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CONTACTLESS DISPLACEMENT CONVERTER WITH SWITCHING MEASUREMENT RANGE

Summary: The main goal of this article is to show the method for automatic change of measuring range of designed displacement-to-voltage converter. The designed displacement-to-voltage converter is used in fully automated test bench for investigation of SMA material properties. The entire designed system makes possible measurements of electro-thermo-mechanical characteristics. The main control components were implemented in LabVIEW program.

Keywords: displacement measurement, LabVIEW, Shape Memory Alloy, SMA, HDD

BEZKONTAKTOWY MIERNIK PRZEMIESZCZENIA LINIOWEGO LUB KĄTOWEGO O PRZEŁĄCZALNYM ZAKRESIE POMIAROWYM

Streszczenie. W artykule przedstawiono rozszerzenie możliwości pomiarowych przetwornika „odkształcenie-napięcie" działającego w złożonym systemie pomiarowym służącym do pomiaru właściwości cięgien wykonanych ze stopu SMA. Liniowa charakterystyka przetwarzania umożliwiła takie oprogramowanie komputera sterującego systemem pomiarowym, oprogramowanego w LabVIEW, aby w przypadku przekroczenia zakresu pomiarowego nastąpiło automatyczne przełączenie zakresu. Zmiana zakresu pomiarowego związana jest z przesunięciem charakterystyki przetwarzania poprzez zmianę wyrazu wolnego liniowej funkcji przetwarzania. W artykule zaprezentowano koncepcję automatycznego przełączania zakresu, sprawdzono realizowalność zadania dla danego przetwornika, przeanalizowano błędy pomiarowe wynikające ze zmiany skali, przedstawiono algorytm działania oraz realizację w programie LabVIEW.

Słowa kluczowe: Miernik przemieszczenia, LabVIEW, Materiały z Pamięcią Kształtu, SMA, HDD

1. INTRODUCTION

Shape Memory Alloys (SMA) are modern materials with controllable properties (SMART materials). With changes in temperature, the crystallographic structure changes in SMA alloys; this alteration influences particular material properties such as rigidity and plasticity. A secondary effect of martensitic transformation of SMA alloy is macroscopic

Shape Memory Effect (SME). The essence of SME is the recovery of original (natural) shape of the material during reverse martensitic transformation. A significant feature of SMA material is the curve of shape change versus temperature at a given mechanical loading of the sample.

SMA materials may be widely used. They may operate as temperature sensors or thermally activated actuators in different branches of science, industry or domestic appliances. Non-typical properties of SMAs make it possible to apply them in design of microdrives and nanodrives. They are used in computer equipment, e.g. hard disk drive heads (HDD) as positioning elements or vibration dampening elements [2,3]. Damping coefficient of element position is controlled with the help of control signal. Temperature is the usual control signal; however, if Joule–Lenz law is applied (resistive heating), then heating current may also be used.

During operation of modern hard disks, when data tracks are tracked and searched, the read-write heads float together with the sliders (slider - element, under which air cushion is generated) over the surface of data carrier. When work is over (disk drive is switched off or it goes into sleep), the heads and the sliders are usually positioned at the so-called loading ramps. The ramps are designed in such a way, that random movement of positioning arms over the data carrier surface is hindered. This is accomplished by appropriate shaping of the slider surface, as shown in Fig.1.

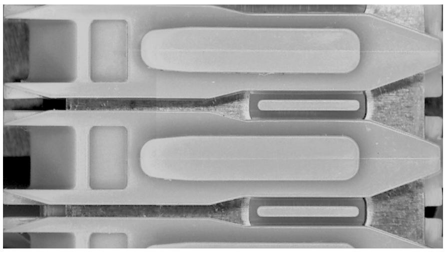

Fig.1. Ramp – Stereomicroscope photo (x50)
Rys.1. Zdjęcie rampy z mikroskopu stereoskopowego (x50)

This shaping of loading ramps and the manner of their positioning in the disk drive requires torque greater than ramp's resistance to motion (torque is generated by the main drive motor). Moreover, rapid slipping of sliders off the ramps is usually related to suspension vibrations, which occur in the direction perpendicular to the data carrier surface; this may facilitate random contact of slider with the data carrier and result in damage of data carrier surface. One of our research goals is to design a loading ramp of modified shape, using Shape Memory Alloy materials.

Design process of such ramp requires good acquaintance with and full identification of SMA material properties. This is possible using a test stand presented in this paper.

In order to measure properties of Shape Memory Alloys we have designed and built a test stand presented in [1, 4, 5]. This stand makes it possible (among other things) to measure a set of characteristics of actuator length change vs. heating current and at different sample mechanical loads. During tests it turned out that for longer connectors the measurement range was exceeded; therefore, in the data analysis it was necessary to re-scale partially the acquired data. This task could be accomplished either by re-programming the "displacement-to-voltage" converter and introducing new processing characteristic into the program controlling the test stand operation or by modifying the control program in such a way that overflow of measurement range could be automatically detected and processing function corrected. We decided to apply the second method, since it is a very general approach.

2. DISPLACEMENT METER

2.1. Meter design

The hardware design of the meter has been described in publication [1], and the complete stand in publications [4, 5]. Signal processing path may be divided into three stages: hardware "displacement-to-voltage" converter, PC-controlled lab voltmeter, digital acquisition and processing of data (carried out with PC). The contactless displacement measurement is performed with the help of H9720 sensor. This is a quadrature sensor, possessing two optical modules of transmitter and receiver, which are geometrically shifted in relation to each other, which makes it possible to measure displacement and distinguish the direction of movement at the same time. This sensor cooperates with a ruler or disk with markers; measurement of both linear and angular displacements is thus possible. Series of pulses is counted by the microcontroller. PWM signal is supplied to the output of "displacement-to-voltage" converter. This signal is then filtered with active low-pass RC filter and fed into voltmeter. The voltmeter operates synchronously in the measurement circuit of laboratory test stand. The processing of voltage value into displacement value is carried out by the computer. Converter data is given in Table 1.

Table 1.

Parameters of "displacement-voltage" transducer

Quantity	Unit	Value
Step (1graduation)	mm	0.085
Step (1graduation)	mV	6.4
Voltage at displacement L=0	mV	329
Measuring range	mm	-4.25 – 17.425
Measuring range	graduation	-50 – 205
Measuring range	mV	8.3 – 1656

2.2. Principle of operation

During tests of longer actuator samples we have often encountered overflow of measurement range of "displacement-to-voltage" converter. We have decided to solve this problem by modifying computer software processing the acquired data. The measurement range of converter has been thoroughly analyzed. Series of converter tests have been carried out, with several overflows taking place. Measurement results are shown in Fig.2.

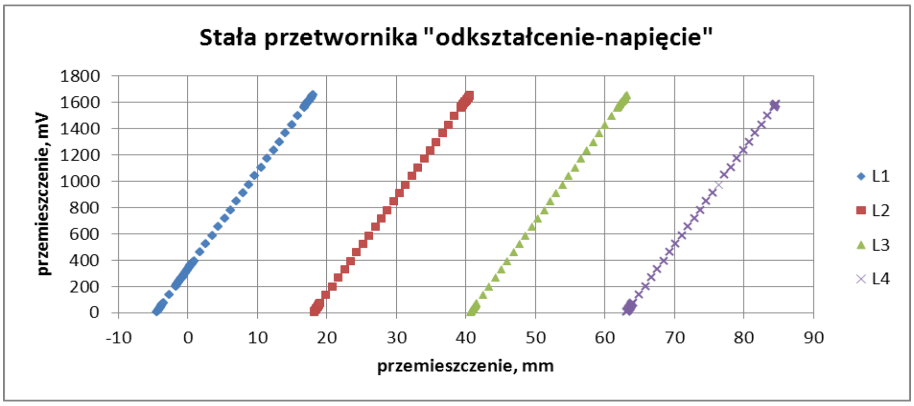

Fig. 2. Processing function of “displacement-to-voltage” converter for different measurement ranges. L1 – L4 – measurement ranges
Rys. 2. Stała przetwornika „odkształcenie-napięcie” dla kilku zakresów pomiarowych, L1 – L4 – zakresy pomiarowe

Next, linear equations describing the function *L[mm] = f(L[mV])* have been determined. Results are presented in Table 2.

Table 2.

Values of linear equation coefficients of converter's processing function.

Detailed coefficients for measurement ranges				
nr	a	b	Δb	R2
-1	0.0132	-26.093	21.7367	1
1	0.0131	-4.3119	0	1
2	0.0132	17.421	21.7329	1
3	0.0132	39.181	21.76	1
4	0.0132	60.942	21.761	1
5	0.0132	82.698	21.756	1

Generalized coefficients		
a'	b'	R2
0.0132	-26.079	0.999984
0.0132	-4.33	0.999998
0.0132	17.419	0.999997
0.0132	39.168	0.999996
0.0132	60.917	0.999997
0.0132	82.666	0.999994

The linear function coefficients present in Table 2 and denoted as a and b are the processing coefficients for successive measurement ranges. On the basis of detailed coefficients, the generalized coefficients a’ and b’ have been determined; a’ is an arithmetic average of a coefficients for all tested ranges, while coefficient b’ changes with a constant step equal to Δb depending on current measurement range.

The adjustment accuracy has been verified in both cases by determining an adjustment coefficient R2. It is defined with the formula:

$$R^2 = \frac{\sum_{i=1}^{n}\left(y'_i - y_{śr}\right)^2}{\sum_{i=1}^{n}(y_i - y_{śr})^2} \tag{1}$$

where:

y_i'– i[th] value y of approximating equation,

y_i – i[th] value y, measurement result,

$y_{śr}$ – average value of y.

3. IMPLEMENTATION OF ALGORITHM FOR AUTOMATIC CHANGE OF SCALE

The results obtained by procedures described in previous section have been implemented in LabVIEW environment. Algorithm is shown in Fig.3.

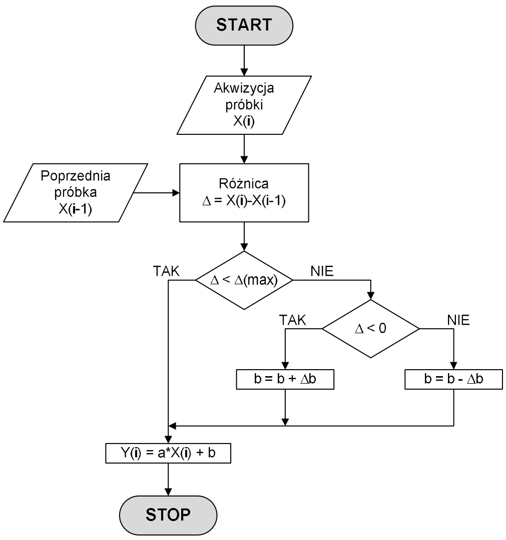

Fig. 3. Algorithm of displacement converter operation
Rys. 3. Algorytm pracy miernika przemieszczenia

In order to detect change in measurement range we set maximum possible change in measured value to Δ. If difference between current measured value X(i) and previous measured value X(i-1) is contained within a set interval $\Delta<\Delta_{MAX}$, then displacement (given in millimetres) is calculated on the basis of current processing function $L[mm] = f(L[mV])$; if value Δ gets outside the interval $\Delta>\Delta_{MAX}$, then it means that scale is exceeded. In such case the sign of Δ is additionally checked. If $\Delta > 0$ then coefficient b is increased by Δb, and then displacement value is calculated using fresh value of coefficient b.

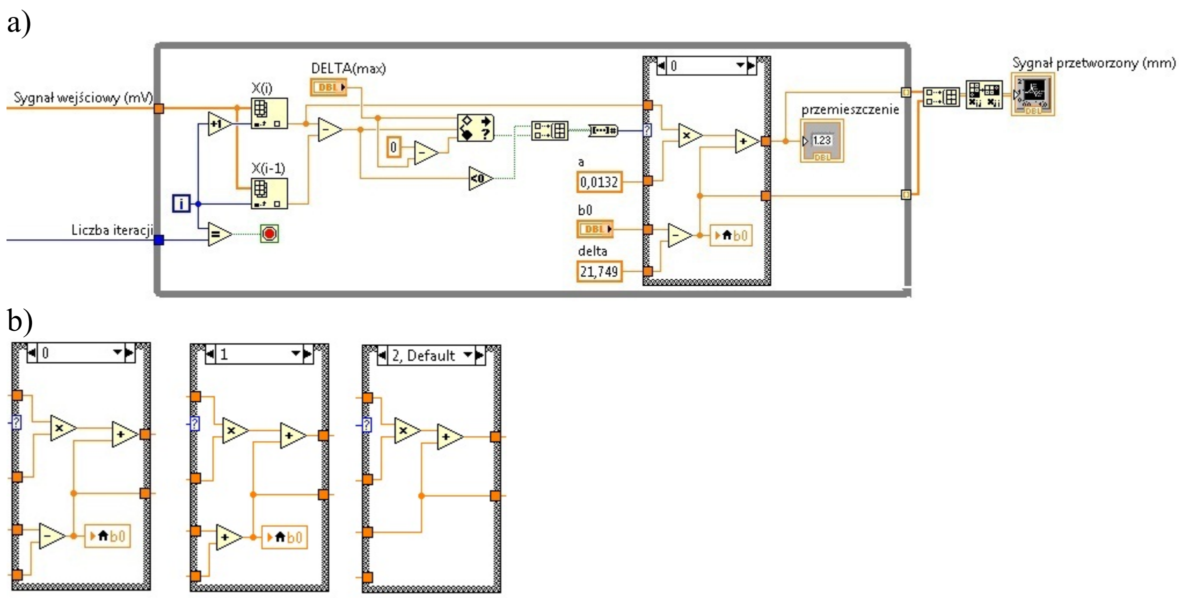

Fig. 4. Implementation of range switching algorithm of the converter: a) Main loop of program, b) Conversion L[mm] = f(L[mV]).
Rys. 4. Implementacja algorytmu czujnika o przełączalnym zakresie: a) Pętla główna realizująca obliczenia, b) Realizacja przetwarzania *L[mm] = f(L[mV])*.

Calculation of displacement is carried out when measurement process is complete. Vector of successive measured values and number of tests constitute input data. "Displacement-to-voltage" converter operates as relative converter; it does not memorize last position. When device is reset, the measurement starts at zero value. Therefore it is assumed that the first interval is measurement interval 1 (*cf.* Fig.2). Example of measurement series with bidirectional movement and switching of measurement range is shown in Fig.5.

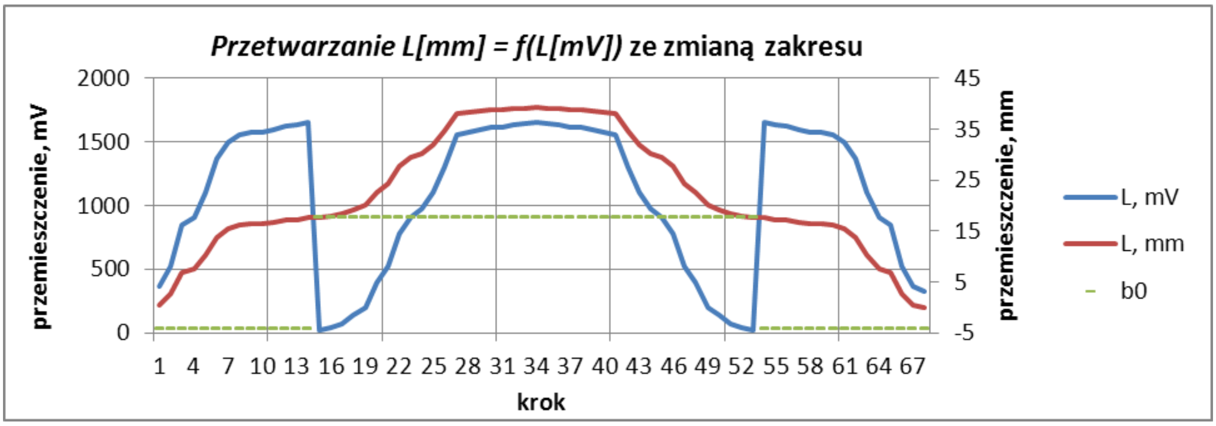

Fig. 5. Example of measurement data for two directions of movement
Rys. 5. Przykładowa seria danych uwzględniająca obydwa kierunki zmiany sygnału przetwarzanego.

4. CONCLUSION

The proposed procedure enlarges the usability scope of designed "displacement-to-voltage" converter. It is possible to increase measurement range without the need for re-programming the converter. The obtained measurement range is limited by the length of used ruler. In case of rotating motion, it is possible to measure a very high number of rotations; this number is due exclusively to the range of variables used in the program controlling the operation of test stand.

Accuracy of displacement measurement is ±3 graduations; in case of ruler used in the test stand this is equivalent to ±0.255 mm (see Table 1). This has been determined as the maximum difference between value counted in the measurement process and approximated value calculated from the generalized formula *L[mm] = f(L[mV])*.

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