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Evaluation of Pt100 Sensor Deflection Effect during Strain Measurements

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***Abstract*—The present work concerns description of additional error sources of temperature measurement done with Pt100 sensors placed on the deflected elements. The authors came across certain problems with temperature measurement while working on an original signal conditioner. For this reason it was decided to conduct more measurement experiments. The aim of experiments was to examine the influence of deflection of Pt100 sensors on their resistance changes. In the article a laboratory stand and the procedure of conducting the research are presented.**

***Index Terms*—Temperature sensors, strain measurement, measurement techniques.**

I. INTRODUCTION

This article is a result of research on an electronic circuit which would enable determining resistance increases of the sensors connected to the system, such as: a strain gauge sensor used to measure deflection or a Pt100 sensor used to measure temperature. The constructed signal conditioner has been described previously in [1] and as a similar circuit in [2]. It has two current sources (J_1 and J_2) which power the system continuously, and four resistance sensors (R_1, R_2, R_3 and R_4) connected into a four-armed bridge (Fig. 1).

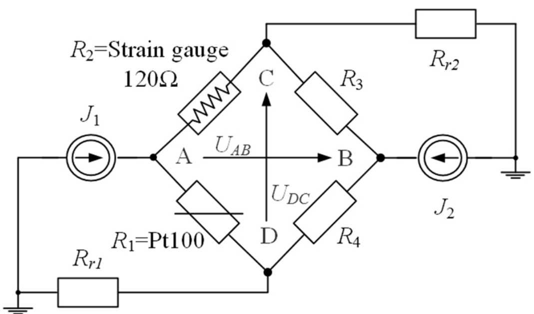

Fig. 1. Two-current-source bridge circuit.

Moreover, two reference resistors (R_{r1} and R_{r2}) were connected to the opposite nodes of the system. It is worth stressing that the current efficiency of the current sources is equal and constant in time. The bridge activity is to measure the potential values in A, B, C and D nodes of the system or the voltages between D-C and A-B nodes. It is easily observable that the value change of one sensor – R_1, R_2, R_3 or R_4 – will cause the change of the voltage difference in nodes A, B, C and D. A system of this configuration works similarly to a Wheatstone bridge circuit with a current supply [3]. Therefore, there is a possibility to change two resistances at the same time in a two-current system, which means that two quantities can be measured simultaneously with the use of a sensor, *e.g.* R_1 sensor can measure deflection and R_2 sensor – temperature.

However, during experiments aimed to confirm the correctness of measurement of the two mentioned non-electrical quantities by the two-current-source bridge circuit, certain difficulties occurred. In the experiment, where the cantilever beam was deflected at given temperature (e.g. 40 °C or 60 °C), unexpected values of temperature were obtained. The occurrence of this deviation caused the authors analyse whether the experiment had been conducted in the appropriate way. First of all, the cantilever beam temperature for different deflections was measured with the use of the non-contact method. A Thermal Imaging Camera NEC Avio InfReC Thermo Gear G100 was used for this purpose. It helped to confirm the temperature stability during experiment (Fig. 2).

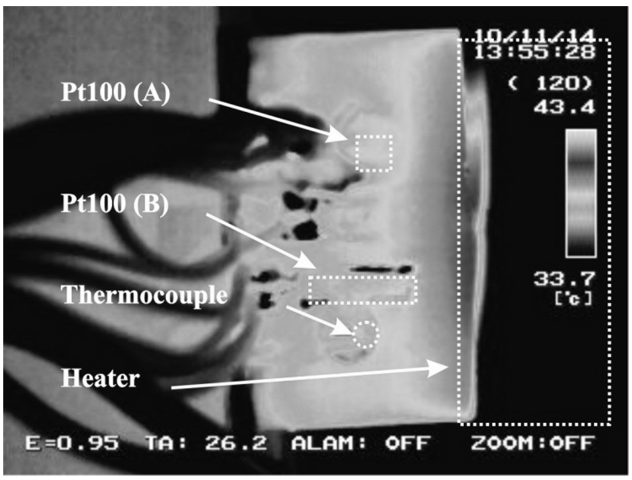

Fig. 2. Thermal image of the cantilever beam (top view) with the sensor position during heating process. In order to obtain clear presentation of temperature distribution around sensors, the heater placed on the right side was covered by a metal shield.

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As the next step of the experiment, the resistance changes of the Pt100 sensor stuck next to the resistance strain gauge in a given constant temperature were examined. It occurred during the test that the deflecting Pt100 sensor (B) changed its resistance, working similarly to a resistance strain gauge.

This unexpected discovery disposed us to write this article where we especially focus on errors caused by inappropriate sticking of sensors on deflecting elements. It is worth stressing that authors did not find any articles about research on Pt100 sensor deflection but the procedure was inspired by testing sensors of other types described in articles [4]–[7].

II. Laboratory Stand

In order to examine the influence of deflection on resistance of the Pt100 sensor, a laboratory stand was created. It consists of three functional modules.

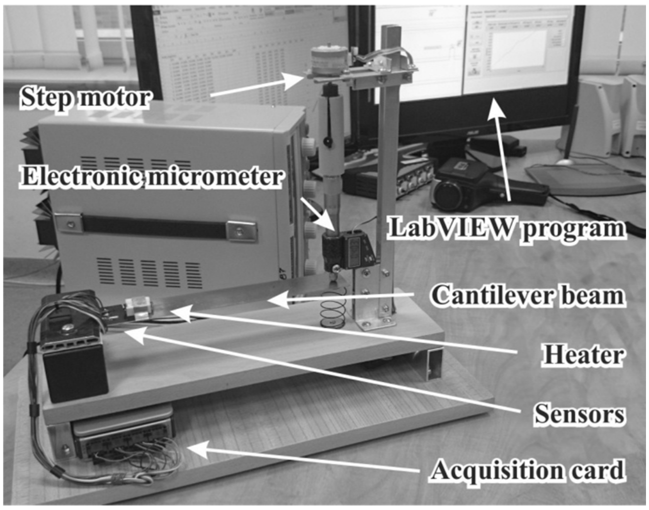

Fig. 3. General view of the laboratory stand.

One of them is a measurement data acquisition system equipped with an NI 9219 data acquisition card. It has 4 channels, sampling rate 100 S/s per channel, analogue input resolution of 24-bits and it supports measurement with the use of thermocouple, RTD and other resistance sensors [8].

Measurement data from sensors placed on the cantilever beam is sent to a PC and processed with the use of software created in the LabVIEW system. It has two functions: data acquisition and processing, which means it converts the value of current resistance of transducers into temperature value. It also records the results on the hard disk as CSV text files. Additionally, the program controls the drive unit of the cantilever beam, which is the other functional module of the measurement stand.

This unit consists of a step motor controlled by an ATmega328 microcontroller, and transistor keys. A digital micrometer with the range from 0 mm to 25 mm, resolution of 0.001 mm and accuracy 0.002 mm is another element of the unit. The step motor drives the micrometer screw which deflects the cantilever beam of a value given by the controlling program. It is worth stressing that the controlling software reads the current position of the deflection position of the cantilever beam from the micrometer with the use of a serial interface.

A steel beam of 250 mm × 40 mm × 1 mm (Fig. 3) is another functional element of the unit. On the top side of it a thermocouple sensor, a strain gauge, a heater constructed on the basis of ceramic resistors of small resistance and two Pt100 sensors of different sizes (Table I) were placed. All sensors were stuck on the beam with high-temperature-resistant glue of the following chemical structure: Bisphenol A + Epichlorohydrin > 50 %, Styrene < 12.5 %) + Triethylenetetramine 10 % (Epidian 53 + Z1).

III. Pt100 Sensors

As it is known, RTD sensors are the elements which react almost linearly to the influence of temperature. They are made of platinum which is a perfect material for sensors because of its high melting point, great temperature coefficient, small chemical activity and stable thermometric characteristics. Additionally, sensors of this type guarantee great precision of temperature measurement, which is about 0.1 °C within the temperature range of 0 °C to 200 °C. Pt100 sensors accepted for this research (Table I) fulfil the IEC 60751 standard and its resistance is 100 Ω at 0 °C and the Temperature Coefficient of Resistance – 0.00385 Ω/Ω/°C within the temperature range 0 °C to 100 °C [9]. The Temperature Coefficient of Resistance was determined experimentally, according to the following equation

$$\sim = \frac{R_{100} - R_0}{100 \cdot R_0} \cdot 10^6, \left[\frac{\text{ppm}}{°\text{C}}\right], \tag{1}$$

where R_0 – the resistance of the sensor at 0 °C, R_{100} – the resistance of the sensor at 100 °C, which equalled: 0.003764 Ω/Ω/°C for sensor A and 0.003775 Ω/Ω/°C for sensor B.

TABLE I. RESISTIVE SENSORS PT-TYPE ON GLASS SUBSTRATE PARAMETERS TAKEN FROM APPLICATION NOTES [10].

RTD type	**Pt100 (A) (PROFFUSE)**	**Pt100 (B) (PROFFUSE)**
Tolerance	class B 0.2 %	class B 0.3 %
Body dimensions	1.7 mm × 2.4 mm × 1.0 mm	9.5 mm × 1.9 mm × 0.9 mm
Operating temperature	-50 °C to 500 °C	-70 °C to 500 °C
Temperature coefficient	3850 ppm/°C	3850 ppm/°C

According to the manufacturer, both sensors comprise within class B, but one of them has smaller deviation error (0.2 %) from the ideal characteristics. It should be stressed that the greater tolerance value, the greater variation of the sensor from the ideal characteristics. The definition of the mentioned class B sensor can be presented as follows

$$\text{class B} = \pm\left(0.3 + 0.005 \cdot T\right), [°\text{C}]. \tag{2}$$

It results from (2) that sensor limited error for 0 °C equals 100 Ω ±0.12 Ω (0.3 °C) and, additionally, we can determine the deviation error from ideal resistance using standardization tables. It equals 138 Ω ±0.3 Ω (0.8 °C) for 100 °C.

IV. MEASUREMENT PROCEDURE

A four-wire method for measuring resistance was used in the measurement procedure. Two wires of this system conduct current to supply the Pt100 sensor and two other wires are used to measure voltage drop on tested resistance. This type of system enables decreasing measurement errors in comparison with a two- or three-wire solution.

During the research, it was also noticed that there is a possibility of self–heating of the sensor caused by the current flowing through it. For this reason, the recommended current value, which cannot be exceeded during tests, is 1 mA. In the experiment described here, the value of the current source equalled 0.5 mA.

During the tests, the cantilever beam, presented in Fig. 3 was additionally covered with a shield (Fig. 4) protecting it from the air movement.

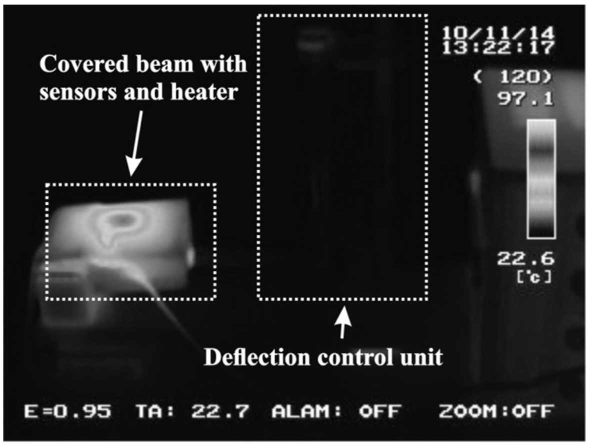

Fig. 4. The cantilever beam was covered by additional shield in order to avoid air disturbances around sensors.

This occurred to be necessary because of the change in resistance being greater than temperature, not – than deflection. Therefore, slight air movements could cool the Pt100 sensors. Additionally, it was decided to heat the cantilever beam slowly, not faster than 0.5 °C per minute. The following conditions of conducting the measurement procedure were assumed (similarly as described in work [11]):

– Heating the cantilever beam at constant temperature in the room and under a shield covering the laboratory stand;

– Continuous monitoring of temperature by a computer program;

– Reading the resistance of sensors at given temperature whose steady state was assumed as temperature change read from a thermoelectric sensor, not bigger than 0.02 °C.

Additionally, it was also assumed that only change in resistance would be measured because all the measurements were conducted below the device precision assured by the manufacturer of a DAQ card. For this reason, Pt100 sensors may be used to measure values of change in resistance, not the absolute temperature values according to the Pt100 sensor standard [9]. This will help determine the increase of resistance changes caused by deflection, hence, similarly as it is done with the use of resistance strain gauges.

It is worth stressing that the change in resistance is a difference of two resistance values (3), i.e. resistance at specific point of deflection R_x and initial value R_{x0}

$$\Delta R_x = \left(R_x - R_{x0}\right). \tag{3}$$

The experiment resulted in obtaining characteristics shown in Fig. 5 and Fig. 6.

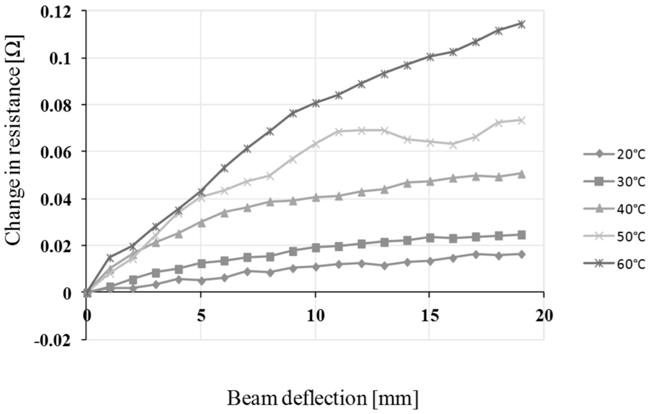

Fig. 5. The dependence of resistance increment of Pt100 sensor (B) (for various temperatures) on the cantilever beam deflection.

It is easily observable that the change in resistance (Fig. 5) for Pt100 sensor (B) is significantly greater at higher temperature in comparison with the one for Pt100 sensor (A).

An interesting phenomenon was observed during the experiment – reaction of the Pt100 (B) sensor connected with resistance increase in relation to temperature increase (Fig. 5). This probably derives from the fact that the resistance of the sensor increased together with the temperature of the cantilever beam which the sensor was stuck on. As a result the deflection of the sensor caused greater changes in the resistance increase deriving from deflection. It should be stressed that Pt100 sensors were stuck on the top of the beam with a force put from the bottom. The deflection, then, caused the inner structures of platinum leads lengthen, which resulted in resistance increase.

The recorded data for Pt100 sensor (A) (Fig. 6) showed unstable changes, which can be explained by a small change of resistance increase.

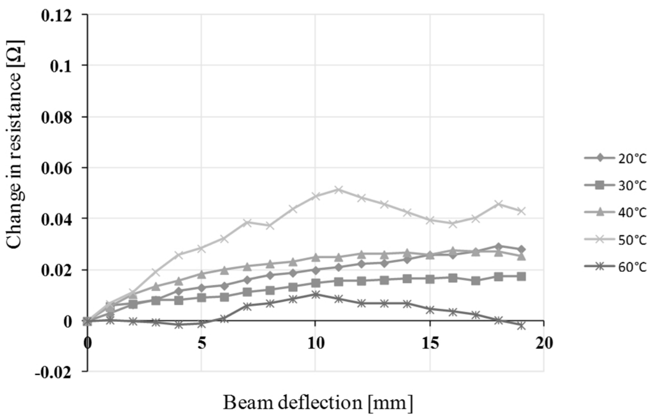

Fig. 6. The dependence of change in resistance of Pt100 sensor (A) (for various temperatures) on the cantilever beam deflection.

Next chart (Fig. 7) presents an example summary of resistance increments of Pt100 sensors and a resistance strain gauge at 20 °C. As we can observe, the characteristics of change in resistance of the strain gauge sensor has a different slope angle (expressed by linear regression) than the characteristics of two Pt100 sensors. The slope angle is related to the gauge factor (GF), which occurs to be about three times smaller for a Pt100 sensors than for a resistance strain gauge. It is worth stressing, however, that the previously mentioned reaction of the Pt100 sensor to deflection is a small disadvantage influencing the error of precise temperature measurement. This inconvenience may be ignored at normal applications under engineering circumstances. Nevertheless, we must be aware of its existence.

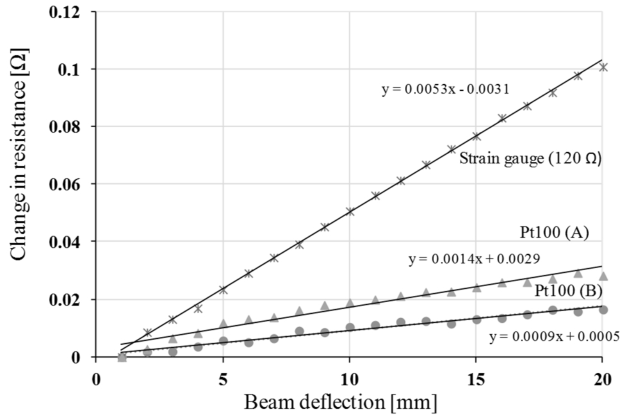

Fig. 7. Summary of change in resistance of Pt100 sensors and a strain gauge sensor at 20 °C in relation to the cantilever beam deflection.

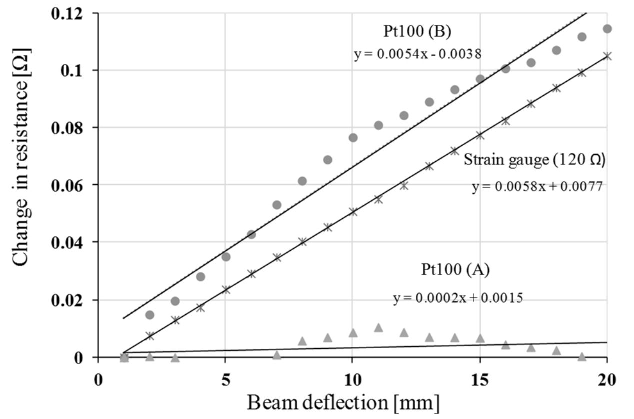

Fig. 8. Summary of change in resistance of Pt100 sensors and a strain gauge sensor at 60 °C in relation to the cantilever beam deflection.

The next characteristics (Fig. 8) shows results of the cantilever beam deflection experiment at 60 °C. As it is observable, the charts for Pt100 (B) sensor and the strain gauge have almost identical slope. The Pt100 sensor, however, has a greater coefficient of resistance change related to deflection in comparison to the strain gauge, whereas the Pt100 sensor only slightly reacted to deflection, so it can be ignored.

V. CONCLUSIONS

Presented experiment was aimed at raising engineers' awareness of the importance of locating resistance sensors on constructions undergoing deflection. In spite of various imperfections of the experiment, the influence of the sensor deflection on the change of its resistance was proved. The authors tried to achieve possibly most precise results of measurement through conducting numerous tests and using an additional cover of the laboratory stand protecting it from incidental air movements. The achieved results were satisfactory, although the device used for measuring resistance had a greater limited error than the value of measured change in resistance. It was possible due to applying a 24-bit ADC transducer in the data acquisition card [8]. It allowed to achieve 30 μΩ resolution which enabled observing phenomena described in this article.

It cannot be denied, however, that deflection of the Pt100 sensor may influence the value of measured temperature. Smaller sensors are less sensitive than bigger ones. Additionally, the track of platinum leads and substrate made of quartz or fused silica has a great influence on the reaction of the sensor to deflection.

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