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Measurement of Diameter and Roundness on Incomplete Outline of Element with Three-Lobbing Deviation

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Abstract

One of the most often produced and controlled elements in the engineering are shafts and holes. In many cases, they are responsible connections, requiring precise control. Measurement of a diameter or roundness deviation for the full profile are well known and commonly used process . However, in many cases it is necessary to measure an element with a incomplete contour . This paper presents results of research on the impact of the incomplete contour length on a diameter and form deviations. We studied the roundness of standard ring with deviation around 0.9 µm and an element of three-lobbing deviation of 37 µm. In both cases, the nominal diameter of the ring was 100 mm.

The study was conducted in two stages. The first one was connected with measurement of the roundness deviation for sections 180°, 90°, 45° while the reference was 36°. Measurements were carried out on a CMM and a formtester (FMM). Results show that for the standard ring with decreasing length of the incomplete contour followed by a decrease of roundness. In the case of the three - lobbing ring the section 180° has a form difference value coincides with the value for full profile, while for shorter angular sections those values are greatly diminished.

In the second stage, detailed studies that apply measuring sections from 360° to 10° grading in 1° were conducted. Measurements were made for different positions of measuring sections according to the extremes of the outline. The values obtained for the ring with three - lobbing character of form deviation allow to conclude that the diameter remains practically constant for sections up to 210°. Then there is a change in their value which depends on the position of the outline section in relation to extremes. Also the roundness deviation value is constant up to about 210° and then falls and the around 36° reaches value below 1 µm. The studies lead to the conclusion that there is a strong influence of angular measurement section and its position relative to the outlines extremes on achieved the diameter and form deviations.

Keywords: diameter measurement; form deviation, roundness; accuracy of measurement; incomplete contour

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1. Introduction

Consumer's requirements for various types of product are connected with continuous improvement of product quality. The issue of quality can be widely treated in this case – starting from a correctness of manufacturing of particular subassemblies, manufactured mechanisms and ending on a service, trainings or operation costs. The offered prices should not be higher than previous consumer prices. This forces the manufacturer to solve the difficult task which is a connection of two contradictory requirements. This situation exacts the use of innovative solutions which allow for a cost reduction on each stage of designing and manufacturing. In connection with this situation, composite materials, manufacturing processes which reduce the waste materials and etc. should be used. In order to confirm the rightness of made activities, it is necessary to conduct different types of control-measuring works. In addition, the general increase of requirements causes that full control of particular geometrical features is needed [1, 2, 3]. The measurement of elements which are circular sectors exacts this control too.

The measurement of the part of a circle is not a trivial task – in case of both cylinder and hole. Depending on the type of measuring task, it is required to give a position of circle centre or origin of radius, diameter or radius of circle/arc and the value of form deviation [4].

2. The possibilities of measurement of a circle with incomplete contour

There are many possibilities of measurement of the part of a circle, i.e. the measurement of an arc [5, 6]. Workshop methods for the verification of radius are based on e.g. contour masters. These tools allow to fit the arc contour to the master and to estimate the approximate value of outer or inner radius. Versatile and accurate methods allow to measure not only the diameter/radius, but also form deviations. It is possible to apply the coordinate measuring machines or formtester [7, 8, 9, 10, 11, 12].

3. Preliminary measurements of the master ring

The master ring with diameter of 100 mm and undefined type of roundness deviation with the value of 0.9 µm and the ring with defined type of roundness deviation – 3-lobbing, with the value of 0.037 mm and diameter of 101.6 mm were measured during the investigations [13, 14].

Each element was measured in a scanning mode with CMM and form measuring machine (FMM). Full contour of the ring – 360° was measured and it was taken as a reference value. Next, incomplete contours were measured for the following sectors: 180°, 90° and 45°. Reduction of measuring length causes that obtained information is only referred to a part of the contour. In order to verify the possibilities of detection of form deviation in relation to the position of measuring length and contour extremum, the following measurements were performed:

- contour of 180° which was measured 4-times – arranged at every 90°,
- contour of 90° which was measured 8-times – arranged at every 45°,
- contour of 45° which was measured 16-times – arranged at every 22.5°.

Figure 1 presents the measurement results of the master ring with the use of CMM. Each line in this figure denotes the different angular range of the measurement. Axis of abscissae shows the angular scale which allows to present the values of roundness deviation in relation to angular position of the starting point of contour measurement. Figure 2 presents the measurement results of the master ring with the use of FMM.

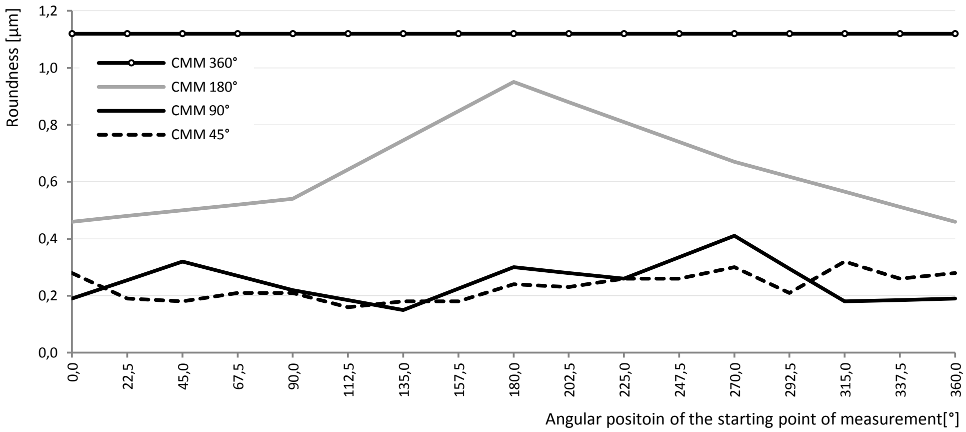

Fig. 1. Measurement results of the master ring with the use of CMM for the defined incomplete contours of circle.

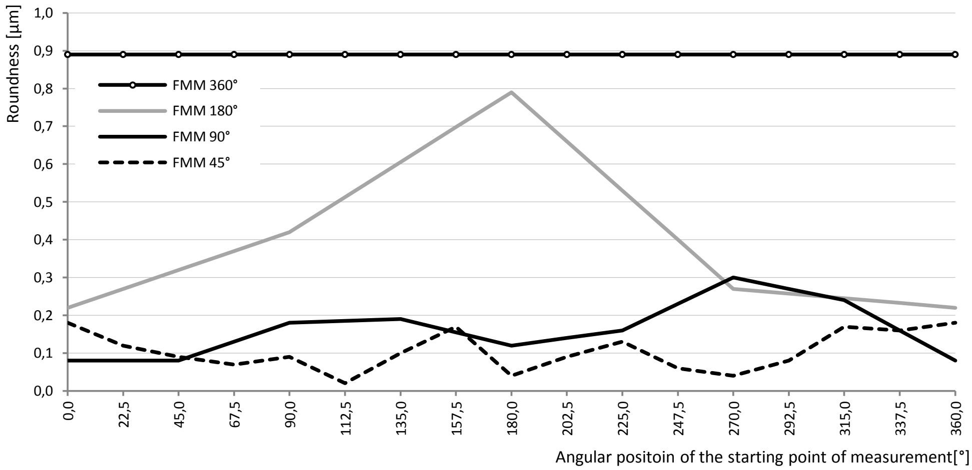

Fig. 2. Measurement results of the master ring with the use of FMM for the defined incomplete contours of circle.

The analysis of the presented measuring data allows to affirm that the results which were obtained with CMM and FMM are converged and the differences are in a range of 0.4 µm. The highest values of deviation were observed for full contour for both devices. Contour of 180° allows to obtain lower deviations, whereas the values of roundness deviation for contours of 90° and 45° are converged – these values are the lowest ones.

The master ring is characterized by very small value of roundness deviation and undefined type of roundness deviation. This situation causes that we can obtain stable values for contours of 90° and 45°. This results from the fact that local peaks and cavities are not present at the circumference of the ring. Therefore, the values of deviation are on a constant level irrespective of the position of the measured contour. In comparison with full contour, the values for these two contours are smaller, because we can't detect all peaks and cavities during the measurement of the part of contour.

4. Preliminary measurements of the ring with 3-lobbing deviation

After the preliminary measurements of the master ring, the measurements of the ring with 3-lobbing deviation were conducted. The ring was measured with the use of CMM (fig. 3) and FMM (fig. 4). The obtained measuring data are illustrated in diagrams by four lines which denote different angular positions of measuring contours. Axis of abscissae shows the angular scale which allows to present the values of roundness deviation in relation to the angular position of measuring length.

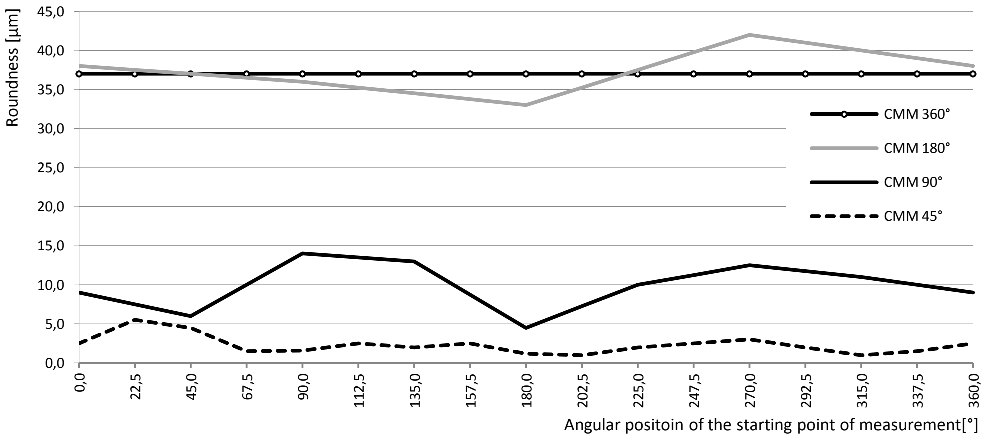

Fig. 3. Roundness of the ring with 3-angular deviation measured with incomplete contour of a circle on the CMM

Fig. 4. Roundness of the ring with 3-angular deviation measured with incomplete contour of a circle on the FMM.

On the basis of analysis of the obtained results from CMM (fig. 3) and FMM (fig. 4) we can observe that the results are converged. Difference between the values of roundness deviation which were obtained from these two devices for full contour does not exceed the value of 0.5 µm. This difference is within the area of measuring uncertainty for both devices, so it can be taken as a correct value.

In case of measurement with the contour of 180 ° a greater difference in the value - of up to 0005 mm can be observed. However, comparison of results for both devices shows a common trend in changing roundness deviation values according to the position of the measured profile . In both cases, the obtained values are greater than those from measurement on the complete profile . Only for the measurement starting from the position 180 ° the deviation value is smaller . The increased value for the 3 – angular contour is related to the fact that the measured comp covers only one extreme circular profile. In the case of the starting the comp outline on 180 °, it covers two extremes which are located at its ends (for 3-angular - peaks or valleys are arranged on every 120 °). This results in a smoothing the profile and at the same time decrease the deviation.

The outlines of the angular length of 90 ° is characterized by similar changes in the value of deviations in shape depending on the initial position of the measuring point. The differences between the coordinate measuring machine and a specialized device for measuring the shape deviations is between 0,001 – 0,002 mm . According to given measurement uncertainty of the CMM for roundness deviation U_{95} = 1.5 µm and U_{95} = 0.3 µm for FMM, it should be noted that these results are consistent . As for outline 180 ° the 90 ° outlines showa similar trend in changes in the value of the deviation for both measuring devices. For outlines 90 ° roundness deviation value is significantly lower than the outline of a complete one and stands at 0.005 - 0.015 mm. Similarly, for the outlines of 45 °, but in this case, the roundness deviation does not exceed 0.005 mm . Roundness deviation obtained for 90 ° and 45 ° are much smaller value than on the full outline and 180 °. This is due to the fact that in the respective case the roundness deviation of the test values are affected by the contour extrems (peaks and valleys) . In the case of a short segment of the outline taken into consideration it is not possible to capture the two extremes of positive and one negative or two negative and one positive . This results in a decrease in roundness deviation .

5. Detailed investigations of the master ring and the ring with 3-lobbing deviation

On the basis of analysis of the preliminary investigations we decided to verify in details the influence of length of measuring sector on the value of roundness deviation and diameter. On the basis of the preliminary measurements it was found that the results obtained with the use of CMM and FMM are converged. Therefore, during detailed investigations we used only the FMM which enable the measurements with lower uncertainty.

The measurements were conducted for angular length in the range of 360° - 10° with a step of 1°. The measurements were performed for the elements which had been used in the preliminary investigations. The master ring had very small value of form deviation and its type of deviation was undefined. For this case of element, the position of measuring length has not any influence on the obtained values – this fact was shown in the preliminary investigations.

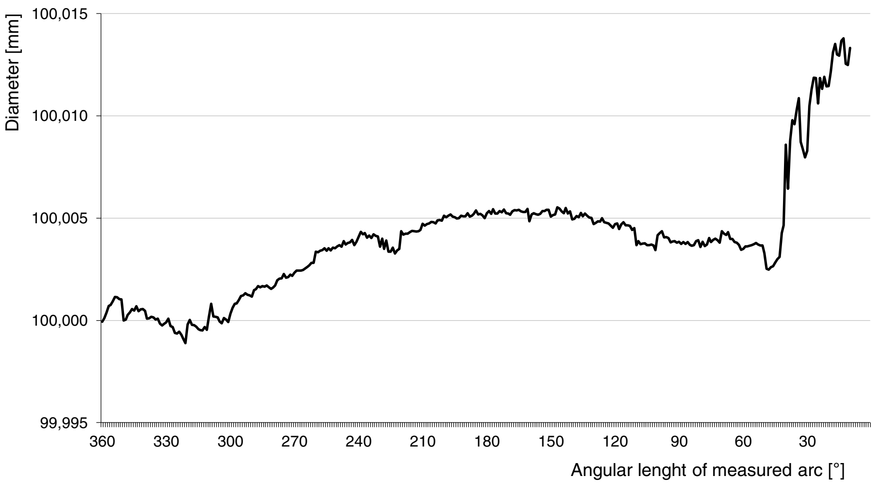

Fig. 5. Measurement results of diameter of the master ring for measuring sectors with different angular lengths.

On the basis of measurement results of diameter of the master ring (fig. 5) it was found that during the first stage (up to ca. 300°) the diameter value is constant. In the range of 300° - 50° this value increases and alters in area of 0.005 mm. For the measuring sectors with angular length below 50° we can see a rapid increase of the diameter value of the measured element – i.e. 0.014 mm higher than the actual diameter.

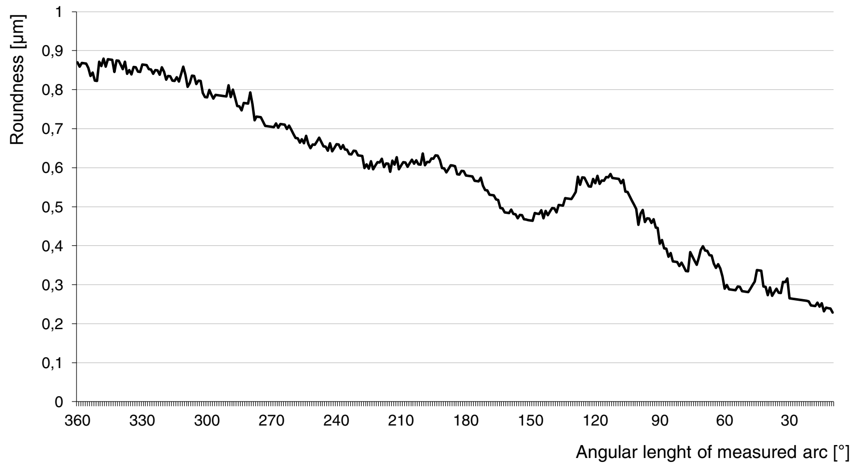

Fig. 6. Measurement results of roundness deviation of the master ring for measuring sectors with different angular lengths.

Figure 6 presents the variation of the value of roundness deviation for the master ring. We can observe that the value of this deviation decreases when measuring sector is reduced. This inclination can be seen from the deviation value of 0.9 μm for full contour of 360° up to the deviation value of 0.2 μm for contour of 10°. It can be stated that this inclination is linear approximately.

For the case of the measurement of the ring with 3-lobbing deviation we can observe three special cases – the middle of measuring length can be placed in positive or negative extremum of contour or between these two extrema. During the detailed investigations, these three cases were verified.

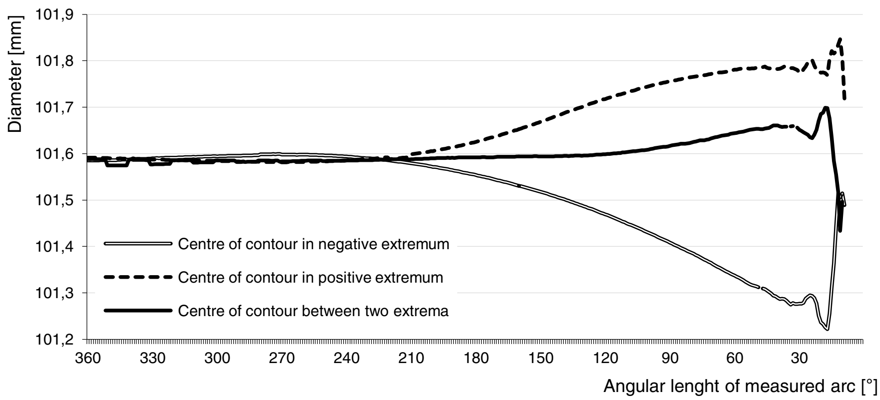

Fig. 7. Measurement results of diameter of the 3-lobbing ring for measuring sectors with different angular lengths.

Analysis of data presented in Figure 7 lead to conclusions that in this case the diameter value for all three positions measuring section is practically constant in the range from 360 ° to 210 °. For the range from 210 ° to 18 ° there is a noticeable change in the diameter. For the measurement section, the middle of which is located between the extremes of the circle diameter value slightly increases to a section of 120 °, then the value increases more significantly reaching 101.7 mm for 18 °. For the measurement section, the middle of which is located in the extreme negative value of the diameter, the contour length decreases from 210 ° and has a 101.23 mm for 19 °. It can be concluded that for a section of an angle of 18 ° difference of diameters result from the location of the test section is

0.6 mm. A length of less than 18 ° does not guarantee they are short enough that the value of the diameter is determined correctly. One can observe a sharp reversal of the sections length in the range of 18 ° - 10 °.

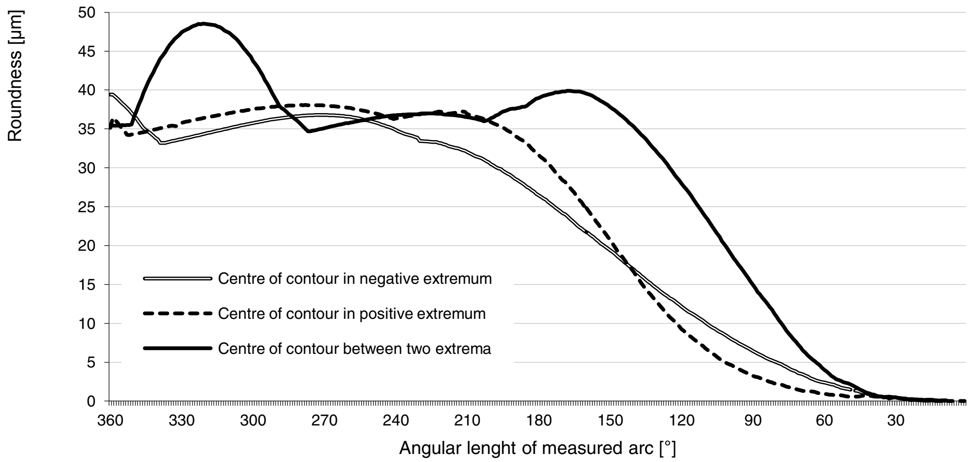

Fig. 8. Measurement results of roundness deviation of the 3-lobbing ring for measuring sectors with different angular lengths.

Figure 8 shows the roundness deviation change depending on changes of the section angular length. Analysis of presented measurement data it can be concluded that the nature of changes in roundness deviation is similar to the test section the middle of which is located in the negative and positive extreme. In both cases, together with the shorter section measuring roundness deviation value increases to 0.003 mm reaching a maximum segment length of 270 °. Then, we observe a decrease of roundness deviation to less than 0,001 mm for the section of less than 40 °. When the test section for which its middle lies between the extremes of the circle outline, significant increase of deviation to 0,049 mm long section of 319 ° was observed, and then decrease to a value corresponding to the deviation for the full outline for a section of 278 °. Then, in the range 278 ° - 204 ° roundness deviation value increases slightly. In the 203 ° - 166 ° value for roundness increases to 166 ° and reaches 0,040 mm. After reaching the roundness deviation value decreases to less than 0,001 mm long section of 36 °. We conclude that the value of the diameter and the roundness deviation vary considerably depending on the angular position and length of the measurement section.

6. Summary

The paper presents a part of the investigations which are conducted in a scope of the influence of measurement of incomplete contour on the values of roundness deviation and diameter. The analyses were done on the basis of the results of investigation which had been obtained with the use CMM and FMM. Discussed in the paper phenomenon of incomplete profile measurement is not subject to a broader analysis in the literature. Measuring practice and experience of the persons involved in the coordinate measurements show that the measurement of the incomplete circle is not easy - especially for shorter arc of 180 °.

Two series of investigations were performed. First, the preliminary investigations were conducted in order to verify the impact of measuring sector with angular length of 360°, 180°, 90° and 45°. Next, the detailed investigations were performed for measuring sector lengths in the range of 10° - 360° with a step of 1°. These investigations have showed that roundness deviations do not always decrease when measuring length is reduced. The position of measuring length in relation to extrema of contour has also an appreciable influence on the value of roundness deviation. The higher the deviation value for full contour, the higher the variation of deviation for reduced measuring sector length. The variation of length of measuring sector and its position have also the impact on the measured value of diameter.

For the case of the master ring, these variations are small. This is due to the fact that the standard ring have form deviation of small value , and its character is a component of many harmonics. For such case shortening the length of the arc causes a change of the measured diameter values and the deviations of shape, but it is relatively small. Undefined form deviations and its low value causes evenly distribution of peaks and valleys in the measured portion of the outline . Consequently, there are strong local changes in the radius that may have a strong impact on the final result of the measurement. When measuring element has three – logging deviation, changes in diameter and roundness tolerances which result from shortening the length of the angular measurement section are more noticeable . This is due to a kind of imbalance between the effects of positive and negative deviations from the reference circle for the measured profile. Shortening profile below 210 ° in the case of measuring the diameter will change its value. In the case of the center of the measuring section on the extreme positive diameter increase while positioning it the middle section on the extreme negative effects in decreases value. It should also be noted that for a section of less than 30 ° the value of the diameter change very much. In the case of the roundness of its value begins to fall for the section of less than 180 ° . This is due to the fact that the length of the test section becomes dominant fragment resembling a bow . So replacing circle may be better suited to the measured profile.

To sum up, we concluded that the measurement of diameter and roundness deviation for incomplete contour is ambiguous and the obtained values depend on many factors. The paper presents part of carried investigations and discusses the impact of three – lobbing deviations on the value of roundness and diameter when measured incomplete profile of a circle with a different length of arc. The authors wish to carry out more extensive analysis of this phenomenon, and the results of an oval circle have already been published [14].

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