensor resistance is linear. Device is capable of measuring strains that changes resistance of the strain gauge up to ± 30 %.

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