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DETERMINATION OF FORM MEASURING MACHINE DISPLACEMENT SENSOR CHARACTERISTICS WITH A USE OF FLICK STANDARD

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Abstract − A new approach towards calibration of FMM displacement sensor with a use of a flick standard is presented. The main drawback of the prevailing procedure is the fact that instrument's probe could have been calibrated only for a single value, whereas following a novel method removes this limitation. Therefore, FMM probe linearity deviations may be determined within a full range of sensor. In the paper, the core idea and sample results presenting performance of the proposed method are outlined.

Keywords: form measuring machine, calibration, sensor characteristics, flick standard

1. INTRODUCTION

The form measuring machines which are on the market these days combine wide measuring ranges, far exceeding one millimetre, with high resolutions of several nanometres. However, as the outcomes of a latterly EURAMET research [1] show, a significant inconsistency between the results achieved by different participating laboratories is still observed. In order to avoid such discrepancies, applying an efficient and reliable procedure of examining FMM displacement sensors characteristics seems to be crucial.

The utmost importance of this issue is outlined when a ratio of signal changes during the measurement to the sensor measuring range is high, too. It is due to the fact that a non-linearity of probe can affect measurement results by introducing false form deviations of the measured object. In some cases, for example when there is a significant eccentricity of the measured part and axis of rotation, errors of form deviation determination may even be larger than a form deviation value itself (!) [2]. This problem can also be easily solved by determination of a sensor characteristics which can be used for systematic error corrections. Some methods of doing so have already been proposed. However, they are not free of serious disadvantages [2].

One of approaches towards sensor characteristics examination demands a use of another, much more accurate and, in result, costly, sensor. Then, the linear displacements measured with both examined and reference sensors are compared. However, the efficiency of this method is unsatisfactory, as it is time-consuming and requires separate calibration station and, therefore sensor removal from FMM. Furthermore, by applying such procedure, there is no information concerning dynamic characteristics of sensor obtained.

In another method of determining sensor non-linearity gauge blocks are used. However, this method is a gruelling one, as it takes a long time and its accuracy may be insufficient.

A straightness standard can also be used in order to obtain sensor characteristics [3], but its applicability is limited to instruments which are equipped with a column with small linearity deviations and to the ones that ensure a constant speed of the measuring gage.

Other ways of determining displacement sensor non-linearity demand the measurement of a known, standard profile with a use of the examined sensor. Then, the profile obtained this way is compared with a nominal one. It is worth mentioning that there is a variety of profiles that can be used as standard, i.e. multi-wave [4] one. Also, a circumferential profile of cylindrical artefact may be applied as a standard one, but it has to be set eccentrically to spindle axis of rotation [2, 5].

The method of sensor characteristics determination proposed in the paper bases on using an artefact named flick standard which is a precise cylindrical element with a small flat part. Flick standards are common equipment of metrological laboratories used to calibrate FMM probes. Prevailing procedure with a use of such artefacts enables calibration only for single values within sensor measuring range, whereas a novel method is a step forward. With a use of the proposed approach, FMM probe characteristics may be determined within a full measuring range.

2. THE PROPOSED METHOD - THEORETICAL BASIS

Nominal measuring ranges of FMM displacement sensors are symmetrical to zero (i.e. ± 1000 μm). So, it is assumed that characteristics of these sensors cross the origin point (0;0). If function *y(x)*, which relates probe readings x and real stylus displacements y (Fig. 1), is a polynomial of k-degree, it does not have a constant term, as it is presented in (1).

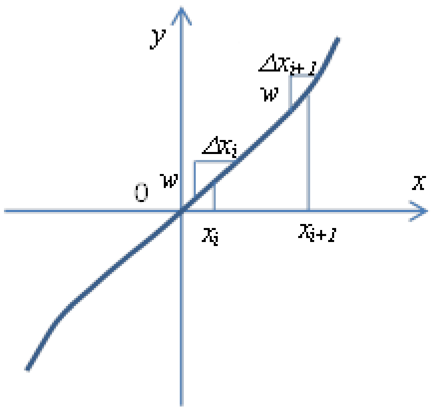

Fig. 1. Sample characteristics of FMM sensors; *x* – reading of a probe being calibrated; *y* – correct reading (real stylus displacement).

$$y = f(x) = \sum_{j=1}^{k} a_j x^j \quad (1)$$

Therefore, a derivative *g(x)* of this function is a polynomial of *k-1* order, as shown in (2):

$$\frac{dy}{dx} = g(x) = \sum_{j=0}^{k-1} b_j x^{j-1}, \quad (2)$$

while coefficients of polynomials *f(x)* and *g(x)* are related as outlined in (3):

$$a_j = \frac{1}{j} b_{j-1}. \quad (3)$$

Due to a non-linearity of sensor characteristics, a constant increase of a measurand (which is a given sensor stylus displacement) $\Delta y_i = w$ results in a different, dependent on sensor working range, increase of the measuring signal Δx_i (Fig. 1). Given the stylus displacement $\Delta y_i = w$ measurements have been made in at least *k* points over the sensor measuring range, the matrix $(x_i;\Delta x_i)$ is obtained. Also, let us assume that x_i values are regularly spaced within whole sensor measuring range that is examined. If *w* value is known and small enough, the derivative of *f(x)* function values, referring to sensor reading x_i can be determined as it is shown in (4).

$$\left.\frac{dy}{dx}\right|_{x=x_i} \cong \frac{w}{\Delta x_i} = \kappa_i \quad (4)$$

When the $(x_i;\kappa_i)$ points are approximated with a polynomial of *k*-1 degree, the coefficients b_j from (2) are obtained. Therefore, the coefficients a_j can be calculated according to (3) and, in result, $y = f(x)$ function can be determined.

Sensor characteristics errors *e(x)* and corrections *δ(x)* within whole measuring range can be calculated, too, as it is shown in (5) and (6) respectively.

$$e(x) = x - y \quad (5)$$

$$\delta(x) = (a_1 - 1)x + \sum_{j=2}^{k} a_j x^j \quad (6)$$

3. THE DEVISED METHOD – IMPLEMENTATION

The proposed method of determining FMM sensor characteristics using a flick standard consists of a few steps that are presented in the chapter.

Firstly, a flick standard, which is characterised by its nominal value of a roundness deviation $RONt_{nom}$, is put on a FMM measurement table. An operator should ensure that an axis of calibration artefact and an axis of rotation are both parallel and centric. Also, if a measuring range of sensor is adjustable, the widest one should be set.

Then, numerous measurements of a flick standard should be performed. In each of the measurements a range of sensor indications should refer to different parts of sensor measuring range. It can be achieved by moving sensor a specified distance towards or outwards the calibration standard before each measurement.

For each *i*-th measurement the roundness deviation value $RONt_{mi}$, as well as an average sensor indication x_i, should be calculated. Then, the ratio κ_i should be determined according to (7).

$$\kappa_i = \frac{RONt_{nom}}{RONt_{mi}} \quad (7)$$

A regression curve fitted to a set of points $(x_i;\ \kappa_i)$ is assumed to be a polynomial *g(x).* After b_j coefficients of this polynomial are determined, the a_j coefficients of *f(x)* functions are calculated according to (3). Then, sensor characteristics errors *e(x)* (5) or corrections *δ(x)* (6) are obtained.

4. METHOD VERIFICATION - RESULTS

In order to verify the method applicability, the characteristics of Talyrond 365 sensor were determined (Fig. 2). The properties of the probe (Talymin 5 gauge), according to its specification [6], are presented in Table 1.

Fig. 2. Test stand – the Talyrond 365 and a flick standard on the table.

In the research, the 2.06 mm measuring range of sensor was set. In the same time, a nominal *RONt* value of an applied flick standard equalled 93.5 µm. One of the flick standard measurement results given in the research is presented in Fig. 3

Table 1. Properties of Talyrond 365 sensor [6].

Name	Talymin 5
Manufacturer	Taylor Hobson
Type	single bias inductive transducer
Normal measuring range	2.06 mm
Normal resolution	0.03 µm
Low measuring range	0.08 mm
High resolution	1.2 nm
Stylus tip force	< 0.15 N (adjustable)

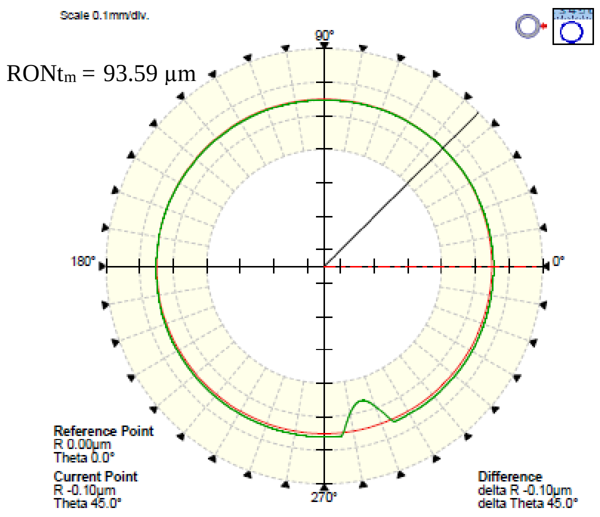

Fig. 3. Sample flick standard measurement result ($x_i = 99$ µm).

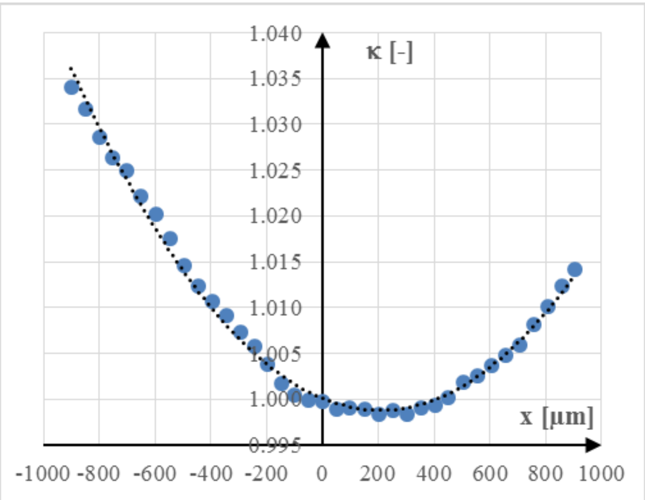

Fig. 4. Data x_i, κ_i obtained in the experiment and a second-order polynomial fitted to them.

The κ_i values, referring to the average standard indications x_i obtained in the experiment, as well as a polynomial of second degree fitted to them (dotted line) is shown in Fig. 4. The equation of this polynomial is as in (8).

$$g(x) = 3.043 \cdot 10^{-8} x^2 - 1.263 \cdot 10^{-5} x + 1.00009 \qquad (8)$$

Then, errors of sensor characteristics have been determined and they are outlined in Fig. 5. The function representing errors of characteristics is given in (9).

$$e(x) = -1.014 \cdot 10^{-8} x^3 + 6.315 \cdot 10^{-6} x^2 - 0.00009x \qquad (9)$$

These results clearly indicate the importance of examining FMM sensor characteristics and introducing non-linearity errors compensation algorithms, as an influence of the sensor non-linearity on probe magnification may exceed ±10 µm at the ends of the measuring range.

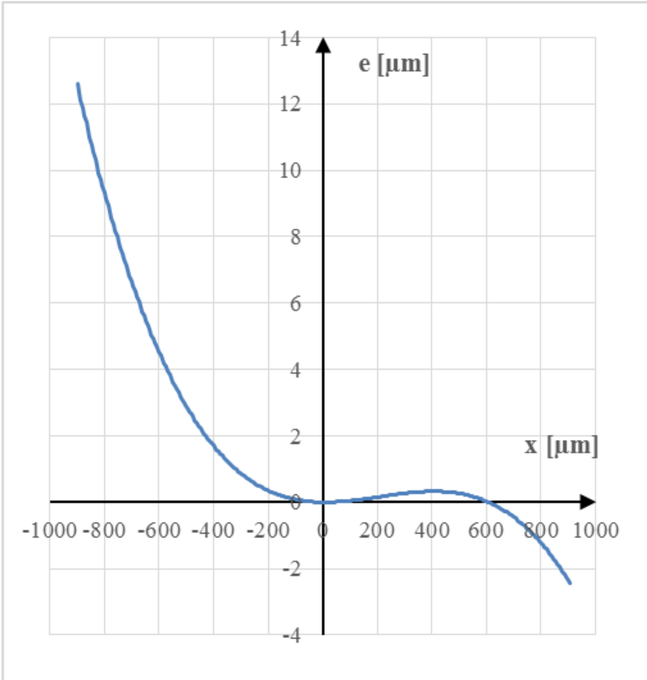

Fig. 5. Errors of Talymin 5 sensor characteristic obtained in the research.

5. REPEATABILITY

Then, repeatability and reproducibility of the results obtained with a use of the proposed method were assessed. In order to do so, the procedure described above was repeated 10 times. The κ_i values given in the research are shown in Fig. 6, whereas a set of sensor errors characteristics is presented in Fig. 7.

To evaluate the repeatability of sensor characteristic determination, *R(x)* parameter was calculated according to (10), where $e_{max}(x)$ and $e_{min}(x)$ refer respectively to maximum and minimum *e(x)* value obtained in the experiment. The calculated *R(x)* values are presented in Fig. 8.

$$R(x) = e_{max}(x) - e_{min}(x) \qquad (10)$$

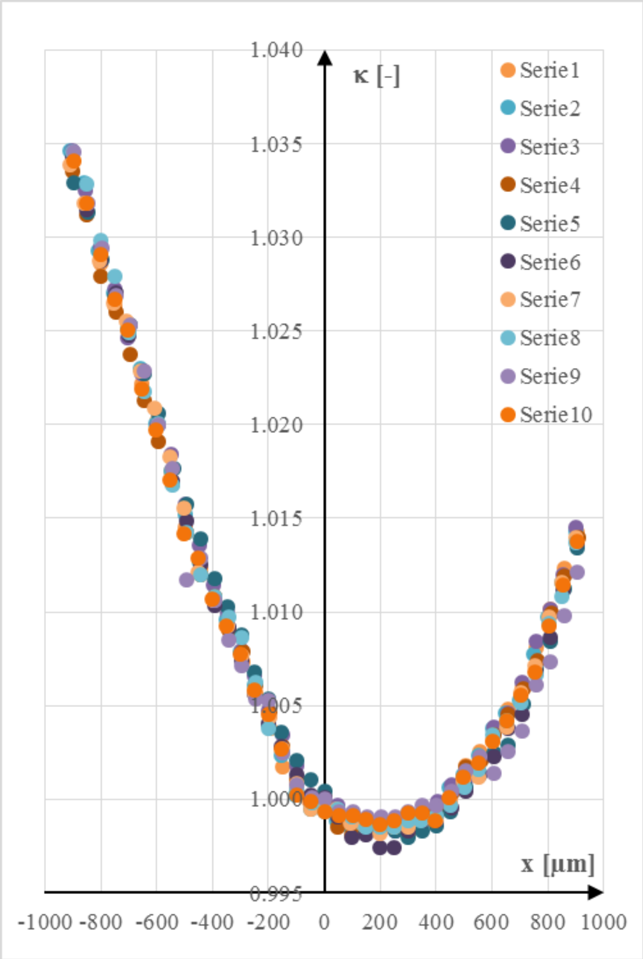

Fig. 6. Data x_i, κ_i obtained in 10 repetitions of the devised procedure.

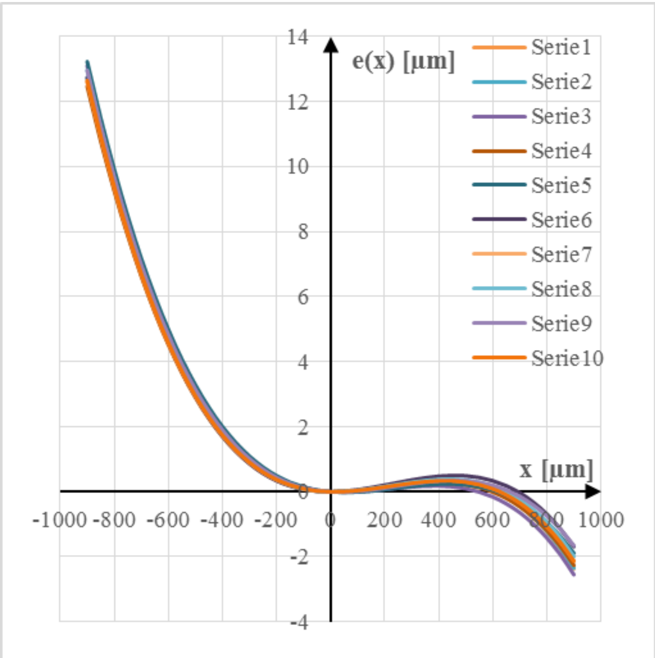

Fig. 7. Errors of Talymin 5 sensor characteristics obtained in 10 repetitions of the proposed procedure.

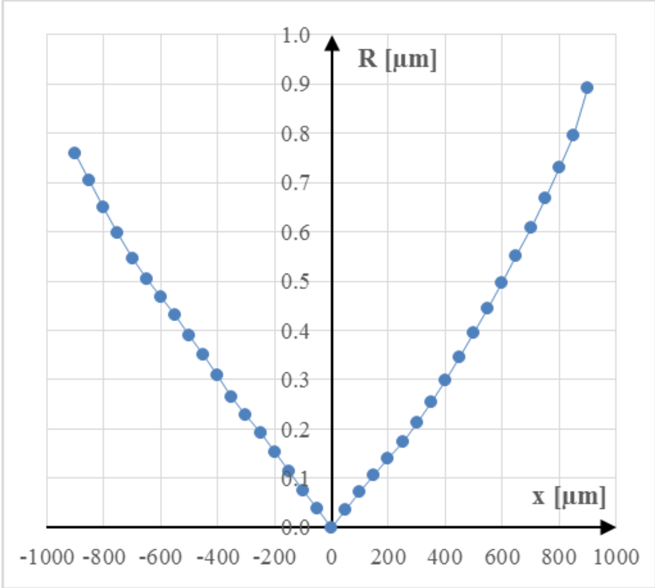

Fig. 8. *R(x)* characteristic.

As the chart in Fig. 8 indicates, repeatability of the results is sufficient to guarantee consistency and reproducibility of the sensor characteristics obtained with a use of the proposed procedure.

6. CONCLUSIONS

The devised method meets the demand for a procedure of FMM sensor characteristics determination which enables proper compensation of probe linearity errors. In effect, it also guarantees high accuracy of the measurement results obtained within total measuring range of a sensor. However, this is not the only advantage of procedure of examining sensor characteristics with a use of flick standards.

Firstly, despite the recommended procedure requires several repetitions of the same tasks, it is quite fast. What is more, it can easily be fully automated, especially when modern FFM sensor characteristics are determined. It is due to the fact that such instruments have built-in modules dedicated to programming measuring strategies.

What is more, the proposed method is simple and, in effect, the interpretation of the obtained results is quite intuitive.

Also, all accessories and tools essential for following the recommended steps are equipment of each metrological laboratory. Thanks to these, a method suggested by the authors may easily be popularised among other institutes.

Moreover, manufacturing flick standards is easy and cost-effective. This advantage becomes even more significant, when the flick standards are compared with straightness [3] or multi-wave [4] artefacts. The difficulties arising both in the process of manufacturing and calibration of these standards makes them costly and seriously affects the uncertainty of sensor characteristics determination.

Furthermore, this method can be applied both to the table and sensor rotating form measuring machines, what makes it even more versatile.

Last but not least, when the proposed procedure is used, performance of a sensor is investigated under the same conditions as during most measurements of industrial parts.

Due to all the factors mentioned above, the recommended method of examining FMM sensors characteristics is a worth-popularising one. However, it should be considered that depth of an applied flick standard should not be too great, as it may limit range within which sensor characteristics can be determined.

ACKNOWLEDGMENTS

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REFERENCES

[1] O. Jusko, H. Bosse, D. Flack, B. Hemming, M. Pisani and R. Thalmann, "A comparison of sensitivity standards in form metrology—final results of the EURAMET project 649", *Meas. Sci. Technol.*, vol. 23, nº. 054006, pp. 1-7, March 2012.

[2] S. Żebrowska-Łucyk, M. Czapski and R. Rudziński, "Fast method for non-linearity of FMM displacement sensors characteristics examination (Szybka metoda wyznaczania nieliniowości charakterystyki czujników przemieszczeń stosowanych w przyrządach do pomiaru odchyłek kształtu", *VII Coordinate Measuring Technique Conference*, pp. 61-69, Bielsko-Biała, Poland, April 2006.

[3] J. Tomasik et al., *Calibration of devices dedicated to length and angle measurement* (*Sprawdzanie przyrządów do pomiaru długości i kąta)*, OW PW, Warsaw, 2003.

[4] O. Jusko, F. Ludicke, *Novel multi-wave standards for the calibration of form measuring instruments*, PTB, Braunschweig, 1999.

[5] S. Żebrowska-Łucyk: "New approach for examination of the displacement sensor characteristics", *Measurement*, vol. 28, nº. 4, pp. 261-267, December 2000.

[6] Talyrond 365 roundness/cylindricity systems. High precision instruments for sub-micron components, Taylor Hobson Ltd, Leicester, 2005.