VERIFICATION OF THE CONCEPT OF SPHERICITY MEASUREMENTS BY THE RADIAL METHOD UNDER INDUSTRIAL CONDITIONS

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Abstract

At the Kielce University of Technology a new concept of accurate measurements of sphericity deviations of machine parts has been developed. The concept is based upon measurement of roundness profiles in many clearly defined cross-sections of the workpiece. Measurements are performed with the use of typical radial measuring instrument equipped with a unit allowing accurate positioning of the ball. The paper presents results of the verification of the developed concept under industrial conditions.

Keywords: measurement, sphericity, radial method

1. INTRODUCTION

The evaluation of geometrical surface structure is a crucial matter in modern manufacturing processes [1, 2]. Among elements utilized in mechanical engineering a particularly important group constitute spherical machine parts that are used mainly in the bearing industry. Measurement of such elements are usually performed with the use of radial instruments. In practice form errors of spherical machine parts are usually evaluated on the basis of results of measurements of roundness profiles in a few selected cross-sections of the specimen. Such approach allows only a rough evaluation of form errors, particularly if there are local irregularities on the surface. A new concept was thus developed at the Kielce University of Technology to enable measurement of spherical specimens along some predefined trajectories so that the surface is densely covered with a grid of points. This approach assumes that measurements can be performed using a typical radial roundness measuring instrument equipped with a special unit for controlled positioning of a measured element.

2. THE PRINCIPLE OF THE NEW CONCEPT

The concept of using typical radial instrument to measure sphericity deviations of machine parts is presented in Fig. 1. The concept required to solve numerous theoretical and practical problems. Therefore the work on development of the concept has been divided into two stages.

The theoretical part of the research work included:

- a definition of an example of a spherical surface;
- the choice of a relevant measuring strategy;
- generation of profiles and their matching;
- filtration of profiles;
- determination of the reference sphere;
- determination of sphericity parameters;
- an approximation of the measured profile with a surface [3].

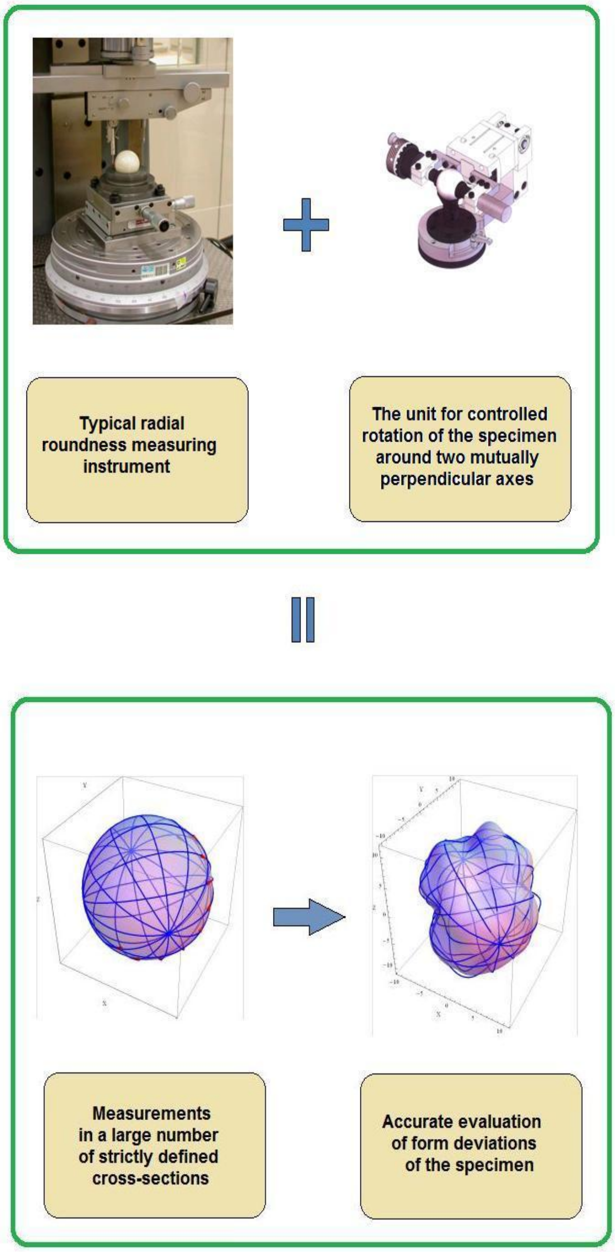

Fig. 1: The concept of the sphericity measurement by the radial method

The practical part of the work included design and construction of the unit for controlled positioning of the measured sphere. Successful solving of above mentioned theoretical and practical problems would make it possible to evaluate deviations of the spherical element on the basis of the set of roundness profiles measured in clearly defined cross-sections. There were numerous measuring strategies tested during the experiment and finally the “cage” strategy was selected to be applied at the verification of the concept under industrial conditions. The trajectory of sensor displacements in the “cage” strategy is shown in Fig. 2.

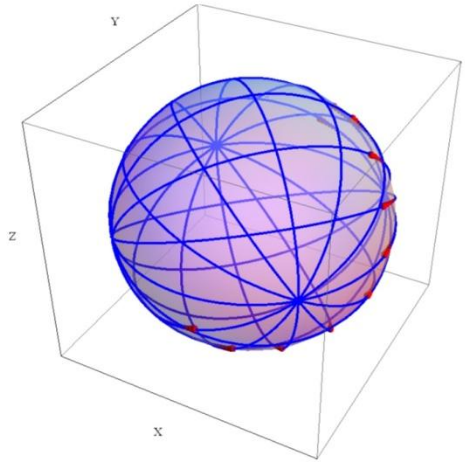

Fig. 2: The “cage” strategy” applied during the experimental verification of the concept

3. EXPERIMENT

In order to verify the concept experimentally the unit for accurate positioning of spherical elements was designed and constructed in the frames of the research grant financed by Polish Ministry of Science and Higher Education.

The unit is shown in Fig. 3.

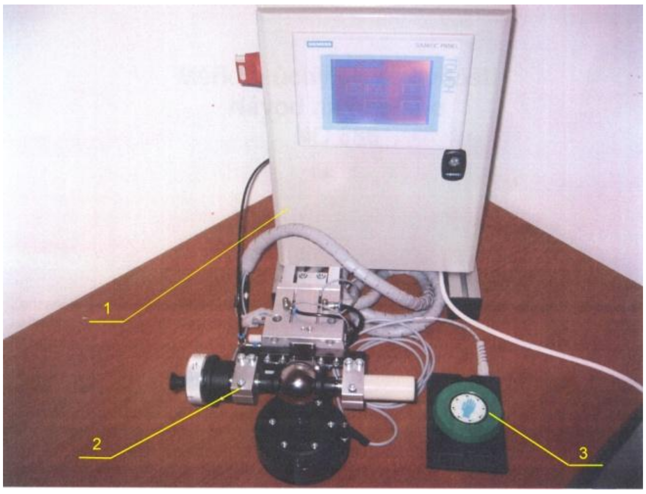

Fig. 3: The system for controlled positioning of the sphere with the setup for catching and lifting of measured elements:

1 – controlling unit, 2 – unit for positioning of spheres, 3 – the controlling button

The verification consisted of measurements of fifty 2 inches bearing balls firstly on the model measuring device and then by the traditional method that is commonly applied in industry, i.e. evaluation of roundness deviations in a few cross-sections of the sphere.

After the measurement data were saved in the computer memory and then transferred to the software permitting accurate analysis of sphericity deviations.

Measurements under industrial conditions were performed with the use of the instrument MWA, series C, by SKF. The measurements were carried out in the way typical for Bering industry, i.e. a roundness deviation in a random cross-section of the ball was evaluated. There were 1024 sampling points taken in one cross-section. The rotational speed of the sensor was equal to 9.837 rev./min. The reference element was the least squares circle. The value of the roundness deviation was determined for unfiltered profile. For each element a diagram of the measured profile was plotted as well as a bar chart of harmonic components. The maximum number of harmonic components was 128. The example of the measurement protocol is shown in Fig. 4.

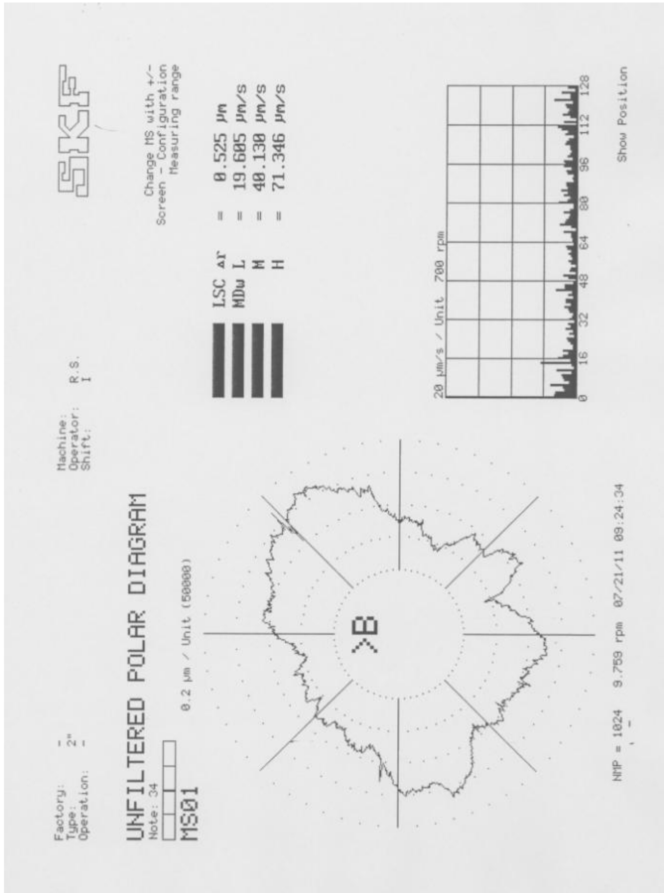

Fig. 4. The protocol of the traditional evaluation of deviations of spherical element

4. RESULTS

For the traditional method the total roundness deviation RONt was determined, whereas for the new method the total sphericity deviation was determined.

The absolute and relative difference between results was also calculated. Relative value was denoted by $w_{\Delta S}$. It was calculated assuming that the reference value is the result obtained by the traditional method (see equation 1).:

$$w_{\Delta S} = \frac{St - RONt}{RONt} \qquad (1)$$

where:

$RONt$ – roundness deviation obtained by the traditional method,

St – sphericity deviation obtained by the new method

In order to see the differences more clearly a diagram show in Fig. 5 was plotted. The diagram shows values of form deviations obtained by the traditional and the new method.

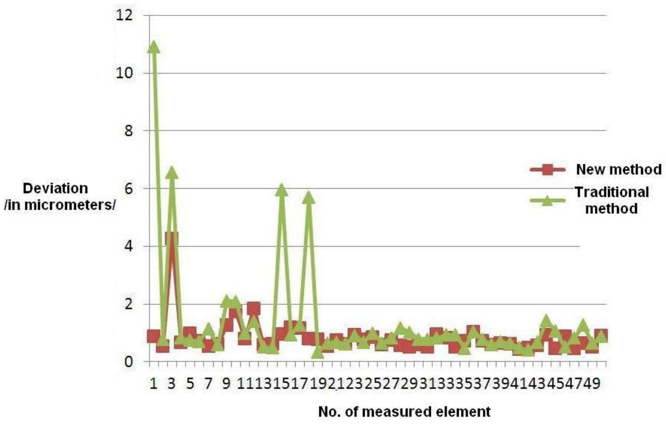

Fig. 5. Deviations evaluated with the use of the new and traditional method

In order to analyze the difference more precisely a diagram shown in Fig. 6 was plotted. It presents relative differences between the results obtained by the traditional and the new method.

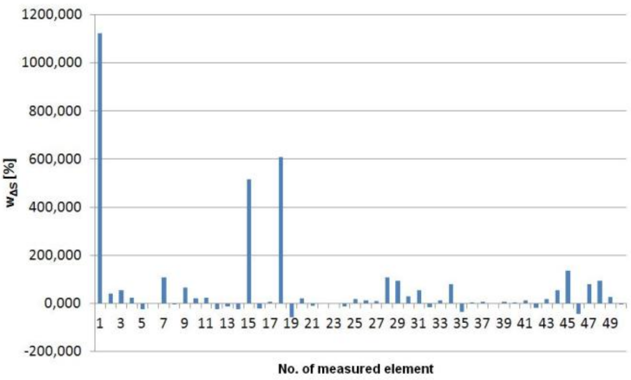

Fig. 6. Relative difference between values of deviations obtained with the use of the new and traditional method

Taking into account the results the surface of elements no. 1, 15 and 18 was examined more accurately, as for these elements differences are abnormally high. It turned out that there are very large local irregularities on the surface of elements no. 1, 15 and 18. These irregularities were not detected by the traditional method, whereas the new method was able to detect them. Thus, one can assume that the method can be very useful in accurate measurements of spherical elements. More accurate analysis of differences between results for most of elements is possible if we ignore extremely high values (i.e. results for elements no. 1, 15 and 18). Fig. 7 presents the diagram of relative difference between results after ignoring values for elements no. 1, 15 and 18.

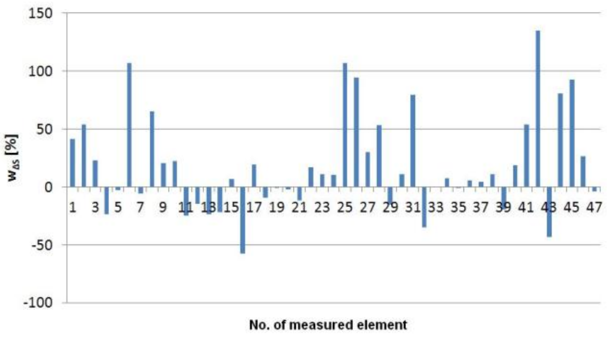

Fig. 7. Relative difference between values of deviations obtained with the use of the new and traditional method after ignoring elements no. 1, 15 and 18

5. DISCUSSION

An analysis of diagram presented in Fig. 7 shows that even after ignoring extremely high values, differences between obtained results are very significant. In order to evaluate the difference statistically, following values were calculated: , maximum, minimum and mean difference as well as a standard deviation. The calculations were performed twice: firstly for all results, and then without results for elements 1, 15 and 18. The results of the calculation are presented in the Table 1. Taking into account interpretation of the results, absolute differences were analyzed. Then, regarding a measurement obtained by the traditional method as a reference and assuming reliability level P=0,95 a confidence level was calculated for a singular sphericity measurement. Another parameters that were evaluated are following: changeability coefficient and method accuracy. The calculations were performed with the use of equations given below:

- confidence level:

$$\left\langle \bar{w}_{\Delta S} - u \cdot s(w_{\Delta S});\ \bar{w}_{\Delta S} + u \cdot s(w_{\Delta S}) \right\rangle \qquad (2)$$

where: $\bar{w}_{\Delta S}$ - mean value of relative difference,
u – expansion coefficient (for assumed reliability level u=2),
s – mean square deviation of a singular difference.

- changeability coeficient V:

$$V = \left\langle \frac{s(w_{\Delta S})}{\bar{w}_{\Delta S}} \right\rangle \qquad (3)$$

- method accuracy:

$$DM = \left| \bar{w}_{\Delta S} \pm us \right|_{max} \qquad (4)$$

Using equations given above there were obtained results give in Table 2. The calculations were performed for two data series: first included all results, in the second results for elements no. 1, 15 and 18 were removed.

Table 1: Statistical parameters for evaluation of relative difference between results obtained by New and traditional method.

$w_{\Delta S}$ [%] (for all elements)		**$w_{\Delta S}$ [%] (elements no. 1, 15 and 18 removed)**	
Mean value $\bar{w}_{\Delta S}$	75,42	Mean value $\bar{w}_{\Delta S}$	32,41
Maximum value $w_{\Delta S\,max}$	1123,09	Maximum value $w_{\Delta S\,max}$	135.09
Minimum value $w_{\Delta S\,max}$	0,165	Minimum value $w_{\Delta S\,max}$	0,165
Mean square deviation $s(w_{\Delta S})$	187,02	Mean square deviation $s(w_{\Delta S})$	33,34

Table .2. Parameters describing method accuracy

Parameters of the method accuracy (for all results)		**Parameters of the method accuracy (results no. 1, 15 and 18 removed)**	
Confidence level [%]	<-298,62;449,47>	Confidence level [%]	<-34,24;99,07>
Changeability coefficient	2,48	Changeability coefficient	1,03
Method accuracy[%]	449,47	Method accuracy[%]	99,07

Results presented in Table 1 show that if one regards all measurements, then the accuracy of the method is equal to 449,47 %. If we ignore results for elements no. 1, 15 and 18, then the accuracy is a little lower, it is equal to 99,07 %, but it is still very high value. It proves that measurement results obtained by the new and the traditional method are totally incomparable. Obtained values of statistical parameters show that the accuracy of the new method is very significantly higher than the traditional method.

6. SUMMARY

Form errors of spherical machine parts are usually evaluated on the basis of measurement results of roundness profiles in a few selected cross-sections of the investigated element. Such approach allows a rough evaluation of form errors only, particularly if there are significant local irregularities on the surface. This is the reason why at the Kielce University of Technology a new concept of sphericity measurements has been developed.

Results of experiments show that proposed method is quite easy to apply. Additionally, it can be more user-friendly if units for automated rotation of spheres were applied. Considering possibilities of practical application of described method one should note that proposed measurement system is relatively simple. It requires accurate instrument for radial roundness measurement and the unit for controlled rotation of measured spheres. Since radial roundness measurement instruments are very common proposed concept can be easily applied in industrial practice

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