

VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Ričardas MASIULIONIS

RESEARCH OF ELECTRONIC DEVICES FOR MONITORING OF SMALL STRAINS

SUMMARY OF DOCTORAL DISSERTATION

TECHNOLOGICAL SCIENCES,
ELECTRICAL AND ELECTRONIC ENGINEERING (01T)



LEIDYKLA
Vilnius TECHNIKA 2012

Doctoral dissertation was prepared at Vilnius Gediminas Technical University in 2007–2012.

Scientific Supervisor

Prof Dr Vygaudas KVEDARAS (Vilnius Gediminas Technical University, Technological Sciences, Electrical and Electronic Engineering – 01T).

The dissertation is being defended at the Council of Scientific Field of Electrical and Electronic Engineering at Vilnius Gediminas Technical University:

Chairman

Prof Dr Habil Roma RINKEVIČIENĖ (Vilnius Gediminas Technical University, Technological Sciences, Electrical and Electronic Engineering – 01T).

Members:

Prof Dr Algirdas BAŠKYS (Vilnius Gediminas Technical University, Technological Sciences, Electrical and Electronic Engineering – 01T),

Prof Dr Habil Steponas GEČYS (Kaunas University of Technology, Technological Sciences, Electrical and Electronic Engineering – 01T),

Assoc Prof Dr Gytis MYKOLAITIS (State Scientific Research Institute Center for Physical Sciences and Technology, Technological Sciences, Electrical and Electronic Engineering – 01T),

Assoc Prof Dr Voitech STANKEVIČ (Vilnius Gediminas Technical University, Technological Sciences, Electrical and Electronic Engineering – 01T).

Opponents:

Prof Dr Jurij NOVICKIJ (Vilnius Gediminas Technical University, Technological Sciences, Electrical and Electronic Engineering – 01T),

Prof Dr Algimantas VALINEVIČIUS (Kaunas University of Technology, Technological Sciences, Electrical and Electronic Engineering – 01T).

The dissertation will be defended at the public meeting of the Council of Scientific Field of Electrical and Electronic Engineering in the Senate Hall of Vilnius Gediminas Technical University at 10 a. m. on 29 January 2013.

Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.

Tel.: +370 5 274 4952, +370 5 274 4956; fax +370 5 270 0112;

e-mail: doktor@vgtu.lt

The summary of the doctoral dissertation was distributed on 28 December 2012. A copy of the doctoral dissertation is available for review at the Library of Vilnius Gediminas Technical University (Saulėtekio al. 14, LT-10223 Vilnius, Lithuania).

© Ričardas Masiulionis, 2012

VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

Ričardas MASIULIONIS

MAŽŲ DEFORMACIJŲ STEBĖSENOS ELEKTRONINIŲ ĮRENGINIŲ TYRIMAS

DAKTARO DISERTACIJOS SANTRAUKA

TECHNOLOGIJOS MOKSLAI,
ELEKTROS IR ELEKTRONIKOS INŽINERIJA (01T)



LEIDYKLA
Vilnius TECHNIKA 2012

Disertacija rengta 2007–2012 metais Vilniaus Gedimino technikos universitete.
Mokslinis vadovas

prof. dr. Vygaudas KVEDARAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Disertacija ginama Vilniaus Gedimino technikos universiteto Elektros ir elektronikos inžinerijos mokslo krypties taryboje:

Pirmininkas

prof. habil. dr. Roma RINKEVIČIENĖ (Vilniaus Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Nariai:

prof. dr. Algirdas BAŠKYS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T),

prof. habil. dr. Steponas GEČYS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T),

doc. dr. Gytis MYKOLAITIS (Valstybinis mokslinių tyrimų institutas Fizinių ir technologijos mokslų centras, technologijos mokslai, elektros ir elektronikos inžinerija – 01T),

doc. dr. Voitech STANKEVIČ (Vilniaus Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Oponentai:

prof. dr. Jurij NOVICKIJ (Vilniaus Gedimino technikos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T),

prof. dr. Algimantas VALINEVIČIUS (Kauno technologijos universitetas, technologijos mokslai, elektros ir elektronikos inžinerija – 01T).

Disertacija bus ginama viešame Elektros ir elektronikos inžinerijos mokslo krypties tarybos posėdyje 2013 m. sausio 29 d. 10 val. Vilniaus Gedimino technikos universiteto senato posėdžių salėje.

Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.

Tel.: (8 5) 274 4952, (8 5) 274 4956; faksas (8 5) 270 0112;

el. paštas doktor@vgtu.lt

Disertacijos santrauka išsiuntinėta 2012 m. gruodžio 28 d.

Disertaciją galima peržiūrėti Vilniaus Gedimino technikos universiteto bibliotekoje (Saulėtekio al. 14, LT-10223 Vilnius, Lietuva).

VGTU leidyklos „Technika“ 2112-M mokslo literatūros knyga.

Introduction

Problem under Investigation

The purpose of investigated system is automatic monitoring of small construction strains with electrical devices. Their main function is to monitor steady state of the already built buildings or separate constructions. Such method allows noticing when strain reaches critical values set by building constructors, also predict possible building crash and take corresponding actions in order to avoid human deaths caused by natural disasters. For this purpose the ordinary devices (monitoring devices) with smaller resolution could be used, but it should be able to let us monitor strains in multiple, distant points of construction. As well as that, strain valuation is used for new buildings. It allows determining durability of the new construction, resistance to acting forces, find their weakest points and plan improvement options of the construction. For this purpose the device (laboratory device) should have higher resolution which enables monitoring strains in multiple, distant points of construction.

The basic purpose of strain monitoring devices is to determine very small strain gauge resistance variations which might be equal to a displacement or strain and could be as low as one-thousandth of percentage. Up to date systems are very expensive especially when measuring changes in various points of construction. Also they are not reliable in outside conditions. Most of known projects that are being done in this area are seeking to improve devices that are using unbalanced Wheatstone's bridge which makes the system very complicated and expensive.

Therefore, detection and monitoring of construction strains (small resistance changes while using strain gauges) in laboratories or on the existing buildings is an ongoing task. The devices used in strain monitoring should be automatic and be able to get data in various distant points of the construction. Also the mechanism should be able to pass on information to distant control and assistant centres. Strains create small changes in gauges resistance. The construction is due to crash when concrete or reinforced concrete construction's strain reaches 3–6 % of a gauge's change. If this resistance band is divide of into 100 (monitoring devices) or into 1000 (laboratorial devices), then the resolution of that devices should be equal to 0.03–0.06 % or 0.003–0.006 % of nominal gauge value. There are lots of unsolved problems in strain detection devices due to the need of high level of automation and multi-measuring function.

Objects of Researches

The objects of this research are:

- The derivation of strain code and range expressions for automatic balancing bridge devices.
- Development and experimental investigation of new automatic multi-point by current balancing devices for monitoring of constructions strains.

The Aim of the Work

The aim of the work – development and research of the new structural circuits of automatic multi-point electronic devices for small strain monitoring.

Tasks of the Work

Tasks of the work were as following:

1. Perform the comparative analysis of methods used by electronic devices for small strain monitoring.
2. Establish link between balancing code and detected strain diapason in Wheatstone's bridges devices.
3. Propose new structural circuits for automatic electronic multi-point monitoring and detective devices of small strain. Perform detailed analysis, computer simulation and examine their characteristics.
4. Perform experimental investigation of the main nodes of proposed new electronic devices for small strain monitoring.

Methodology of Research

This project involves analytic, digital and experimental research methods. The variants of small resistance changes identification systems are analyzed using analytical methods. Proposed new structures for monitoring of construction strains by balancing currents are analyzed using analytical methods. The software packages "Electronics Workbench" and "Multisim 11.0" are used for computer simulation. The constructed laboratory model for the testing of the system operation and main parameters are studied using experimental methods.

Scientific Novelty of the Work

1. Expressions of Received dependencies between gauge resistance change (constructions strains) and balancing code of multi-point device using balancing Wheatstone's bridge and expressions of a gauge resistance working range were estimated.

2. A new device of automatic multipoint monitoring of constructions strains by balancing currents was proposed. Structure of devices using two current sources was developed and investigated.
3. A new structure of automatic multipoint monitoring of constructions strains using one current source was developed and investigated.
4. A new structures of automatic multipoint monitoring of constructions strains by balancing the currents and using the digital to analog converters with the current output were designed.

Practical Value of the Work Results

The offered solutions enable to use devices with a more simple structure for the multipoint monitoring of small resistance changes and constructions strains. Proposed solutions can be used to monitor and investigate strains of mechanical and aerial construction also can be applied to evaluate of other parameters (pressure, mass, weight, etc.).

Defended Propositions

1. A new device of multipoint detection of small resistance changes by balancing currents with two current sources is designed for multipoint monitoring of strains and gauges can be placed up to 10 meters from the main unit.
2. A new device of multipoint detection of small resistance changes with a single current source allows simplifying research devices, reducing the impact of environmental conditions to the results of strain monitoring and is suitable for both laboratory as well as monitoring equipment.
3. Proposed devices allow reach detectable strain range up to $\pm 30\%$. It allows usage of digital analogue converters with up to 3 bits less in comparison to balancing bridge devices and with up to 8–12 bits less in proportion to unbalancing bridge devices. As well as that, these devices allow to reduce the impact of disturbances and noises to detection results.

Approbation of the Work Results

Five scientific articles on the subject of dissertation were published: one article is published in scientific journal, included in the ISI Web of Science database, one article – in scientific journal, included in the ISI Proceedings database, two articles – in scientific journals, included in the Copernicus database, one article – in other peer-reviewed scientific publication.

The work results were introduced and discussed in the 8 scientific conferences, 5 of them international and 3 national audiences.

The Scope of the Dissertation

The dissertation consists of: introduction, four chapters, conclusion, lists of used published materials and list of author's publications on the subject of dissertation. The dissertation includes 112 pages, 48 figures, 2 tables and 82 numbered formulas. 65 references were used during the writing of the dissertation.

1. Analytic review of methods of electronic devices for monitoring of small strains

The chapter dedicated to the analysis of practical use of methods for strains monitoring, their deviations, possibility of application use of these methods in automated multipoint systems. Strain gauges are mainly used in electronic devices for strain identification. They are glued to the deformable construction or its element and deformed (stretched or compressed) same as the construction. Under investigation due to gauge deformation is its resistance changes. The method of application the Wheatstone bridge is widely used for accurate measurement of small resistance changes.

There are two main ways of measuring the change of resistance: a) use the unbalanced bridge, b) use the balanced bridge. Currently in practice, unbalanced Wheatstone bridges are commonly used where the change in the gauge resistance is measured by digital methods. These changes of disbalance voltage are measured using 16 or more bits of the analog-digital converters (ADC). The automatic device that uses a balanced Wheatstone bridge is proposed. In this case, $R-2R$ type of digital-to-analog converters (DAC) is used to balance the resistance. Changing DAC control code and resistance of one bridge arm at the same time seeks to make the bridge disbalance voltage potentially closer to closer to the 0 after bridge balancing. Bridges is powered by constant voltage and direct current. It is noted that direct current supplied schemes are less susceptible disturbances and noise, but in practice it is now used fairly rarely.

The quarter, half and full bridge circuits of switching strain gauges by long wire for monitor a number of remote one from the other points is used in electronic devices. They use unbalanced bridges equipment, but they are quite complex. Before the measurements are made, connected cables and amplifiers have to be calibrated to a particular channel, maintained at a constant voltage supply. Devices with balanced bridges are more simple, there is no high requirements on power supplies, connecting cables and amplifiers connections wires, the automatic system is closed, but they have not been analyzed fully.

2. Analysis and formation of structures of balanced electronic devices for monitoring of small strains

The chapter analyzes the devices for automatic multipoint monitoring of construction strains using the strain gauges. The expressions of resistance change dependence on the control code of automatic device using the balanced Wheatstone bridge are developed. The setting range of resistance changes is stated. A new structure of automated multipoint device using balanced currents for strain monitoring are proposed and analyzed.

Dependence of DAC control difference code on strain gauge resistance change for automatic devices while measuring small resistance changes using the balanced Wheatstone bridge has been obtained. The measurements of strain gauge are taken when it is unloaded and loaded.

$$m_m = \delta R_{j1m} \frac{2^n R_4}{R_{SAK}}, \quad (1)$$

where δR_{j1m} – the relative change of the active sensor, n – the number of DAC bits, R_{SAK} – full resistance of DAC, R_4 – constant resistance of bridge resistor.

As can be seen from (1), the difference of the two codes is directly proportional to the relative change of resistance of the gauge, that is proportional to the strain. In addition, influence of the difference of active and passive gauges resistance and connection wire resistances are eliminated. Resistance change of active gauge caused by climatic conditions is compensated by actuated passive gauge.

The number of required DAC bits to ensure device resolution has been set

$$n \geq \frac{1}{\log 2} \log \frac{\Delta R_3}{\Delta R_{ml}}, \quad (2)$$

where ΔR_3 – range of readjusting of resistor R_3 ; ΔR_{ml} – maximum allowable resolution of the strain measurement.

Analytic review and research showed, that one of the way to increase the range of strain measurement reduce noise and disturbances influence is to use a current powered circuits. The proposed new scheme consists of two current sources I_1 and I_2 , when one of the current output is digitally regulated. These two sources supply two – active and compensating gauges R_{j1} and R_{j2} (Fig. 1).

The scheme is balanced by adjusting the current I_2 in the start of monitoring (when the structure unloaded). The value of code of the current balancing is obtained. Then current balancing is performed on the loaded construction. The code of strain gauge resistance (strain) will be equal to:

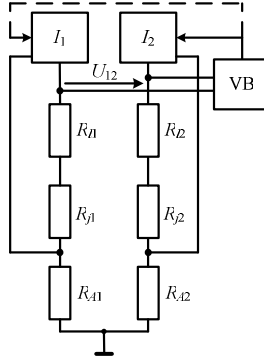


Fig. 1. Structural diagram of monitoring of small resistance changes (strains) balancing of currents: I_1 , I_2 – first and second current source; VB – control unit

$$m_m = m_a - m_n = 2^n \frac{I_1}{I_{\max}} \cdot \frac{R_m}{R_A + R_{j2}}, \quad (3)$$

where: I_1 – the current of first current source, $I_{\max}$ – maximum value of the adjusting current source, R_m – resistance of gauge at measurement moment, R_A – resistance value of the reference precise resistor; R_{j2} – resistance of unloaded strain gauge.

As can be seen from (3), 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 .

The adjustment range of current sources depends on the maximum possible measured resistance change. This change can be up to $\pm 30\%$ for steel strains, up to $\pm 6\%$ for concrete products and so on. Assuming for steel strain measurement $I_1 = 5 \text{ mA}$, $R_A = R_{j1} = 100 \Omega$, $R_{j \max} = 30 \Omega$, then the monitoring devices need $n = 7$ bits, and laboratory devices – $n = 10$ bits DAC for regulation of currents.

A new structure of balanced scheme for monitoring of construction strain with one digital controlled current source is proposed and tested. It has been shown that the digital alteration code is the same as in the circuits with the two current sources. The structure is simpler than the structure with two sources. It eliminate the influence of current instability generated by two current sources (for example, drift, as the strain monitoring can be carried out for a long time – months, years).

It has been proposed new structural circuits for monitoring of construction strain with two current DAC. Two analogous current DAC have been formed in one microchip, they use 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

$$m_m = \frac{2^n I_1}{I_{\max}} \delta R_{j1a}, \quad (4)$$

where $\delta R_{j1a} = \Delta R_{j1a} / R_{j2}$ – relation of the resistance changes of the loaded active strain gauge and the resistance of compensating gauge.

Obtained equation indicates that the DAC control code is directly proportional to the gauge resistance change. However, the current DAC has only 10 bits and device resolution does not meet the requirements for laboratory equipment.

In order to increase the resolution, structure of device with three current DAC was proposed (Fig. 2). The current of the device second DAC output is equal to $I_B = I_A - I_d$, where I_d – the maximum readjusting current. The same type third current DAC (DD3) is designed to balance the current and the current

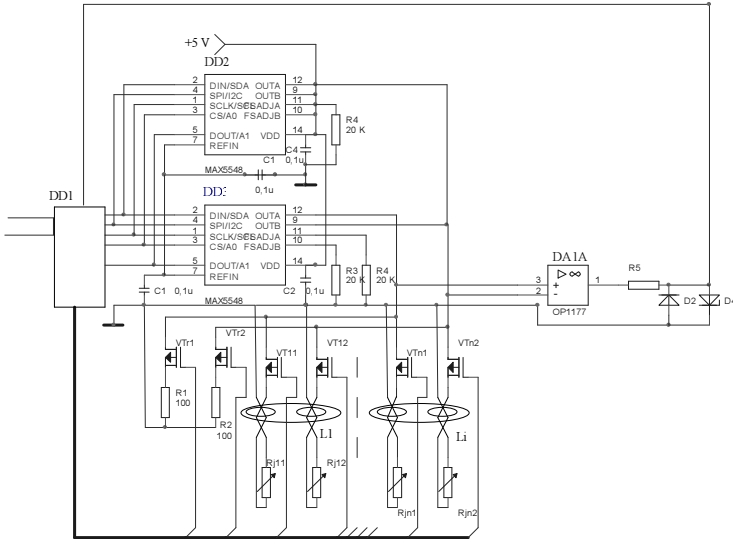


Fig. 2. Strain monitoring device using three current digital-to-analog converters

output is connected in parallel with the second DAC output. In this case, the first two DAC are constant current sources, and the third is determined by balancing the currents, so the initial and strain measurement codes is determined by the strain size and does not affect the strain measurement.

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.

3. Modeling and research of devices for monitoring of constructions strains

In modelling suggested devices and the operation of their main nodes, the aim was to verify the correctness of proposed devices by balancing currents and obtained theoretical findings for monitoring of construction strain (detection of small resistance changes). Also it was important to detect the results influenced by instability of elements of the device and any other changes in environmental conditions, interferences. Two models of main nodes of the researched devices were constructed by using software packages “EWB5.0” and “MultiSim11”. The research in simulating the procedure was done by changing parameters of devices elements and simulating changes of environmental conditions or interferences.

Two computerised balancing currents models with two current sources were created. It was confirmed that scheme can be balanced when either the first or the second current source is controlled by DAC and the resistance of potentiometer which simulates the active gauge is changed $\pm 28\%$. The achieved DAC code dependencies on change of the gauge resistance are linear. In the second chapter it was analytically detected that this dependence is linear when I_2 current is being changed. Although when current I_1 is being changed, the dependence mentioned above is complicated and not linear. Therefore the research has approved theoretical assumptions that it is possible to detect small resistance changes while using the suggested current balancing method.

The model created by MultiSim11 was analysed and the following conditions were introduced to monitor their influence to the results: operation of the device at a long term, change of environmental temperature and electromagnetic interferences.

It was examined the influence of resistance value changes of one resistors in two current sources with analogous resistors to monitoring results. It was detected that with a change of one resistance of one of the sources against the

other resistance by $\pm 1,2 \Omega$ (i.e., $\pm 0,12 \%$) the resolution reaches the laboratory equipment allowable limit ($\pm 90 \mu V$).

There dependence of disbalance voltage on changes in temperature of resistors $R_0 - R_3$ in the first current source while the temperature of resistors in the second current sources remain the same and stays equal to nominal value was also detected. Modelling proved that when the difference in temperatures of analogue resistors reaches $3^\circ C$ then disbalance voltage becomes equal to the resolution of laboratorial equipment.

In reality both current sources are at the same level and their conditions are the same. Therefore examination of disbalance voltage affected by temperature change when there are differences in the identity coefficients has been performed. It was concluded that differentiation of R_3 and R_7 at the range of temperatures from -30 up to $+30^\circ C$ will not exceed the requirements of laboratorial equipment even when resistors temperature identity coefficients is from 0.95 up to 1.05 and has the highest influence on the values of currents. At the same time in laboratorial environment where temperature varies from $5^\circ C$ up to $+30^\circ C$, the resistance difference due to R_3 and R_7 changes will not exceed requirements set by laboratorial equipment, even if the resistors temperatures identity coefficient $k = 0.85-1.15$.

Modelling proved that disbalance voltage resolution will not exceed the allowable resolution of laboratorial equipment even if the the temperatue of strain gauge R_{j2} is being changed $\pm 18^\circ C$ in relation to compensating gauge. Disbalance voltage resolution will not exceed monitoring device's resolution even if the temperature of one of the gauge's will be changed by $\pm 30^\circ C$ in relation to another gauge's temperature.

Modelling results (Fig. 3) shows that disbalance voltage limit $\pm 90 \mu V$ is not exceeded when identity coefficient k changes from 0.85 to 1.15 taken into account that the strain gauges temperature ranges from $-30^\circ C$ to $+30^\circ C$ and the temperature coefficient of the first gauge is equal to the temperature coefficient of the second gauge multiplied by identity coefficient. Therefore it is assumable that even if the environmental temperatures of the active and compensated gauges would be different, the differentiation of the scheme will not exceed the given limits. Also the results suggest that in most of the cases only one compensated gauge per device could be used.

A device for monitoring construction strains with the use of balancing currents was created in the environment with industrial interferences. Interference signal is generated by variable voltage 50 Hz source which is connected to strain gauges R_{j1} and R_{j2} . With the help of potentiometer it is possible to change voltages which are sent to gauges. As well as that the generated interference identity coefficient could be changed. It is obvious when

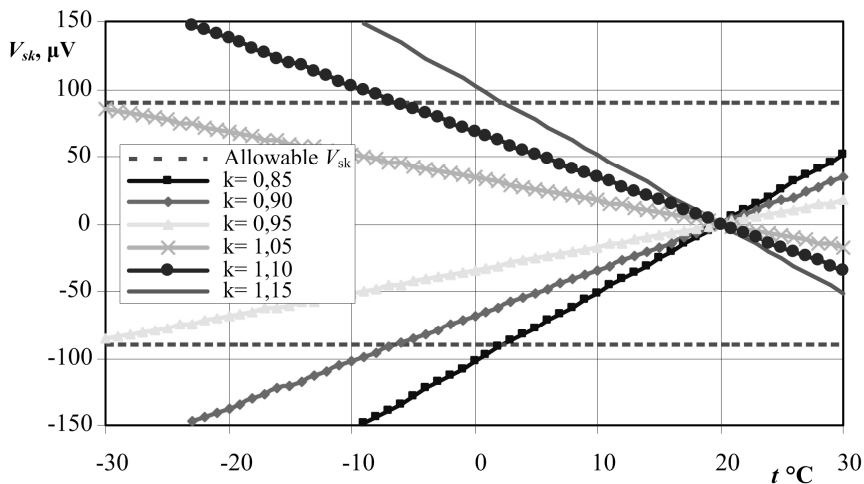


Fig. 3. Dependence of disbalance voltage on temperature of strain gauge with different temperature coefficients

identity coefficient is 1 (interferences on both sides of gauge's chain) the interference voltage ΔV_{sk} is equal to zero and strain detection tolerance does not appear. This happens despite of the value of connected interference voltage. ΔV_{sk} increases when the value of active interferences of connected conductors changes. The higher interference voltage, the lower identity coefficient. This condition should be fulfilled in order not to overcome the value $\pm 90 \mu V$ of voltage difference in resolution measured by laboratorial devices. There was a modelling made with generating current interferences. It was detected that devices are very sensitive to asynchronous interferences. Therefore connecting cables should provide the ability to create synphasic interferences in both wires of the connecting gauges.

4. Experimental research of devices nods for monitoring of constructions strains

The main point of the experimental study was to verify in practice the proposed current balancing method and its practical functioning, accessible range and tasked resolution both for the construction monitoring and laboratory equipment for detection of strain.

The first task was to verify in practice the scheme operation with the current balancing. The results of experiments, during which the resistance values of an active sensor simulation potentiometer were changed, has showed that changing of the second supporting source, and thus the current I_2 , the

scheme balance was achieved. The results show that the dependence of the current generated by second source, after the balance is achieved, on the sensor R_{j1} resistance changes is linear, so that confirms the obtained theoretical results. Research has shown that current sources used during the experiment do not provide sufficient current stability for the laboratory equipment requirements.

An experimental model was made, in which the operational amplifiers with big amplifications coefficient were used for current sources. Dependence of device currents I_1 , I_2 on voltage drop in gauge R_{j1} was measured, which shows that the current instability and their difference satisfy the requirements for laboratory equipment. During experimental study it was also found that the proposed scheme allows recovering all required range of the current readjusting.

Experimental model was made and studied, in which other types of current sources were used. In this case the gauges are connected to the case ground, thus simplifying diagrams of gauges connections. During the experimental studies of this model the long-term performance stability and the work of the model with the gauges connected by long (10 m) twisted-pair cable were investigated. The influence of industrial frequency interference was examined. A twisted-pair cable was tangled up with a high-current (~ 10 A) industrial frequency conductor and the influence of electromagnetic interference on the size of disbalance voltage and stability of the scheme was examined. The test results (Fig. 4) show that the stability of current difference in time meets the

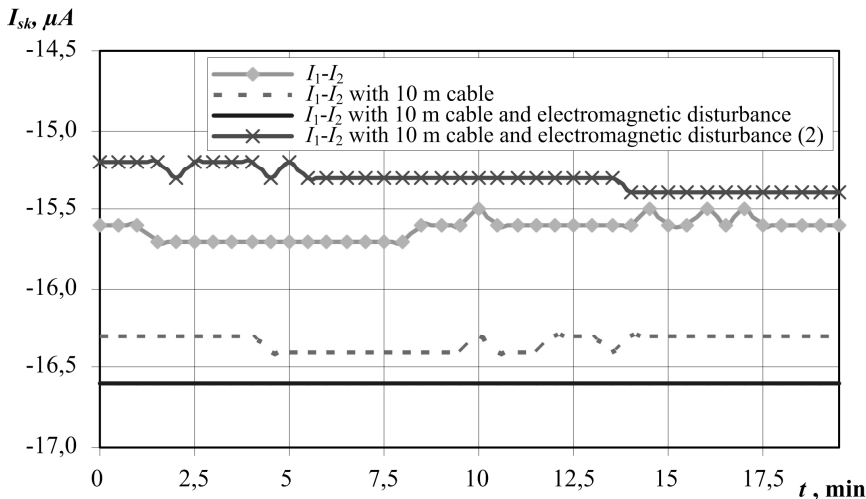


Fig. 4. Dependence of currents difference on time

requirements of laboratory and monitoring equipment in all scenarios; when simply connecting sensors, when connecting them with long twisted pair cables and when exposing them with an electromagnetic interference. Measured disbalance voltage value over time has shown that the experimental scheme is only suitable for deformation monitoring equipment. The scheme for the laboratory test equipment should be made using other, more stable current sources.

General Conclusions

1. Balancing Wheatstone's bridge devices while using type R-2R digital-to-analog converters is superior to unbalanced bridge method when it is used for small resistance change detection. This is due to less sensitivity to voltage supply, inaccuracies caused by interferences that are compensated by the closed automated system. Also the value and change of connection cables resistance or discrepancies in intensifying amplifier's coefficient have no influence to strain detection results.

2. There new scheme of balanced currents for constructions strains monitoring using two and one digital control current sources was proposed, created and analyzed. Mathematical equations of the change in achieved codes and gauge resistance (strain size) were obtained while the current of one or the other arm was regulated. The obtained results enable to detect the required current control bits number in order to receive required resolution. It was confirmed that the easiest option would be to control current of the arm where compensated gauge is switched on which makes the dependence more simple and linear. It was proved that the circuit is less sensitive to drifts of the current source in the scheme with one current source.

3. Two new construction strain monitoring schemes with balancing currents and usage of current digital-to-analog converter were proposed, formed and examined. It was proved that usage of integrated current digital-to-analog converter enables to create simple and flexible devices for construction strain monitoring. The dependences between detected code and gauge's changes were obtained. Depending on the characteristics of the examinable material it is optional to choose the value of gauge's supply current, the range of strain change and resolution.

4. Computer simulation of proposed method for strain monitoring using balancing currents confirmed the theoretical findings. It was shown that while balancing currents the achieved digital codes are proportional to change of resistances (construction strains). Also resistance change range is guaranteed at $\pm 28\%$ for balancing currents and 8 bits digital-to-analog converter was used for monitoring and 10 bits was used for laboratory equipment.

5. Computer simulation results show that the change of the gauges temperature when the identity coefficient between the gauge temperature is 0.5 disbalance voltage deviation does not exceed the maximum value of the deviation of given temperature range from -18 to $+30$ °C, and the coefficients between 0.85 and 1.15 disbalance voltage deviation do not exceed the maximum value of the deviation of given temperature range from -30 to $+30$ °C range. These results allow selecting of measurement schemes with single compensation gauge for all channels in particular cases.

6. The proposed new balancing construction strain detection scheme with two digital control current sources is fully automated and superior to the commonly used strain detection equipment with unbalanced Wheatstone bridge methods. The current change is directly proportional to a change of strain gauge resistance. Results do not depend on the reference voltage instability and none of the strong industrial electromagnetic interferences generated in 10m length connecting wires had any influence on small resistance change (construction strain) monitoring. Therefore there is a possibility to connect strain gauges with up to 10 m connecting wires from the main strain detection panel.

List of Published Works on the Topic of the Dissertation In the reviewed scientific periodical publications

Masiulionis, R., Kvedaras, V., Kvedaras, R. 2011. Analysis of balancing methods of measurement of small resistance changes. *Elektronika ir elektrotechnika*. 8(114): 3–6. ISSN 1392-1215. (ISI Web of Science).

Masiulionis, R. 2010. Deformacijų matavimo balansuojant sroves metodo tyrimas. „*Mokslas – Lietuvos ateitis = Science – future of Lithuania*“. *Elektronika ir elektrotechnika*. Vilnius: Technika. 2(1): 68–72. ISSN 2029-2341. (IndexCopernicus).

Masiulionis, R. 2011. Elektroninių įrenginių tyrimas deformacijai matuoti. „*Mokslas – Lietuvos ateitis = Science – future of Lithuania*“. *Elektronika ir elektrotechnika*. Vilnius: Technika. 3(1): 63–67. ISSN 2029-2341. (IndexCopernicus).

In the other editions

Kvedaras, V., Kvedaras, R., Masiulionis, R. 2008. Methods of strain measurements in construction monitoring systems. *The 25th International Symposium on Automation and Robotics in Construction (ISARC 2008)*. Vilnius:Technika: 343–349. ISBN 9789955283041. (ISI Proceedings).

Masiulionis, R. 2008. Mažų varžos pokyčių nustatymo balansuojant sroves metodas. *11-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis“*. ELEKTRONIKA IR ELEKTROTECHNIKA. Vilnius: Technika: 32–41. ISBN 9789955283737.

About the author

Ričardas Masiulionis was born in 1982 in Molėtai. In year 2001 he graduated from Molėtai Gymnasium. In 2005 he graduated from Vilnius Gediminas technical university in Electronics faculty and acquired the bachelor's degree in electrical engineering. In 2007 he graduated from Vilnius Gediminas technical university in Electronics faculty and has obtained Master's degree in electrical engineering. 2007–2012 he has been studying for a PhD at Vilnius Gediminas technical university in Department of Electrical Engineering. From 2007 till 2012 he has been working as an assistant at Vilnius Gediminas technical university in Electronics faculty, Department of Electrical Engineering.

MAŽŲ DEFORMACIJŲ STEBĖSENOS ELEKTRONINIŲ ĮRENGINIŲ TYRIMAS

Problemos formulavimas ir darbo aktualumas

Tirtosios sistemos paskirtis – automatinis mažų konstrukcijų deformacijų stebėjimas elektroniniais įrenginiais. Jų pagrindinė funkcija yra stebėti įvairių jau pastatytų statinių ir atskirų konstrukcijų statinę būklę, nes tada galima laiku pastebėti kai deformacijos pasiekia kritines vertes, iš anksto numatyti galimą statinio avariją, imtis atitinkamų priemonių ir išvengti žmonių aukų įvairių stichinių nelaimių metu. Šiems tikslams taikoma įranga (stebėsenos įranga) gali būti paprastesnė, turėti mažesnę skiriamąją gebą, tačiau įgalinanti vykdyti deformacijų stebėjimą daugelyje nutolusių vienas nuo kito konstrukcijų taškų. Naujai suprojektuotų konstrukcijų bandymams atlikti, kai reikia nustatyti tam tikros naujo tipo konstrukcijos patvarumą ir atsparumą veikiančioms jėgoms, nustatyti silpnąsias jų vietas, numatyti tobulinimo ar konstrukcijos sustiprinimo būdus taip pat plačiai taikomi deformacijų matavimai. Įranga deformacijų stebėjimui laboratorijose turi turėti didesnę skiriamąją gebą, dažnai įgalinanti vykdyti deformacijų stebėjimą daugelyje konstrukcijos taškų.

Deformacijų stebėjimo įrenginiai yra naudojami įtempių jutiklių varžos mažų pokyčių proporcingų poslinkiui ar deformacijai ir siekiančių tūkstantąsias procento dalis nustatymams. Iki šiol naudotos sistemos yra brangios, ypač kai tenka vertinti pokyčius daugelyje konstrukcijos taškų. Be to, žinomos sistemos

lauko sąlygomis negarantuoja patikimų rezultatų. Daugumoje žinomų šios srities darbų ir sistemų siekiama įvairiais būdais patobulinti įrenginius, naudojančius nebalansuotą Vitstono tiltelį, ko pasekoje sistema tampa labai sudėtinga ir brangi.

Todėl konstrukcijų deformacijų (varžų mažų pokyčių – naudojant įtempio jutiklius) nustatymas laboratorijose ir stebint eksploatuojamus statinius yra aktualus uždavinys. Įrenginiai, nustatantys deformacijas, turi būti automatiniai, vykdančys matavimus daugelyje sudėtingų konstrukcijų ar statinių dažnai nutolusių vienas nuo kito taškų. Įrenginiai turi turėti galimybę perduoti informaciją į nutolusius valdymo, dispečerinius ar pagalbos centrus. Deformacijos sukelia nedidelius jutiklio varžos pokyčius. Kai betono ar gelžbetonio konstrukcijų deformacija sukelia 3–6 % jutiklio pokytį, konstrukcija dažniausia pradeda irti. Jeigu šis varžos diapazonas dalinamas į 100 (stebėsenos įrangai) ar 1000 (laboratorinei įrangai) dalių, gaunama, kad įrangos skiriamoji geba turi sudaryti 0,03–0,06 % ar 0,003–0,006 % jutiklio vardinės vertės. Įvertinant, kad deformacijų nustatymo įranga turi būti automatinė ir daugiataškė, matoma, kad yra daug spręstinių problemų.

Tyrimų objektai

Darbo tyrimo objektai yra:

- deformacijų kodo bei diapazono išraiškų išvedimas automatiniais balansuojamų tiltelių įrenginiams;
- naujų automatinių daugelio taškų konstrukcijų deformacijų stebėjimo balansuojant sroves įrenginių sudarymas bei eksperimentinis tyrimas.

Darbo tikslas

Darbo tikslas – mažų deformacijų stebėsenos automatinių daugiataškių elektroninių įrenginių naujų struktūrinių schemų sukūrimas bei jų tyrimas.

Darbo uždaviniai

Darbo tikslui pasiekti darbe reikia spręsti šiuos uždavinius:

1. Atlikti mažų deformacijų stebėsenos elektroninių įrenginių metodų palyginamą analizę.
2. Nustatyti ryšį tarp balansavimo kodo ir nustatomos deformacijos (varžų mažų pokyčių) diapazono balansuojamų Vitstono tiltelių įrenginiuose.
3. Pasiūlyti mažų deformacijų stebėjimo automatinių daugiataškių elektroninių įrenginių ir nustatymo įrenginių naujas struktūrines schemas. Atlikti jų analizę, kompiuterinį modeliavimą ir ištirti jų savybes.

4. Atlikti pasiūlytų mažų deformacijų stebėjimo naujų elektroninių įrenginių pagrindinių mazgų eksperimentinį tyrimą.

Tyrimų metodika

Darbe taikomi analitiniai, skaitmeniniai ir eksperimentinio tyrimo metodai. Varžų mažų pokyčių identifikavimo sistemos variantai analizuojami analitiniais metodais. Pasiūlytos naujos konstrukcijų deformacijoms nustatyti balansuojant srovės struktūros analizuojamos analitiniais metodais. Kompiuteriniam imitavimui naudojami skaitmeniniai programavimo paketai „Electronics Workbench“ ir „Multisim 11.0“. Sistemos veikimo ir pagrindinių parametrų nustatymui sukonstruotas laboratorinis maketas tiriamas eksperimentiniu metodu.

Darbo mokslinis naujumas

Rengiant disertaciją buvo gauti šie elektros ir elektronikos inžinerijos mokslui nauji rezultatai:

1. Išvestos varžų mažų pokyčių (konstrukcijų deformacijų) daugiataškio nustatymo naudojant balansuojamą Vitstono tiltelį balansavimo kodo priklausomybės nuo jutiklio varžos pokyčio ir jutiklių varžų pokyčių nustatymo diapazono išraiškos.
2. Pasiūlytas naujas konstrukcijų deformacijų automatinio daugiataškio stebėjimo balansuojant srovės įrenginys, sudaryta ir ištirta įrenginio su dviem srovės šaltiniais struktūra.
3. Sudaryta ir ištirta nauja konstrukcijų deformacijų daugiataškio stebėjimo balansuojant srovės su vienu srovės šaltiniu struktūra.
4. Sudarytos naujos konstrukcijų deformacijų automatinio daugiataškio stebėjimo balansuojant srovės struktūros naudojant skaitmeninius-analoginius keitiklius su srovės išėjimu.

Darbo rezultatų praktinė reikšmė

Pasiūlyti sprendimai leidžia mažų varžų pokyčių ir konstrukcijų deformacijų daugiataškiams stebėjimams naudoti paprastesnės struktūros įrenginius. Pasiūlyti sprendimai gali būti naudojami mechaninių, aviacijos konstrukcijų deformacijoms tirti ir stebėti, pritaikyti ir kitų parametrų (slėgio, masės, svorio ir t. t.) nustatymams.

Ginamieji teiginiai

1. Naujas varžų mažų pokyčių daugiataškio nustatymo balansuojant srovės su dviem srovės šaltiniais įrenginys skirtas daugiataškiams deformacijų stebėjimams, o jutikliai gali būti nutolę iki 10 m nuo pagrindinio įrenginio.

2. Naujas varžų mažų pokyčių daugiataškio nustatymo su vienu srovės šaltiniu įrenginys leidžia supaprastinti tyrimų įrenginius, sumažinti aplinkos sąlygų įtaką deformacijų stebėsenos rezultatams ir tinka tiek laboratorinei, tiek ir stebėsenos įrangai.
3. Pasiūlyti įrenginiai leidžia pasiekti stebimų deformacijų diapazoną iki $\pm 30\%$, naudojant mažesnius trimis skiltimis skaitmeninius-analoginius keitiklius lyginant su balansuojamo tiltelio įrenginiais ir mažesnius 8–12 skilčių skaitmeninius-analoginius keitiklius lyginant su nebalansuojamo tiltelio įrenginiais, sumažinti trukdžių ir triukšmų įtaką nustatymo rezultatams.

Darbo rezultatų aprobavimas

Disertacijos tematika atspausdinti penki moksliniai straipsniai: vienas – moksliniame žurnale, įrašytame į ISI Web of Science duomenų bazę, vienas – moksliniame žurnale, įrašytame į ISI Proceedings duomenų bazę, du – moksliniuose žurnaluose, įrašytuose į Copernicus duomenų bazę, vienas – kitame recenzuojamame mokslo leidinyje.

Darbo rezultatai pristatyti ir aptarti 8-iose mokslinėse konferencijose, iš kurių 5 tarptautinės konferencijos ir 3 respublikinės.

Disertacijos struktūra

Disertacijoje yra 112 puslapių, 48 paveikslai, 2 lentelės ir 82 numeruotos formulės. Rašant disertaciją panaudoti 65 literatūros šaltiniai.

Disertaciją sudaro reziumė, įvadas, keturi skyriai, rezultatų apibendrinimas, naudotos literatūros ir autoriaus publikacijų disertacijos tema sąrašai.

Įvadiniame skyriuje nagrinėjamas problemos aktualumas, formuluojamas darbo tikslas ir uždaviniai, pristatomi autoriaus pranešimai ir publikacijos, pateikiama disertacijos struktūra.

Pirmajame skyriuje pateikta literatūros apžvalga. Jame analizuojami praktikoje naudojami deformacijų nustatymo metodai, pateikiami jų privalumai ir trūkumai, galimybės naudoti šiuos metodus automatizuotose sistemose. Skyriaus pabaigoje formuluojamos išvados.

Antrajame skyriuje pateikti balansuojamų konstrukcijų deformacijų nustatymo būdai. Yra atlikta balansuojamo Vitstono tiltelio metodo analizė. Pateiktas naujas deformacijų stebėjimo balansuojant srovės metodas ir atlikta jo analizė. Jame išskiriami du galimi būdai: su dviem srovės šaltiniais ir su vienu srovės šaltiniu. Pastarajame būde išskiriami pranašumai, kurie sumažina triukšmų ir trukdžių įtaką nustatymo rezultatams.

Trečiajame ir ketvirtajame skyriuose pateikti kompiuterinio modeliavimo ir eksperimentinių tyrimų rezultatai. Buvo sumodeliuotas ir praktiškai patikrintas pasiūlyto srovės balansavimo metodo praktinis veikimas. Patikrintas įrenginių stabilumas ir jų darbas imituojant realias sąlygas.

Bendrosios išvados

1. Balansuojamo Vitstono tiltelio su R-2R tipo skaitmeniniais-analoginiais keitikliais įrenginiai varžos mažų pokyčių nustatymui yra pranašesni už nebalansuojamo tiltelio įrenginius, nes jie yra nejautrūs maitinimo įtampos nestabilumui. Trukdžių įnešamos klaidos dažnai yra kompensuojamos uždaroje automatinėje sistemoje, deformacijų nustatymo rezultatams neturi įtakos jungiamųjų kabelių varžos dydis ir jų pokyčiai bei stiprintuvo stiprinimo koeficiento nustatymo netikslumai.
2. Pasiūlyta, sudaryta ir ištirta nauja srovių balansavimo konstrukcijų deformacijų stebėsenos struktūrinė schema su dviem ir su vienu skaitmeninio reguliavimo srovės šaltiniais. Nustatytos balansavimo procese gautų kodų verčių ir jutiklio varžos (deformacijų dydžių) pokyčio, kai reguliuojamos vienos arba kitos šakos srovės, matematinės išraiškos. Gautos išraiškos leidžia nustatyti reikiamą srovės reguliavimo skilčių skaičių tam, kad gauti užduotą skiriamąją gebą. Nustatyta, kad paprastesnė išraiška ir tiesinė priklausomybė gaunama, kai srovė yra reguliuojama šakoje, kurioje yra įjungtas kompensacinis jutiklis, todėl tikslinga reguliuoti šią srovę. Parodyta, kad schema su vienu srovės šaltiniu yra mažiau jautri srovės šaltinio dreifams.
3. Pasiūlytos, sudarytos ir ištirtos dvi naujos srovių balansavimo konstrukcijų deformacijų stebėsenos schemas su srovės skaitmeniniais-analoginiais keitikliais, turinčios žymiai didesnes galimybes: leidžiančios programiniu būdu keisti žadinimo srovės dydį, skiriamąją gebą ir stebimų deformacijų diapazoną.
4. Kompiuterinis pasiūlyto konstrukcijų deformacijų nustatymo metodo balansuojant srovės schemas imitavimas patvirtino teorines išvadas, parodo, kad balansuojant srovės gaunami skaitmeniniai kodai proporcingi varžų (t. y. konstrukcijų deformacijų) pokyčiams, užtikrinamas $\pm 28\%$ varžų pokyčių nustatymo diapazonas srovių balansavimui naudojant 8 skilčių skaitmeninius-analoginius keitiklius stebėsenai ir 10 skilčių – laboratorinei įrangai.
5. Kompiuterinio modeliavimo rezultatai parodo, kad kintant jutiklių temperatūrai, kai tapatumo koeficientas tarp jutiklių temperatūrų yra 0,5 disbalanso įtampos nuokrypa neviršys užduotos nuokrypos maksimalios vertės temperatūrų nuo -18 iki $+30$ °C diapazone, o prie koeficientų tarp

0,85 ir 1,15 disbalanso įtampos nuokrypa neviršys užduotos nuokrypos maksimalios vertės temperatūrų diapazone nuo -30 iki $+30$ °C diapazone. Šie rezultatai konkrečiais atvejais leidžia pasirinkti matavimo schemas su vienu kompensaciniu jutikliu visiems kanalams.

6. Pasiūlyta nauja balansuojama konstrukcijų deformacijų nustatymo schema su dviem skaitmeninio reguliavimo srovės šaltiniais yra pilnai automatizuojama ir pranašesnė už praktikoje dažnai naudojamus deformacijų nustatymo įrenginius su nebalansuojamo Vitstono tiltelio metodais. Joje srovės pokytis yra tiesiogiai proporcingas įtempio jutiklio varžos pokyčiui, nustatymo rezultatai nepriklauso nuo atraminės įtampos nestabilumo, o stiprūs pramoniniai elektromagnetiniai trukdžiai, generuoti 10 m ilgio jutiklių prijungimo laiduose, neturi įtakos varžų mažų pokyčiams (konstrukcijų deformacijų nustatymo rezultatams). Todėl nutolusius nuo pagrindinės deformacijų nustatymo plokštės įtempių jutiklius galima prijungti iki 10 m jungimo kabeliais.

Trumpos žinios apie autorių

Ričardas Masiulionis gimė 1982 m. Molėtuose. 2001 m. baigė Molėtų gimnaziją. 2005 m. baigė bakalauro studijas Vilniaus Gedimino technikos universitete Elektronikos fakultete ir įgijo elektros inžinerijos bakalauro kvalifikacinį laipsnį. 2007 m. baigė magistro studijas Vilniaus Gedimino technikos universiteto Elektronikos fakultete ir įgijo elektros inžinerijos magistro kvalifikacinį laipsnį. 2007–2012 m. studijavo doktorantūroje Vilniaus Gedimino technikos universiteto Elektrotechnikos katedroje. Nuo 2007 iki 2012 m. dirba asistentu Vilniaus Gedimino technikos universiteto Elektronikos fakultete Elektrotechnikos katedroje.

Ričardas MASIULIONIS

RESEARCH OF ELECTRONIC
DEVICES FOR MONITORING OF SMALL STRAINS

Summary of Doctoral Dissertation
Technological Sciences, Electrical and Electronic Engineering (01T)

Ričardas MASIULIONIS

MAŽŲ DEFORMACIJŲ STEBĖSENOS
ELEKTRONINIŲ ĮRENGINIŲ TYRIMAS

Daktaro disertacijos santrauka
Technologijos mokslai, elektros ir elektronikos inžinerija (01T)

2012 12 28. 1,5 sp. I. Tiražas 70 egz.
Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
<http://leidykla.vgtu.lt>
Spausdino UAB „Ciklonas“
J. Jasinskio g. 15, 01111 Vilnius