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A DEEP-FLICK STANDARD APPLIED FOR DETERMINATION OF FMM SENSOR INDICATION ERRORS

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Abstract: Rationale, as well as a theoretical framework, of a new method for determining form measuring machine (FMM) sensor indication errors with a use of deep-flick standard is presented in the paper. Moreover, the proposed method has been compared with the already existing approaches to this issue, including the ones recommended by the FMM makers. Some experimental results received for the Talymin 5 sensor by Taylor Hobson – a world leader in manufacturing of the top-accuracy metrological equipment of the kind, have been outlined, too. The obtained outcomes prove that the devised method may be used for getting sensor's characteristics efficiently and, therefore, also for implementing corrections that minimise errors caused by sensor's nonlinearity effectively.

Keywords: form measurement machine (FMM), flick standard, sensor indication errors, calibration.

1. INTRODUCTION

Departures of mechanical elements from their nominal form may both cause severe difficulties in assembly and decrease an operational reliability by introducing vibrations or the increased and variable friction. Therefore, an accurate measurement of form deviations remains a fundamental task in predicting a performance of end products. What is more, thorough knowledge of scale and type (i.e. ovality, polygonal shapes) of mechanical parts' form deviations being a result of a manufacturing process gives an opportunity to identify their technological sources. In result, the manufacturing process can be significantly improved.

When the factors mentioned above considered, it cannot be surprising that the geometrical product requirements are becoming more and more complex and stringent. In effect, also a proper product verification demands carrying out measurements of the top accuracy. In order to achieve this, the metrological properties and capabilities of form measuring machines (FMMs), which are applicable to measurements of cylindrical elements', are under constant and rapid development. An example of such instrument is presented in the figure 1.

However, the FMM's part that affects the form measurement accuracy the most significantly – a sensor – has not been noticeably improved since decades, as due to the specific working conditions and necessity for measuring complex mechanical parts (fig. 2) these sensors have to meet numerous demands, i.e.:

- small size and light weight,
- interchangeability of styluses differing in their length and shape in order to measure complicated elements, e.g. with deep, small-diameter holes,
- ability to change nominal angular position of a stylus within a broad range,
- ability to measure in two orientations: both horizontal and vertical one,
- adjustable stylus tip force,
- wide measuring range (as large as a few millimetres),
- high resolution (not exceeding several nanometres).

Fig. 1. Talyrond 365 by Taylor Hobson

The sensors that meet all these requirements are the inductive ones. The changes of dimensions of the measured part are reflected in the changes of angular position of a stylus arm. Then, also an armature connected to this stylus moves between coils, changing their inductance, as it is shown in the figure 3.

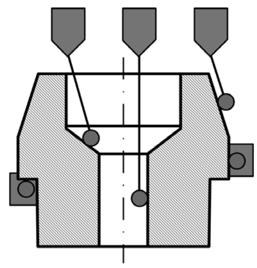

Fig. 2. Complexity of measurements conducted with a use of FMM

Unfortunately, a necessity for modifying nominal angular position of a stylus arm during measurement of different surfaces of the measured part introduces extensive indication errors of a sensor as it is shown in the figure 4.

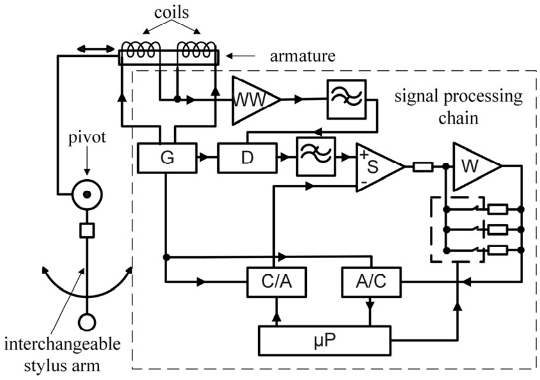

Fig. 3. Inductive sensor applied in FMM

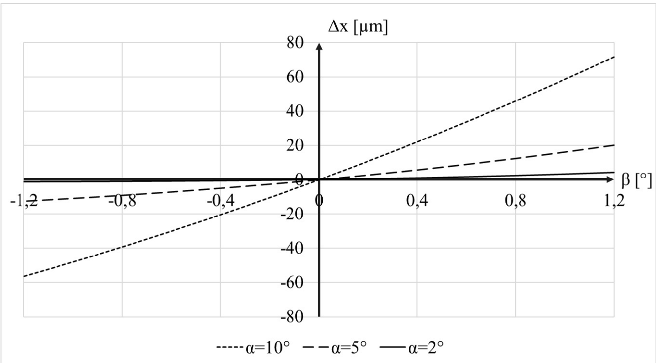

Fig. 4. An impact of stylus angular position during measurements of mechanical parts on indication errors Δx (Talymin 5 gauge, stylus length: 200 mm, measuring range:±1,03 mm)

In the chart the stylus angular position α corresponds with sensor's 0 indication, whereas β angle refers to the changes of stylus angular position within the sensor measuring range of ±1,03 mm, as presented in figure 5.

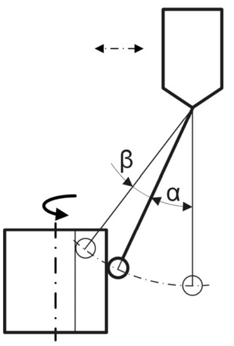

Fig. 5. Stylus angular position and dynamics during measurements

However, these errors – usually exceeding the true values of form deviations numerous times (!) – cannot be eliminated easily, but without doing so, the measurement results may be totally distorted (fig. 6).

Therefore, numerous different approaches have been proposed to determine sensor indication errors and minimise their influence on the measurement results. These approaches with their drawbacks have been presented in table 1. The method proposed in the paper is free of the listed limitations.

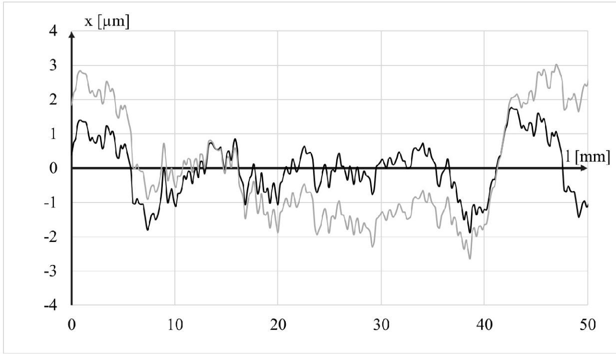

Fig. 6. The same straightness profile measurement results obtained with two different parts of sensor's measuring range being used for acquiring data (x – ordinate value, l - profile length)

Table 1. Methods for sensor's indication errors determination - comparison

Method	Drawbacks	Reference
Comparative method	- an expensive extra sensor required - additional measurement stand has to be modified depending on the investigated sensor and a stylus being used - characteristics obtained in conditions differing from the ones during the practical measurements - only disassemblable sensor may be tested	[1]
Multiwave-standard	- just mean amplification coefficient estimated - no information concerning sensor characteristics - costly standard that cannot be easily calibrated - non-intuitive interpretation of results	[2]
Gauge blocks	- extremely time-consuming - data obtained only at a few isolated points within measuring range - characteristics obtained in conditions differing from the ones during the practical measurements	[3]
Single flick standard measurement	- just mean amplification coefficient estimated - no information concerning sensor characteristics	[4]
Straightness standard	- costly standard - method not applicable to instruments which do not support measurements along spindle rotation axis	[5]
Cylindrical artefact set eccentrically	- non-standard, specially designed stylus tip must be used	[6]

2. ALGORITHM

The algorithm of determining sensor characteristics has already been presented in [7]. However, in order to keep the disquisition clear, its crucial statements are repeated in the paper.

The presumption that the sensor's characteristics crosses the origin point (0,0) and can be described by the polynomial of k-degree (often the third or the fifth one) was made. Therefore, a function which shows the relation of gauge readings x to real stylus displacements y (Fig. 7) is:

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

where: a_j – the polynomial coefficients.

A change of the measuring signal Δx_i refers to a known increase of a given stylus displacement $\Delta y_i = w$ (Fig. 7). If measurements of $\Delta y_i = w$ value are performed in at least k points within the sensor measuring range, the derivatives of $f(x)$ function values, referring to sensor reading x_i can be determined as it is presented in (2).

$$\left.\frac{dy}{dx}\right|_{x=x_i} \cong \frac{w}{\Delta x_i} = \kappa_i \tag{2}$$

After approximation of data points $(x_i;\kappa_i)$ with a polynomial of k-1 degree, the $f(x)$ polynomial coefficients are determined and, therefore, sensor characteristics within a total measurement range is obtained. Also, the subtraction of y from x values makes the estimation of indication errors e possible. After subtraction of a regression line from the given function $e(x)$, also the nonlinearity errors $e_l(x)$ are determined. Finally, when all indication errors are calculated, necessary corrections are implemented.

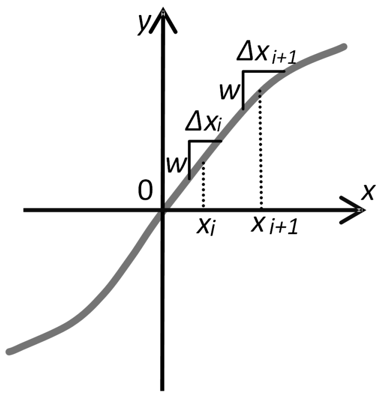

Fig. 7. Sample characteristics of an FMM sensor

Fig. 8. A set of deep-flick standards

The flick standards, which are cylinders with a deep flick that is parallel to a cylinder's rotation axis, have already been quite common in metrological laboratories, so they were chosen to be the reference ones in the proposed method. Then, the flick depth corresponds with the measurand value w. A set of such standards, differing in their nominal flick-depth is presented in the figure 8.

3. SAMPLE RESULTS

In order to verify performance of the proposed method, numerous experiments have been made. Sample results of one of them are presented in the paper. In order to check solution's practical applicability a flick standard of nominal depth w = 186,4 μm was used to determine Talymin 5 sensor characteristics.

The deep-flick standard was measured numerous times, each time using a different part of sensor's measuring range, and then nominal depth was compared with the measured ones. Quotients of these two figures are equal to κ_i values which are presented in the figure 9. Then, following the already described procedure, polynomial is fitted to this set of points and a_j coefficients are calculated. Then, also, indication errors as well as non-linearity ones are estimated. The final results are presented in the figure 10.

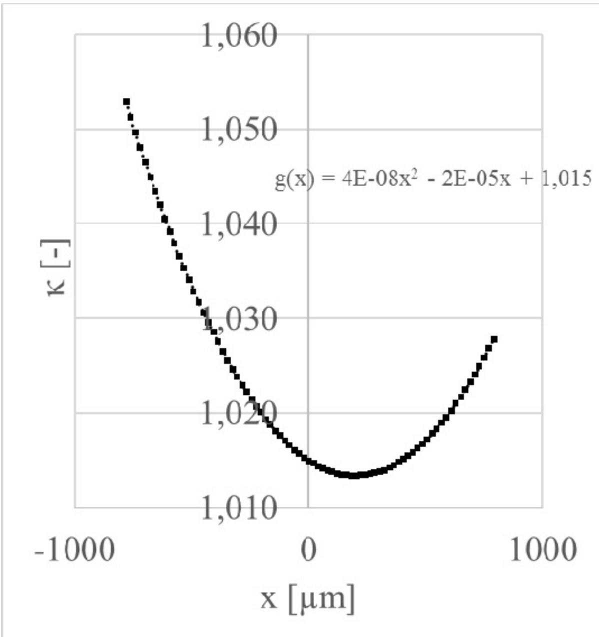

Fig. 9. κ_i values given experimentally

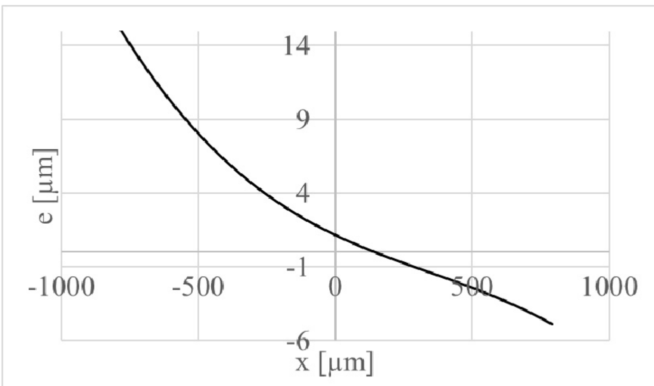

Fig. 10. Indication errors $e(x)$ of Talymin 5 gauge

4. CONCLUSION

The proposed method for determining FMM sensor's indication errors seems to be an efficient alternative to the already popularised ones, as it does not require using any costly standards and is applicable to all FMMs – even the ones which have their capabilities limited to roundness profiles measurements. However, further investigation is needed in order to assess an impact of factors affecting the uncertainty of the method (outlined in the Ishikawa diagram in the figure 11) and to conduct its full metrological validation.

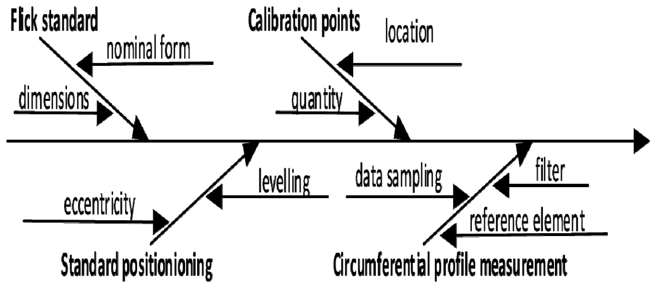

Fig. 11. Factors affecting the uncertainty of sensor's indication errors determination with a use of the method presented in the paper

5. ACKNOWLEDGEMENTS

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WYZNACZANIE BŁĘDÓW WSKAZAŃ CZUJNIKÓW MASZYN DO POMIARU ODCHYŁEK KSZTAŁTU I POŁOŻENIA (FMM) PRZY ZASTOSOWANIU WZORCÓW Z GŁĘBOKIM ŚCIĘCIEM

W niniejszym artykule zaprezentowano podstawy teoretyczne nowej metody wyznaczania błędów wskazań czujników indukcyjnych, w której stosowany jest wzorzec z głębokim ścięciem. Ponadto autorka przedstawiła obszerne uzasadnienie dla podjęcia tej tematyki badawczej, a także porównała zaproponowaną metodę z już istniejącymi rozwiązaniami, w tym przede wszystkim tymi, które zalecane są przez producentów urządzeń FMM. W artykule zamieszczone zostały również przykładowe wyniki otrzymane w ramach eksperymentalnej weryfikacji działania nowej metody dla czujnika indukcyjnego Talymin 5 firmy Taylor Hobson – wiodącego producenta maszyn służących do pomiaru odchyłek kształtu i położenia. Uzyskane wyniki potwierdzają, że dzięki zastosowaniu zaproponowanej metody możliwe jest efektywne wyznaczenie błędów wskazań czujników, a co za tym idzie, poprzez wprowadzenie odpowiednich poprawek – metoda ta umożliwia również aktywną korekcję nieliniowości charakterystyki czujników. Jednocześnie nowy sposób wyznaczania błędów wskazań czujników maszyn nie wymaga zastosowania ani odrębnego stanowiska badawczego, ani niestandardowych końcówek pomiarowych, a jedynie wzorca kształtowego. Co więcej metoda ta może być stosowana również w przypadku mniej zaawansowanych maszyn FMM, które służą do pomiaru wyłącznie profili poprzecznych, ale nie pozwalają mierzyć profili wzdłużnych.

Słowa kluczowe: urządzenie do pomiaru odchyłek kształtu i położenia (FMM), wzorzec ze ścięciem, błędy wskazań czujnika, wzorcowanie.