Unconventional double-current circuit – accuracy measures and application in two-parameter measurement

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Abstract- In this paper some interesting and novel features of a four-terminal (4T) network are presented. A single DC current source is switched over and connected in turns to opposite arms of the four-element bridge circuit. This two-voltage-output circuit is called a double current bridge. The output voltages are dependent on the arm resistance increments and their values are given in absolute and relative units. The accuracy measures (limited errors and standard uncertainties) of two transfer functions are presented. A simple application with two sensors acting as strain gauges and RTD's is presented. The simplified signal conditioning formulas of two-parameter measurement of strain and temperature of a cantilever beam are discussed. Some results achieved with the use of the circuit are presented.

I. Introduction

Wheatstone's bridge is one of basic and well known measurement tool. This circuit, equipped with additional elements of modern technology such as analog-to-digital converter (ADC) or microprocessor systems provides great accuracy and speed of conducted measurement [3], [5]. Most of those systems are based on measuring one quantity. However, a group of measurement methods which are used to measure several quantities at the same time is also worth noticing [1], [4], [8], [9]. A system measuring immittance variation, based on simultaneous measurement of two parameters of resistance increments in a four-terminal (4T) network, can be an example [2], [7], [8]. Two types of such conditioning and analog signal measurement are presented in literature [9]. One of them is a double circuit of two four-arm classic bridges connected in cascade.
As far as the authors know, the proposed bridge circuit and its application (measurement of two quantities) is novel. The authors of the article have not come across a work describing an accuracy analysis for two simultaneously measured parameters. The two-component approach [10] of describing the bridge circuit accuracy (limited errors and standard uncertainties) is used.

II. Unconventional double-current circuit and the parameters

The simple relations in a double current bridge are described.

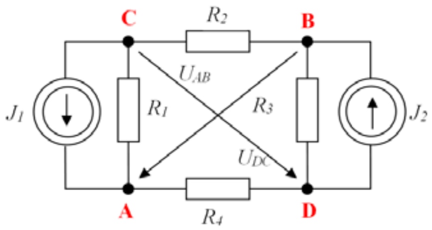


Figure 1. Double current bridge (2J) - theoretical circuit [6].

As shown in Fig. 1, a double current bridge is supplied by two equal current sources $J=J_1=J_2$. The output voltages of the bridge are:

$$U_{AB} = J\frac{R_1R_4 - R_2R_3}{\sum R_i} \equiv J\ r_{AB}(\varepsilon_i), \qquad (1)$$

$$U_{DC} = J \frac{R_1 R_2 - R_3 R_4}{\sum R_i} \equiv J \ r_{DC}(\varepsilon_i), \qquad (2)$$

where: $\sum R_i = R_1 + R_2 + R_3 + R_4, r_{DC}, r_{AB}$ - open-circuit voltage to current parameters of D-C and A-B outputs. In further analysis, it is assumed that resistances R_i in the bridge are variables and are represented by equation:

$$R_i = R_{i0}(1 + \varepsilon_i), \qquad (3)$$

where R_{i0} - initial (nominal) resistances, ε_i - relative increments of resistances (i=1, 2, 3, 4).
Bridge transfer functions (1), (2) can be simplified to products of their initial sensitivities t_0', t_0" in the balance and normalized unbalance functions $f'(\varepsilon_i)$, $f''(\varepsilon_i)$. Their formulas can be expressed by initial values R_{i0} and increments of all resistances, i.e. $R_i=R_{i0}(1+\varepsilon_i)$ and R_{i0} referencing to one of the first arm, i.e.: $R_{20} \equiv mR_{10}$, $R_{40} \equiv nR_{10}$ and $R_{30}' = (m/n)R_{10}$ or $R_{30}'' = (n/m)R_{10}$, as is shown in Table 1. It results from two balance states of this bridge-circuit.

Table 1. Open-circuit voltage to current parameters in function of relative increments of resistance

Circuit with arbitrary R_i	Open-circuit voltage to current parameters of A-B and D-C outputs (r_{AB}, r_{CD})	
In balance: $r_{AB0} = 0$ $R_{10} \cdot R_{40} = R_{20} \cdot R_{30}$ $R_{20}=mR_{10}, R_{40}=nR_{10}$ $R_{30}' = (m/n)R_{10}$ **or** $r_{CD0} = 0$ $R_{10} \cdot R_{20} = R_{30} \cdot R_{40}$ $R_{20}=mR_{10}, R_{40}=nR_{10}$ $R_{30}'' = (n/m)R_{10}$	$r_{AB} \equiv \frac{U_{AB}}{J} = \frac{R_1 R_4 - R_2 R_3}{\sum R_i} \equiv t_0' f'(\varepsilon_i)$ (4) where: $t_0' \equiv \frac{m\,n R_{10}}{(m+n)(1+m)}$ $f'(\boldsymbol{\varepsilon}_i) = \frac{\Delta L'(\boldsymbol{\varepsilon}_i)}{1+\varepsilon'_{\Sigma R}}$ $\varepsilon'_{\Sigma R} = \frac{m(m\varepsilon_2 + \varepsilon_1) + n(m\varepsilon_4 + \varepsilon_3)}{(m+n)(1+m)}$ $\Delta L'(\varepsilon_i) = \varepsilon_1 - \varepsilon_2 - \varepsilon_3 + \varepsilon_4 + \varepsilon_1\varepsilon_4 - \varepsilon_2\varepsilon_3$	$r_{CD} \equiv \frac{U_{CD}}{J} = \frac{R_1 R_2 - R_3 R_4}{\sum R_i} \equiv t_0'' f''(\varepsilon_i)$ (5) where: $t_0'' \equiv \frac{m\,n R_{10}}{(m+n)(1+n)}$ $f''(\boldsymbol{\varepsilon}_i) = \frac{\Delta L''(\boldsymbol{\varepsilon}_i)}{1+\varepsilon''_{\Sigma R}}$ $\varepsilon''_{\Sigma R} = \frac{m(n\varepsilon_2 + \varepsilon_3) + n(n\varepsilon_4 + \varepsilon_1)}{(m+n)(1+n)}$ $\Delta L''(\varepsilon_i) = \varepsilon_1 + \varepsilon_2 - \varepsilon_3 - \varepsilon_4 + \varepsilon_1\varepsilon_2 - \varepsilon_3\varepsilon_4$

If the sensors are situated in all arms of the bridge circuit and their nominal resistances are equal and their resistance changes are small (thus $\varepsilon_i\varepsilon_j << \varepsilon_i + \varepsilon_j$ and $\Sigma R_{i0}\varepsilon_i << \Sigma R_{i0}$), the simplified version of the equations can be provided as follows:

$$U_{DC} = t_0''(\varepsilon_1 + \varepsilon_2 - \varepsilon_3 - \varepsilon_4), \qquad (6)$$

$$U_{AB} = t_0'(\varepsilon_1 - \varepsilon_2 - \varepsilon_3 + \varepsilon_4). \qquad (7)$$

III. Accuracy measures

Assume that open-circuit voltage to current parameters r_{AB}, r_{CD} constist of two components. The parameters r_{AB0}, r_{DC0} are initial values and Δ_{rAB}, Δ_{rCD} are the increments of r_{AB}, r_{CD}.

$$r_{AB} = r_{AB0} + \Delta_{r\,AB} \qquad (8)$$

$$r_{CD} = r_{CD0} + \Delta_{rCD} \qquad (9)$$

Then one can modify equations (1) and (2) as follows:

$$U_{AB} = J(r_{AB0} + \Delta_{r\,AB}) \equiv U_{AB0} + J\,t_0' f'(\varepsilon_i), \qquad (10)$$

$$U_{CD} = J(r_{CD0} + \Delta_{r\,CD}) \equiv U_{CD0} + J\,t_0'' f''(\varepsilon_i). \qquad (11)$$

Actual (absolute) errors of parameters r_{AB0} and r_{DC0} are related to initial sensitivities t_0', t_0". The relative errors δ_{rAB0}, δ_{rCD0} are the functions of algebraic sum of the initial (zero) errors of all the resistances [10]

$$\delta_{rAB0} \equiv \frac{\Delta_{rAB0}}{t_0'} = \delta_{10} - \delta_{20} - \delta_{30} + \delta_{40}, \qquad (12)$$

$$\delta_{rCD0} \equiv \frac{\Delta_{rCD0}}{t_0''} = \delta_{10} + \delta_{20} - \delta_{30} - \delta_{40}. \tag{13}$$

Actual relative errors δ_{Ri} of resistances can be expressed by initial errors δ_{i0} and errors $\delta_{\varepsilon i}$ of their increments

$$\delta_i \equiv \frac{\Delta_i}{R_{i0}} = \delta_{i0}\left(1+\varepsilon_i\right) + \Delta_{\varepsilon i} = \delta_{i0}\left(1+\varepsilon_i\right) + \varepsilon_i \delta_{\varepsilon i}, \tag{14}$$

$$\delta_{Ri} \equiv \frac{\Delta_i}{R_i} = \delta_{i0} + \frac{\Delta_{\varepsilon i}}{1+\varepsilon_i} = \delta_{i0} + \frac{\varepsilon_i}{1+\varepsilon_i}\delta_{\varepsilon i}. \tag{15}$$

Actual (absolute) errors of parameters r_{AB} and r_{DC} are also related to initial sensitivities t_0', t_0":

$$\delta_{rAB} \equiv \frac{\Delta_{rAB}}{t_0'}, \tag{16}$$

$$\delta_{rCD} \equiv \frac{\Delta_{rCD}}{t_0''}. \tag{17}$$

Their equations are more complicated. Actual values of measurement errors of bridge transfer functions r_{AB} and r_{CD} result from the total differential of analytical equations (4) and (5) from Table 1. After ordering all components of actual errors δ_{Ri} of resistances R_i one can estimate absolute errors Δr_{AB} (20a) and Δr_{CD} (20b). Then with (14- 17) the following accuracy measures can be expressed:

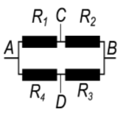
- relative actual errors (21a) and (21b),
- relative limited errors (22a) and (22b),
- random (mean square) measures (23a) and (23b).

All the accuracy measures are ordered in Table 2. Additionally, actual errors of increments r_{AB}-r_{AB0} and r_{CD}-r_{CD0} are defined. They were related to r_{AB} and r_{CD} parameters as follows:

$$\delta_{rAB\,r} \equiv \frac{\Delta_{rAB} - \Delta_{rAB\,0}}{r_{AB}} = \frac{t_0'\delta_{rAB} - t_0'(\delta_{10} - \delta_{20} - \delta_{30} + \delta_{40})}{t_0' f'(\boldsymbol{\varepsilon}_i)} = \frac{\delta_{rAB} - (\delta_{10} - \delta_{20} - \delta_{30} + \delta_{40})}{f'(\boldsymbol{\varepsilon}_i)}, \tag{18}$$

$$\delta_{rCD\,r} \equiv \frac{\Delta_{rCD} - \Delta_{rCD\,0}}{r_{CD}} = \frac{\delta_{rCD} - (\delta_{10} + \delta_{20} - \delta_{30} - \delta_{40})}{f''(\boldsymbol{\varepsilon}_i)}. \tag{19}$$

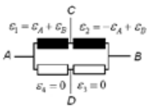
Table 2. Accuracy measures of the voltage to current parameters of 2J bridge in general case.

Parametera of circuit	Measure	Accuracy measures δ_{rAB}, $\lvert\delta_{rAB}\rvert$, $\bar{\delta}_{rAB}$ of r_{AB}	Accuracy measures δ_{rCD}, $\lvert\delta_{rCD}\rvert$, $\bar{\delta}_{rCD}$ of r_{CD}
General case	Actual errors: absolute and relative	$\Delta_{rAB} = R_1 \frac{R_4 - r_{AB}}{\Sigma R_i}\delta_{R1} - R_2 \frac{R_3 + r_{AB}}{\Sigma R_i}\delta_{R2} - R_3 \frac{R_2 + r_{AB}}{\Sigma R_i}\delta_{R3} + R_4 \frac{R_1 - r_{AB}}{\Sigma R_i}\delta_{R4}$ (20a)	$\Delta_{rCD} = R_1 \frac{R_2 - r_{CD}}{\Sigma R_i}\delta_{R1} + R_2 \frac{R_1 - r_{CD}}{\Sigma R_i}\delta_{R2} - R_3 \frac{R_4 + r_{CD}}{\Sigma R_i}\delta_{R3} - R_4 \frac{R_3 + r_{CD}}{\Sigma R_i}\delta_{R4}$ (20b)
 $R_1=R_{10}(1+\varepsilon_1)$ $R_2=R_{20}(1+\varepsilon_2)$ $R_3=R_{30}(1+\varepsilon_3)$ $R_4=R_{40}(1+\varepsilon_4)$ $\varepsilon_i \geq -1$		$\delta_{rAB} \equiv \frac{\Delta_{rAB}}{t_0'} = \sum_{i=1}^{4} w'_{Ri}\delta_{Ri} = \sum_{i=1}^{4} w'_{Ri}(\delta_{i0} + \frac{\varepsilon_i}{1+\varepsilon_i}\delta_{\varepsilon i})$ (21a) where: $w'_{R1} = \frac{1+\varepsilon_1}{1+\varepsilon'_{\Sigma R}}\left[(1+\varepsilon_4) - \frac{r_{AB}}{R_{40}}\right]$ $w'_{R2} = -\frac{1+\varepsilon_2}{1+\varepsilon'_{\Sigma R}}\left[(1+\varepsilon_3) + \frac{r_{AB}}{R_{30}}\right]$ $w'_{R3} = -\frac{1+\varepsilon_3}{1+\varepsilon'_{\Sigma R}}\left[(1+\varepsilon_2) + \frac{r_{AB}}{R_{20}}\right]$ $w'_{R4} = \frac{1+\varepsilon_4}{1+\varepsilon'_{\Sigma R}}\left[(1+\varepsilon_1) - \frac{r_{AB}}{R_{10}}\right]$	$\delta_{rCD} \equiv \frac{\Delta_{rCD}}{t_0''} = \sum_{i=1}^{4} w''_{Ri}\delta_{Ri} = \sum_{i=1}^{4} w''_{Ri}(\delta_{i0} + \frac{\varepsilon_i}{1+\varepsilon_i}\delta_{\varepsilon i})$ (21b) where: $w''_{R1} = \frac{1+\varepsilon_1}{1+\varepsilon''_{\Sigma R}}\left[(1+\varepsilon_2) - \frac{r_{CD}}{R_{40}}\right]$ $w''_{R2} = \frac{1+\varepsilon_2}{1+\varepsilon''_{\Sigma R}}\left[(1+\varepsilon_1) - \frac{r_{CD}}{R_{30}}\right]$ $w''_{R3} = -\frac{1+\varepsilon_3}{1+\varepsilon''_{\Sigma R}}\left[(1+\varepsilon_4) + \frac{r_{CD}}{R_{20}}\right]$ $w''_{R4} = -\frac{1+\varepsilon_4}{1+\varepsilon''_{\Sigma R}}\left[(1+\varepsilon_3) + \frac{r_{CD}}{R_{10}}\right]$
	Limited errors	$\lvert\delta_{rAB}\rvert = \sum_{i=1}^{4}\lvert w'_{Ri}\rvert\,\lvert\delta_{Ri}\rvert = \sum_{i=1}^{4}\lvert w'_{Ri}\rvert\left(\lvert\delta_{i0}\rvert + \frac{\lvert\varepsilon_i\rvert}{1+\varepsilon_i}\lvert\delta_{\varepsilon i}\rvert\right)$ (22a)	$\lvert\delta_{rCD}\rvert = \sum_{i=1}^{4}\lvert w''_{Ri}\rvert\,\lvert\delta_{Ri}\rvert = \sum_{i=1}^{4}\lvert w''_{Ri}\rvert\left(\lvert\delta_{i0}\rvert + \frac{\lvert\varepsilon_i\rvert}{1+\varepsilon_i}\lvert\delta_{\varepsilon i}\rvert\right)$ (22b)

	Random measures	$\bar{\delta}_{rAB} = \sqrt{\sum_{i=1}^{4} w_{Ri}^{'2}\, \bar{\delta}_{Ri}^{2}} = \sqrt{\sum_{i=1}^{4} w_{Ri}^{'2}\left(\bar{\delta}_{i0}^{2} + \frac{\varepsilon_i^2}{(1+\varepsilon_i)^2}\bar{\delta}_{\varepsilon i}^{2}\right)}$ (23a) correlation coefficient k_{ij}=0		$\bar{\delta}_{rCD} = \sqrt{\sum_{i=1}^{4} w_{Ri}^{"2}\, \bar{\delta}_{Ri}^{2}} = \sqrt{\sum_{i=1}^{4} w_{Ri}^{"2}\left(\bar{\delta}_{i0}^{2} + \frac{\varepsilon_i^2}{(1+\varepsilon_i)^2}\bar{\delta}_{\varepsilon i}^{2}\right)}$ (23b) correlation coefficient k_{ij}=0		
Measures for r_{AB0}=0	Actual errors	$\delta_{rAB0} = \delta_{10} - \delta_{20} - \delta_{30} + \delta_{40}$	Limited errors	$\left\|\delta_{rAB0}\right\|_m = \sum \left\|\delta_{i0}\right\|$ (24a)	Mean square measures k_{ij}=0	$\bar{\delta}_{rAB0} = \sqrt{\sum \bar{\delta}_{i0}^{2}}$ (25a)
Measures for r_{CD0}=0		$\delta_{rCD0} = \delta_{10} + \delta_{20} - \delta_{30} - \delta_{40}$		$\left\|\delta_{rCD0}\right\|_m = \sum \left\|\delta_{i0}\right\|$ (24b)		$\bar{\delta}_{rCD0} = \sqrt{\sum \bar{\delta}_{i0}^{2}}$ (25b)

Actual (26a, 26b, 28a, 28b) and limited (27a, 27b, 29a, 29b) relative errors for the circuit with two sensors (with two resistances R_1 and R_2 variable) is shown in Table 3. All of errors depend on the two increments ε_A and ε_B (what represent two measured quantities A and B). They are also the functions of δ_{i0} (zero errors) and $\delta_{\varepsilon i}$ (gain errors) of resistors and sensors. This is novelty in defining of the accuracy measures in two parameter (2D) measurement.

Table 3. Accuracy measures of the voltage to current parameters of 2J bridge if all arm initial resistances are equal and two increments of resistance variable.

Parameters of circuit	Miary R_i	Related accuracy measures of bridge of r_{AB}, r_{CD}	
		related to initial sensitivities t_0' or t_0''	of increments r_{AB}-r_{AB0} and r_{CD}-r_{CD0}
ΔR_1 and ΔR_2 variable	arbitrary	$\delta_{r\,AB} = \frac{4-2\varepsilon_A+6\varepsilon_B}{4(1+\varepsilon_B)}(\delta_{10}-\delta_{20}-\delta_{30}) + \frac{4+2\varepsilon_A+6\varepsilon_B}{4(1+\varepsilon_B)}\delta_{40} + \frac{\varepsilon_A+\varepsilon_B}{1+\varepsilon_B}\delta_{\varepsilon 1} + \frac{\varepsilon_A-\varepsilon_B}{1+\varepsilon_B}\delta_{\varepsilon 2}$ (26a)	$\delta_{r\,ABr} = \frac{2+\varepsilon_B}{4\varepsilon_A}\left[\frac{3-2\varepsilon_A+6\varepsilon_B}{4(1+\varepsilon_B)}(\delta_{10}-\delta_{20}-\delta_{30}) + \frac{3+2\varepsilon_A+6\varepsilon_B}{4(1+\varepsilon_B)}\delta_{40} + \frac{\varepsilon_A+\varepsilon_B}{1+\varepsilon_B}\delta_{\varepsilon 1} + \frac{\varepsilon_A-\varepsilon_B}{1+\varepsilon_B}\delta_{\varepsilon 2}\right]$ (26b)
$\varepsilon_1 = \varepsilon_A + \varepsilon_B$, $\varepsilon_2 = -\varepsilon_A + \varepsilon_B$, $\varepsilon_3 = 0$, $\varepsilon_4 = 0$, $\varepsilon_A^2 \approx 0$, $\varepsilon_B^2 \approx 0$, $\varepsilon_A\, \varepsilon_B \approx 0$.	if $\left\|\delta_{i0}\right\| = \left\|\delta_0\right\|$ $\left\|\delta_{\varepsilon 1}\right\| = \left\|\delta_{\varepsilon 2}\right\| \equiv \left\|\delta_{\varepsilon}\right\|$	$\left\|\delta_{r\,AB}\right\| = \frac{4+2\left\|\varepsilon_A\right\|+6\left\|\varepsilon_B\right\|}{1+\left\|\varepsilon_B\right\|}\left\|\delta_0\right\| + \frac{2(\left\|\varepsilon_A\right\|+\left\|\varepsilon_B\right\|)}{1+\left\|\varepsilon_B\right\|}\left\|\delta_\varepsilon\right\|$ (27a)	$\left\|\delta_{r\,ABr}\right\| = \frac{2+\left\|\varepsilon_B\right\|}{4\left\|\varepsilon_A\right\|}\left[\frac{3+2\left\|\varepsilon_A\right\|+6\left\|\varepsilon_B\right\|}{1+\left\|\varepsilon_B\right\|}\left\|\delta_0\right\| + \frac{2(\left\|\varepsilon_A\right\|+\left\|\varepsilon_B\right\|)}{1+\left\|\varepsilon_B\right\|}\left\|\delta_\varepsilon\right\|\right]$ (27b)
	arbitrary	$\delta_{rCD} = \frac{1+2\varepsilon_B}{1+\varepsilon_B}(\delta_{10}+\delta_{20}) - (\delta_{30}+\delta_{40}) + \frac{\varepsilon_A+\varepsilon_B}{1+\varepsilon_B}\delta_{\varepsilon 1} + \frac{\varepsilon_B-\varepsilon_A}{1+\varepsilon_B}\delta_{\varepsilon 2}$ (28a)	$\delta_{r\,CDr} = \frac{(2+\varepsilon_B)(\delta_{10}+\delta_{20})}{2(1+\varepsilon_B)} + \frac{2+\varepsilon_B}{4\varepsilon_B}\left[\frac{\varepsilon_A+\varepsilon_B}{1+\varepsilon_B}\delta_{\varepsilon 1} + \frac{\varepsilon_B-\varepsilon_A}{1+\varepsilon_B}\delta_{\varepsilon 2}\right]$ (28b)
$r_{AB} = \frac{R_{10}\;\varepsilon_A}{2+\varepsilon_B}$ $r_{CD} = \frac{R_{10}(2\varepsilon_B-\varepsilon_A^2+\varepsilon_B^2)}{4+2\varepsilon_B}$	if $\left\|\delta_{i0}\right\| = \left\|\delta_0\right\|$ $\left\|\delta_{\varepsilon 1}\right\| = \left\|\delta_{\varepsilon 2}\right\| \equiv \left\|\delta_{\varepsilon}\right\|$	$\left\|\delta_{r\,CD}\right\| = \frac{4+6\left\|\varepsilon_B\right\|}{1+\left\|\varepsilon_B\right\|}\left\|\delta_0\right\| + \frac{2(\left\|\varepsilon_A\right\|+\left\|\varepsilon_B\right\|)}{1+\left\|\varepsilon_B\right\|}\left\|\delta_\varepsilon\right\|$ (29a)	$\left\|\delta_{r\,CDr}\right\| = \frac{2+\left\|\varepsilon_B\right\|}{1+\left\|\varepsilon_B\right\|}\left[\left\|\delta_0\right\| + \frac{(\left\|\varepsilon_A\right\|+\left\|\varepsilon_B\right\|)}{2\left\|\varepsilon_B\right\|}\left\|\delta_\varepsilon\right\|\right]$ (29b)

IV. Two-parameter measurement of strain and temperature change

In order to illustrate the concept of operation of a system measuring two parameters at the same time, a prototype version was worked out. The system presented in Fig. 2 can be used to examine strain in one axis (e.g. x-axis by strain gauge R_1) and temperature (strain gauge or resistance thermometer R_2). Simultaneous measurement of strain in two axes (e.g. x-axis strain gauge R_1, y-axis strain gauge R_2) is another possibility. This type of measurement system can be also applied to measure other quantities which can be measured with the use of resistance parametric sensors.

Possibility of compensation of temperature influence on a measurement strain gauge resistance (without using additional temperature sensors) is also great advantage of such solution. It can be achieved through simultaneous measurement of temperature and resistance of a strain gauge by indirect method, examining appropriate voltage on the diagonals of a double-current bridge.

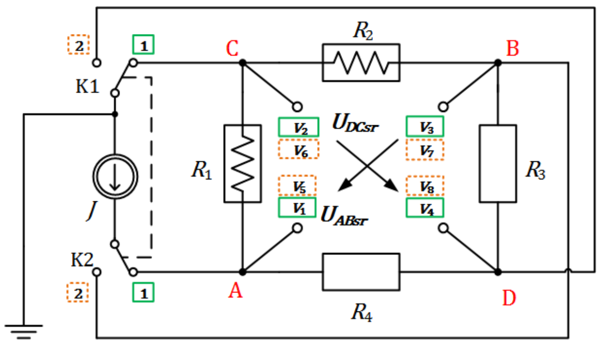


Figure 2. Double current bridge (2x1J). as an input analog part of measurement system (J-current source, R_1, R_2 – sensors, R_3, R_4 – resistors, K1, K2 – electronic switches)

The experimental test on the 2x1J circuit was made. The goal was to measure the real change in temperature of strain gauges in the point of sensor placement and the mechanical stress (deflection of cantilever beam). The circuit was tested with two metal (foil) strain gauges TF-3/120 (Tenmex). Both output voltages are the means of voltages measured in two cycles [2]

$$U_{DCsr} = 0.5t_0''(\varepsilon_1 + \varepsilon_2), \tag{30}$$

$$U_{ABsr} = 0.5t_0'(\varepsilon_1 - \varepsilon_2). \tag{31}$$

The changes in resistance of strain gauges consist of two components: $\varepsilon_1 = \varepsilon_A + \varepsilon_B$, $\varepsilon_2 = -\varepsilon_A + \varepsilon_B$, respectively. One of them is the increment of temperature change ΔT, the other one is the increment (or decrement) of mechanical stress caused by bending force F_B. Using two identical strain gauges in a bridge, indicates the same sign and value of the relative increments in temperature. If one gauge is compressed (Fig. 3) and the other one is stretched at the same time, the increments of the mechanical stress have the opposite signs.

$$\varepsilon_1^{'}(\Delta T) = \varepsilon_2^{'}(\Delta T) = \varepsilon_B, \tag{32}$$

$$\varepsilon_1^{''}(e_B) = -\varepsilon_2^{''}(e_B) = \varepsilon_A. \tag{33}$$

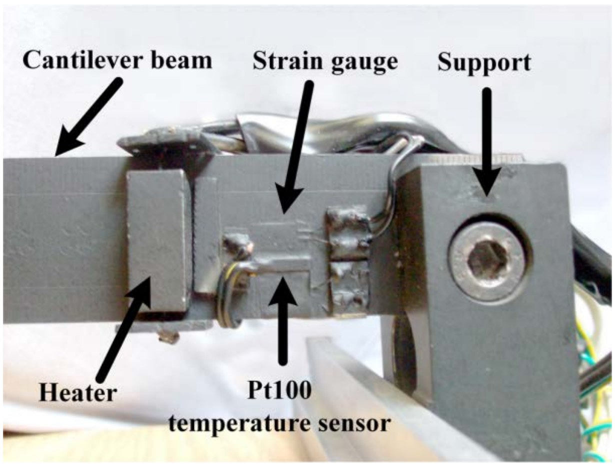


Figure 3. Localization of heater, RTD sensor and strain gauge.

The measurements were taken for several (constant) temperatures of a cantilever beam (20°C, 30°C, 40°C, 60°C) while the beam was bent with the use of micrometer screw in the range from 0 until 10 mm. As shown in Fig. 4 there is a significant influence of rising temperature T on the ε_i intercept. The slope is nearly the same. The reference temperature is 20°C.

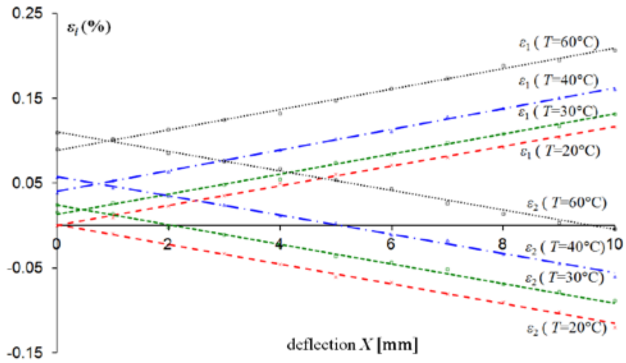


Figure 4. The relative resistance increments ε_1, ε_2 in the function of the beam *X* deflection while temperature *T* is changing

V. Conclusions

The two-component approach of describing the unconventional double-current circuit accuracy is proposed. It has a form of sum of the initial stage and the bridge imbalance accuracy measures (Table 3). Transfer coefficients, their limited errors and standard uncertainties as the functions of relative increments of resistance ε_i are shown for the bridge circuit with two sensors. The application of this circuit in simultaneous measurement of strain and the temperature change is presented. The measurements confirmed that there is linear relationship between and deflection and relative resistance increments of strain gauges (Fig. 4).

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