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THE ROUNDNESS DEVIATION MEASUREMENT WITH COORDINATE MEASURING MACHINES
MJERENJE DEVIJACIJE KRUŽNOSTI NA KOORDINATNIM MJERNIM STROJEVIMA

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Summary: *In the article, the form deviation (roundness) measurement with the Coordinate Measuring Machine has been discussed. The influence of the measuring points number and the type of the roundness deviation on the result (since different fitting elements are used) has been presented. The obtained investigation results prove that a minimal number of points is not enough for measurement, while too large of a number does not improve the measurement, as well. A recommendation on the measuring points number has been given.*

Key words: - coordinate measuring technique
- roundness

Sažetak: *U ovom članku razmatrano je mjerenje devijacije oblika (kružnosti) na koordinatnim mjernim strojevima. Prikazan je utjecaj broja mjernih točaka i tip devijacije kružnosti na rezultat. Dobiveni rezultati istraživanja dokazuju da minimalni broj točaka nije dovoljan za mjerenje, dok preveliki broj točaka ne poboljšava mjerenje. Dana je preporuka o broju mjernih točaka.*

Ključne riječi: - koordinatna mjerna tehnika,
- kružnost

1. INTRODUCTION

The customers' demands enforce the continual development of the technologies. The shortening of operating time combined with quality improvement is expected. Thus, a wider metrological analysis is needed, which ensures complete knowledge about the manufactured product. The measuring devices of higher accuracy should be applied.

One of the solutions is to use specialized devices for particular metrological tasks – e.g. for roundness measurement. However, in such a case, many specialized devices must be purchased. To avoid this, a Coordinate Measuring Machine may be applied for many tasks. CMM combines many conflicting characteristics like accuracy and elasticity with high speed of measurement. It may be stated that CMM is able to perform measurement at the same tempo as the manufacturing process runs. The idea of coordinate measurement is to analyze the coordinates of the localized measuring points. Those points are used to determine any geometrical shape of the measured detail, such as point, line, plane, circle, cylinder, and so on. When the diameter of a circle is to be calculated mathematically, the coordinates of three measuring points are enough. In metrology, in order to reach a higher certainty, the minimal point number is four. However, the higher the number of points, the higher the "certainty" of the achieved result of measurement. In the case of a circle, the measured parameters are: diameter (radius), coordinates of the center and the form deviations.

Industrial practice indicates that pulse measuring heads are used mostly for measurement with a minimal recommended number of points. In many cases, circles are measured with 4 points, and hardly ever with more than 16 points. The performed investigations proved that this is not enough, especially as the measured detail is to be combined with other in narrow tolerance [1].

2. THE CALCULATED FITTING ELEMENT IN THE ROUNDNESS MEASUREMENT RESULTS

The results of circle measurement are influenced by the following factors: the number of measuring points, the distribution of points and the chosen fitting element. The standard ISO 6318 gives four fitting elements for a circle: Least Square Circle (LSC), Minimal Circumscribed Circle (MCC), Maximal Inscribed Circle (MIC) and the Minimal Zone Circle (MZC) (see Figure. 1).

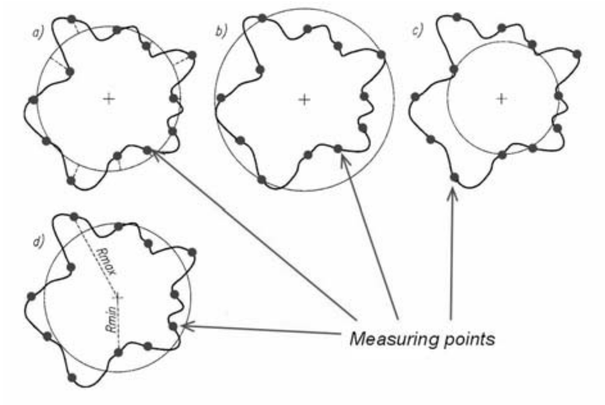

Figure 1. Fitting elements according ISO 6318: a) Least Square Circle (LSC), b) Minimal Circumscribed Circle (MCC), c) Maximal Inscribed Circle (MIC), d) Minimum Zone Circles (MZC)

The most commonly used fitting element is the Least Square circle, which is inappropriate in many cases, especially for moving joints with narrow tolerance. The Gaussian method gives the „mean" shape of the measured detail. When the measured circle is to cooperate in narrow tolerance, the measurement with Minimal Circumscribed Circle (MCC) or Maximal Inscribed Circle (MIC) should be performed.

The research on errors of fitting methods has been performed for several circles placed in the examined detail [2]. Fig. 2 shows the differences between radiuses calculated for the same measuring points, but using different fitting methods. The results differ between one another, and mostly from the correct one.

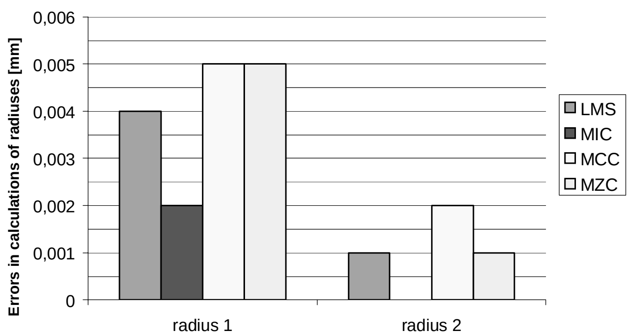

Figure 2. Errors generated by the fitting model

The software analysis shows that in most cases (up to 90% of measuring tasks) the Gaussian fitting method is used. Surprisingly, this most common fitting method shows the lowest level of correct results – only 8% [2]. Moreover, it is absolutely inappropriate for some measuring tasks. E.g. for obvious reasons, it is recommended for the shafts MCC method, and for the openings MIC method. This way, the information on the center position is achieved, and above all on actual diameter determining the ability of examined details to be joined and to cooperate.

3. MINIMAL NUMBER OF THE POINTS USED FOR THE MEASUREMENT

The investigation proved that a so-called minimal number of points (4) is not enough for the circle measurement. The calculated values of the diameter, position of the center and the form deviation bear large error [1]. The achieved results are also influenced by type of the fitting element. In case of the ovality of a measured circle, 4 measuring points would generate substantially different results, depending on the position of the measuring points (Figure 3).

When the measuring points are placed on the far points of the oval, the Maximal Inscribed Circle may be placed in another disadvantageous way. It would be based on 3 points collected by measurement, which would affect the position of the center in one axis (Figure 4).

Additionally, the calculated coordinates of the circle center are affected by the errors of the CMM measurement. Those errors determine the direction of displacement of the calculated center. The value of displacement does not depend on the diameter of the circle, it depends only on the form deviation value. The larger the form deviation, the larger the displacement (Figure 5).

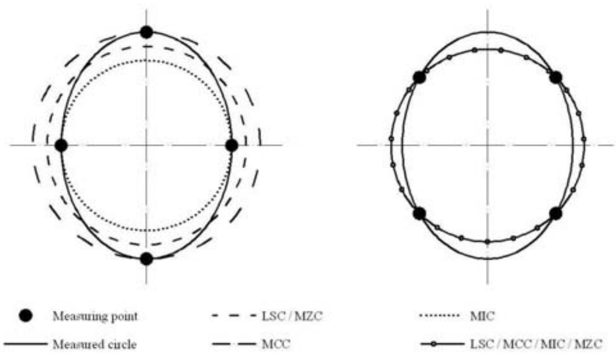

Figure 3. The results of roundness measurement influenced by the distribution of the measuring points and different fitting methods

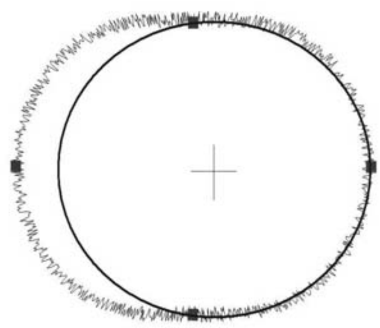

Figure 4. Measurement of the circle with ovality deviation using 4 points

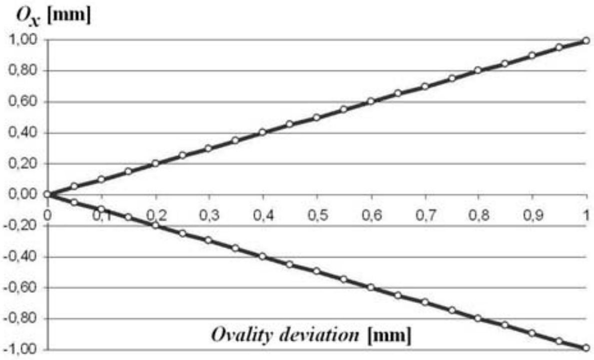

Figure 5. The circle center location O_x (in x-axis) versus the value of ovality deviation

4. THE INFLUENCE OF THE FITTING ELEMENT AND THE NUMBER OF POINTS ON THE CIRCLE MEASUREMENT RESULTS

In order to increase the effectiveness of the Coordinate Measuring Machine, an appropriate strategy of measurement should be worked out. Among other things, the number of points should be chosen for a particular measurement, depending on the purpose and parameters (tolerance, form deviations etc.) of the measured detail. An appropriate number of points ensures the achievement of correct results of measurement for a known uncertainty of the CMM, with the shortest operation time. The number of measuring points depends on the circle diameter, the form of the deviation model (determined by the technology of machining) and the assumed fitting element.

The larger the number of measuring points, the higher the accuracy of measurement, but pulse measuring heads require more operating time. It is not economically justified to collect a larger number of points with the pulse head, because of the operating time and damage of the measuring head. Each measuring head has a certain number of points it is able to collect without trouble. On the other hand, the scanning heads are designed to collect a large number of points. They are alternative for the pulse heads, but they are more expensive and require expensive control software. Thus, the recommendations should be worked out on an appropriate number of points for the given form deviation model and fitting element. Also such factors as the CMM's accuracy and the tolerance of the measured detail should be taken into consideration, too.

The research performed at the Division of Metrology and Measuring Systems proves that the minimal number of measuring points is absolutely not enough. However, it also shows that an excessive increase in the measuring points is unnecessary, because of further displacement of the circle center, the value of the radius changes and roundness deviations drop under the values of CMM's uncertainty.

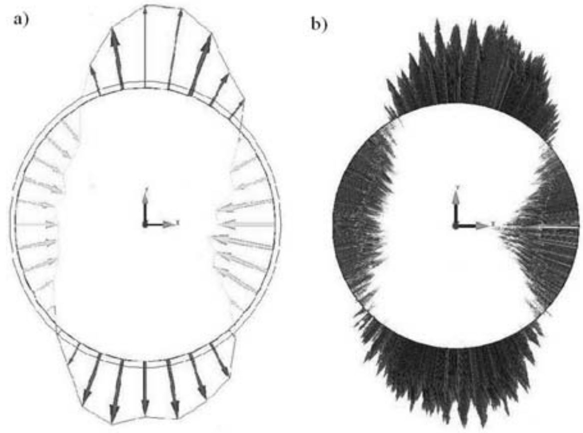

Figure. 6 Graphs of the form deviations: a) pulse measurement with 36 points; b) scanning measurement with 2992 points (10 points per mm)

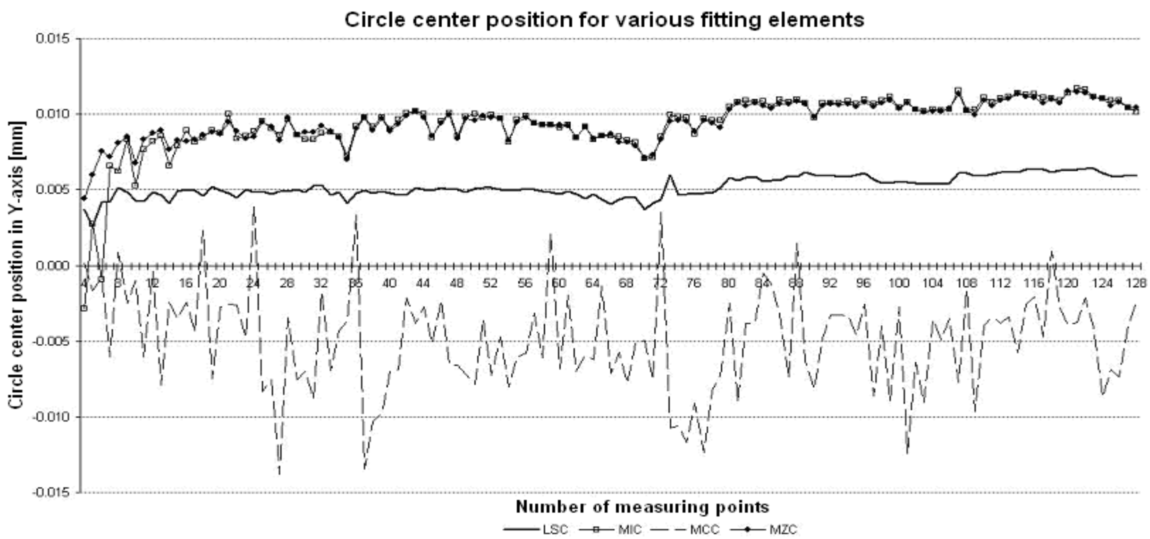

Figure 7. The influence of measuring points number on the calculated circle center position in Y – axis for different fitting elements (WMP-MPE$_E$ = ± (1.5 + L/333 [μm])

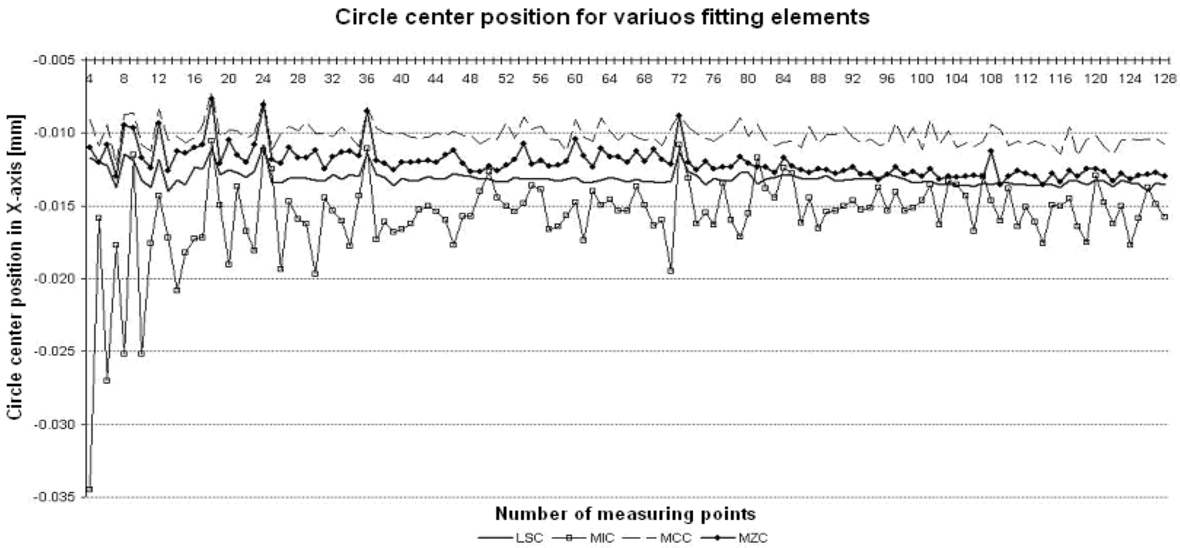

Figure 8. The influence of measuring points number on the calculated circle center position in X – axis for different fitting elements (WMP-MPE$_E$ = ± (1.5 + L/333 [μm])

Figure 6 presents the results of measurement of detail with form deviation (ovality). The measurement has been performed with two Coordinate Measuring Machines of uncertainty MPE$_E$ = ± (5 + L/200) [μm] and MPE$_E$ = ± (1,5 + L/333) [μm]. The achieved results confirmed the previous simulation results. The machines with different uncertainty generate the same character of changes in particular parameters. The difference is only in the value of results distribution for different uncertainty. In that case, the first stabilization of the circle center position appears for 36 measuring points. The second stabilization appears only after the number 72 is exceeded (Figure 7 and Figure 8).

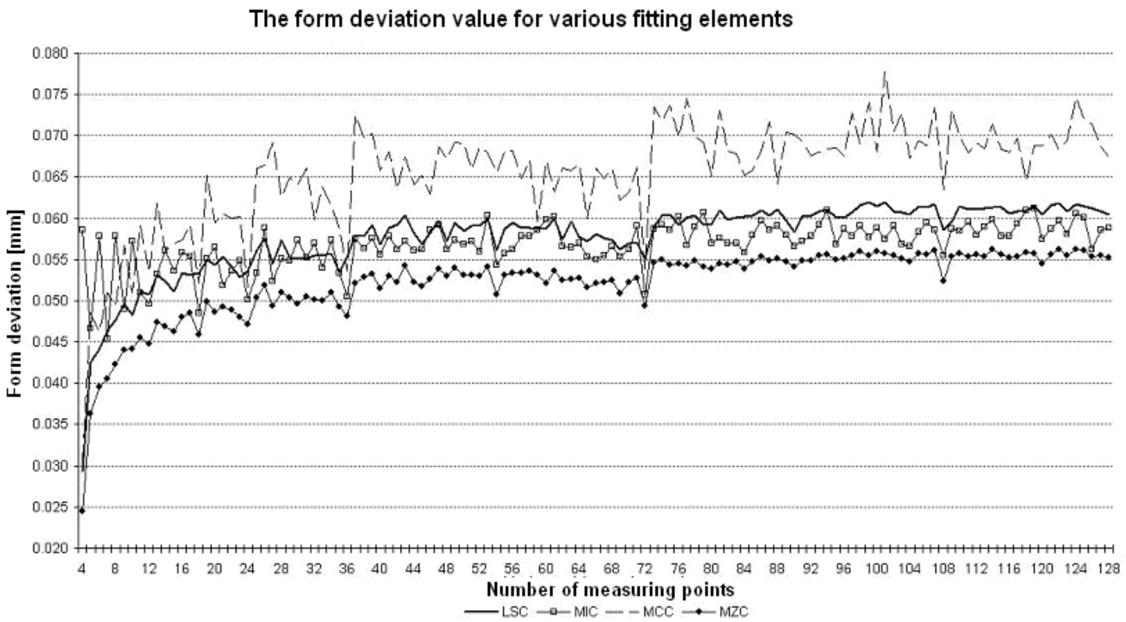

Figure 9. The influence of measuring points number on form deviation value for different fitting elements (WMP-MPE$_E$ = ± (1.5 + L/333 [μm])

When diameter is being measured, the fitting element plays an important role. The results for the Least Square Circle (LSC) and the Minimal Zone Circle (MZC) give similar results for any number of points from 4 to 128. The calculated radius value differs in the range of CMM's uncertainty. At the same time, the stabilization of the calculated circle position is reached when the point number is 36 both for the Maximal Inscribed Circle and the Minimal Circumscribed Circle. The second stabilization appears also after the number 72 is exceeded (Figure 9). Differences between MCC and MIC, as well as LSC and MZC, are determined by the definition of the fitting element itself, while the MCC and MIC methods describe the actual form of the detail. It influences the accuracy of the measuring detail evaluation in terms of its functional characteristics. The minimal number of measuring points is not enough for the measurement of roundness deviation. Just as in the case of circle center position, stabilization of the achieved value is reached after the number of points exceeds 36. Here also, the second stabilization is seen, which appears after the number of points reach 72. Similarly, as in case of radius, a small distribution of the results appears for the LSC and MZC models. When the number of points exceeded 72, the distribution would drop to the level of the CMM's uncertainty (Figure 10).

5. CONCLUSIONS

Coordinate Measuring Machines are able to perform the measurement of roundness. With that purpose, both pulse and scanning measuring heads may be applied. The limitation is determined by the uncertainty of the Coordinate Measuring Machine. It should ensure measurement with an accuracy of 10% of tolerance that is acceptable for measured detail. In some extreme situations, these limitations may be increased to up to 20% of tolerance.

The research described above has proven that a minimal number of measuring points (for the circle it is 4) is not sufficient and could generate significant differences in the results. It has been also proven that the functional characteristics of the measured element should be evaluated using models of the Minimal Circumscribed Circle for shafts and Maximal Inscribed Circle for orifices (sleeve).

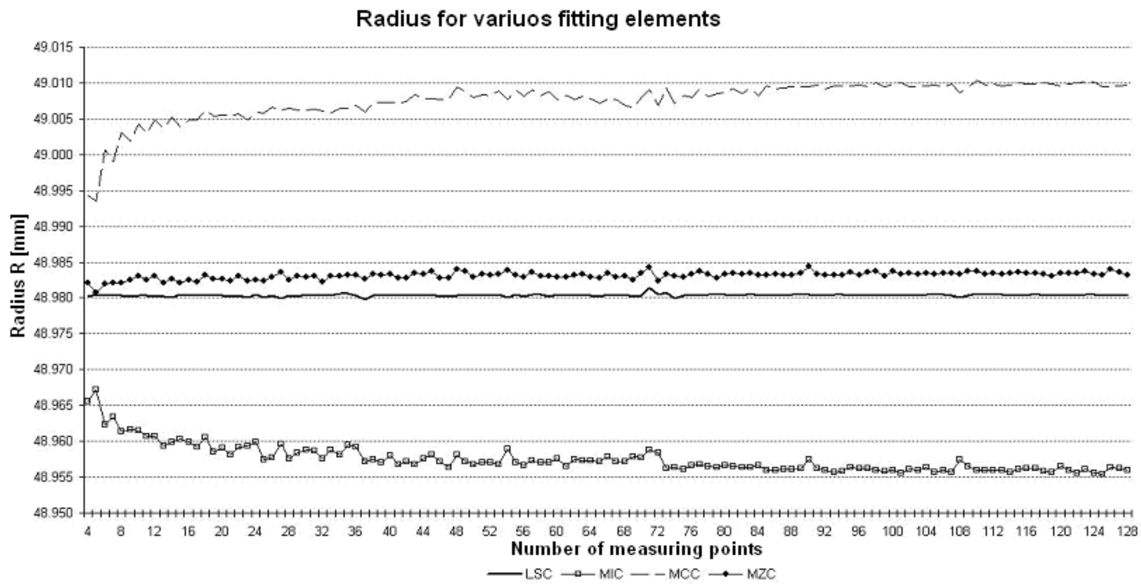

Figure 10. The influence of measuring point number on radius R for different fitting elements (WMP-PE_E = ± (1.5 + L/333 [μm])

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