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IMPLEMENTATION OF NOISE REDUCTION TO ROUNDNESS MEASUREMENT IN CROATIAN NATIONAL LABORATORY FOR LENGTH

V. Šimunović[1], G. Baršić[2]

[1] Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia, vedran.simunovic@fsb.hr
[2] Faculty of Mechanical Engineering and Naval Architecture, Zagreb, Croatia, gorana.barsic@fsb.hr

Abstract:

Measurement devices for form and roughness use the measurement probe that converts the displacement into an electrical signal. In addition to the form/roughness information, the measurement signal can contain undesirable noise due to mechanical, electrical, thermal, and other influences that can lead to an error in the measurement result. Given the growing demands to reduce measurement uncertainty, especially in the form and roughness measurement, noise is a limiting factor.

In 2019 the EMPIR project entitled Traceability for contact probe and stylus instrument measurements (18PRT01 ProbeTrace) was launched. This project aims to develop traceable and cost-effective measurement capabilities for the calibration of form and surface roughness standards with uncertainties in the range of 10 nm to 100 nm. To achieve targeted uncertainties, noise reduction software with numerical methods for random noise bias reduction must be developed to pre-process roughness and form profile data.

The novel method that will be investigated in the ProbeTrace project is based on Random Noise Bias Removal, where only a few repeated measurements are needed to obtain unbiased results. Software based on random noise bias reduction will be presented in this paper, along with the results of applied noise reduction to roundness measurement data in the Croatian National Laboratory for Length (FSB).

Keywords: roundness measurement; random noise bias reduction; Fourier reduction; random component exclusion

1. INTRODUCTION

Noise is a limiting factor in surface roughness and form metrology. As noise can come from different sources, there are different definitions. So, we differentiate instrument noise, measurement noise, static or dynamic noise, etc. Regardless of the source, noise has an extraneous effect that distorts the signal or inhibits its measurement. Hence, noise is one of the main challenges in surface roughness and form metrology.

The first step in the noise reduction process is to access the instrument and environmental noise by performing tests in static conditions to determine the noise level and characteristics. When testing in dynamic conditions, the effect of the measurement process due to the movement of instrument parts and dynamic contact of probe and specimen should be recorded.

In case of systematic noise, i.e., spindle error in roundness measurement, error separation techniques can be conducted to reduce the influence of systematic error on the measurement result. If noise is random but with dominated frequencies out of the region of interest of the measurement signal, then filtering can be used for noise reduction. If that is not the case, noise reduction methods like averaging of subtraction methods can be applied.

2. NOISE REDUCTION IN FORM AND SURFACE MEASUREMENT

Two methods can be employed to determine the measurement noise, one is based on the subtraction technique [1], and the other is based on averaging technique [2].

The subtraction technique requires two repeated measurements on the sample in quick succession at the same position. The data of one measurement is subtracted from the data of the other such that the resulting data only contains information about the measurement noise. The subtraction method combines the variances of two identical probability distributions that each characterize the instrument's noise. [2]

Current techniques for determining the measurement noise are based broadly on the assumption that the measurement noise can be decreased by averaging repeated measurements.

Averaging techniques used in dimensional metrology are presented in the paper [3]. One technique takes data at systematically chosen positions to remove errors that fit a particular form. Another is to take a large number of measurements at positions at which the errors are assumed to be uncorrelated. If the errors are normally distributed, their contribution to the averaged result reduces with 1/√n.

Another approach is the application of random noise reduction (noise bias reduction) in form and surface measurement recommended by Haitjema and Morel [4] [5] [6], which employs three steps:

Parameter extrapolation:

Extrapolation of roundness parameter *RONq* is described in [5].

Reduction of Fourier terms:

By reducing all Fourier coefficients, unbiased profile can be reconstructed by following steps:

- the Fourier transform is taken from the individual profiles, and the mean profile
- calculation given in [5] is applied to obtain the amplitudes of the noise-reduced profile
- inverse Fourier transform of this corrected spectrum is taken
- if a noisy frequency is encountered, the power may be reduced to a negative number. In that case, the power of the frequency is set to zero

Random phase exclusion:

The Fourier terms are sorted by statistical importance. Starting with the most significant frequency, the *RONq* parameter is calculated and compared to the extrapolated $RONq_{object}$ parameter. If the limit is not met, the next frequency is added to the spectrum until *RONq* meets $RONq_{object}$. [6]

A detailed explanation and calculation model can be found in [5].

3. NOISE DETERMINATION IN STATIC CONDITIONS

Croatian National Laboratory for Length uses roundness measuring instrument Mahr MMQ3 (Figure 1) with custom-made acquisition and software that incorporates all the relevant data analysis methods; roundness error evaluation, incomplete profile analysis, outlier detection, drift monitoring, spindle error separation with the multi-step method, Gaussian and Spline filtering in Fourier space and spectral analysis [7].

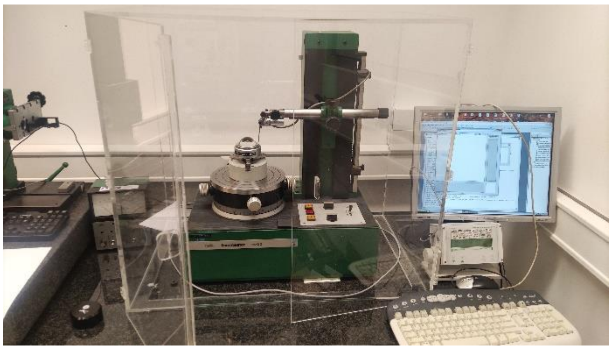


Figure 1: Roundness device at FSB

The accuracy and measurement uncertainty of roundness measurements at FSB is limited by spindle error and noise level. The subject of this paper is the determination of noise levels and the implementation of noise reduction methods.

To prevent errors caused by temperature gradient, a roundness device is placed in a shield that ensures temperature deviation ± 0.05 ºC during the measurement process.

The device probe has been fixed to determine the noise level in static conditions. The signal was recorded without a spindle rotation for 12 seconds, corresponding to the measurement time, Figure 2.

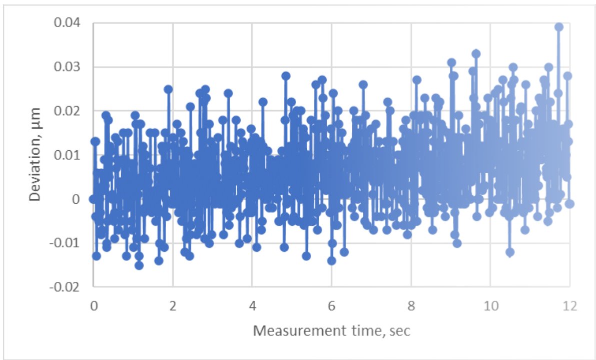


Figure 2: Noise level - static

The standard deviation of noise level equals s = 9 nm, and the measurement range equals R = 54 nm.

A special frame was made to allow spindle rotation with a fixed probe position, Figure 3. In that way, dynamic errors of spindle rotation are included in the measurement signal.

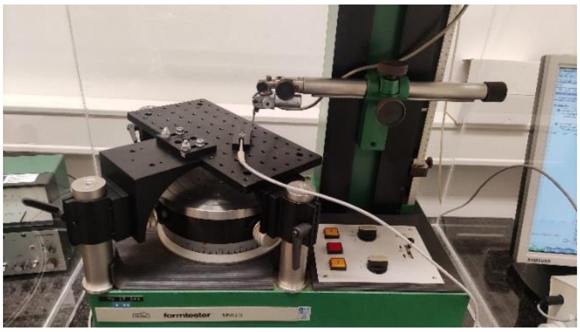


Figure 3: Measurement of noise – static with spindle rotation

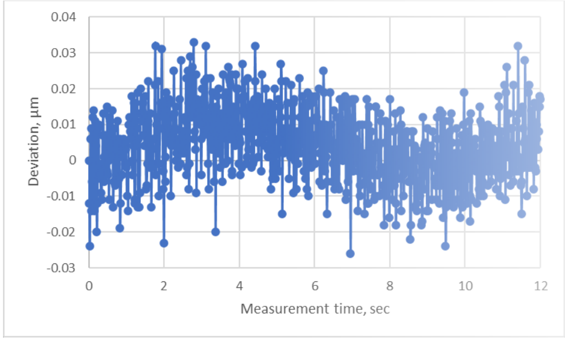


Figure 4: Noise level – static with spindle rotating

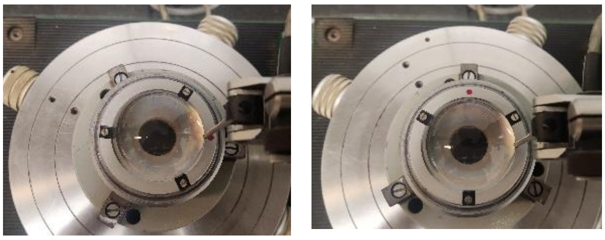
Calculated standard deviation of noise level equals s = 10 nm and measurement range equals R=59 nm.

4. RANDOM NOISE REDUCTION

FSB, as one of the partners in the ProbeTrace project, has developed a software toolset for random noise bias reduction based on Haitjema and Morel's work [4] [5] [6]. The toolset was written in Python as class NR with functions for Fourier reduction and random component exclusion methods and functions for calculating *RONt*, *RONq,* and *RONqobject* parameters. Upload of measurement data can be done from txt files.

Random noise reduction using developed software has been applied to measurement data obtained on the precise sphere. *RONt* of the sphere from the Calibration certificate equals 14 nm, with expanded uncertainty of 7 nm (k = 2).

Two sets of measurements, each with 10 repeated measurements, have been taken for different orientations of the sphere, as presented in Figure 5. In the first set, each measurement had 3600 points, and each measurement counted 660 points in the second set. The probe's position in Figures 5 a) and 5 b) also represents the initial position of the measurement.



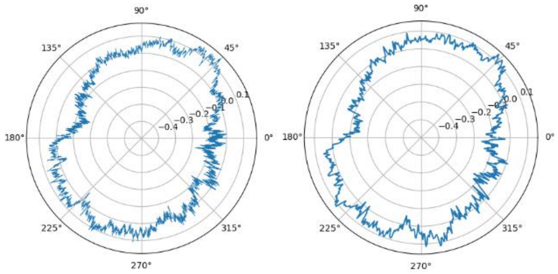
a) First orientation b) Second orientation

Figure 5: Sphere measurement

The results of the *RONt* are given in Table 1, and roundness profiles are presented in Figures 6 and 7.

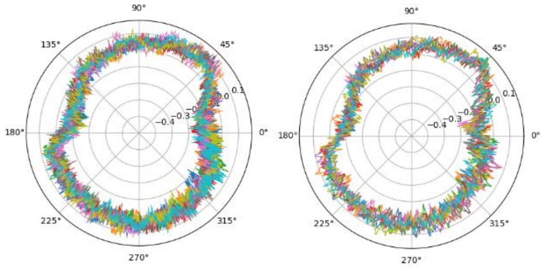
Table 1: *RONt* values on a precise sphere

Measurement No.	*RONt* - First orientation, µm	*RONt* - Second orientation, µm
1	0.344	0.299
2	0.308	0.307
3	0.288	0.341
4	0.335	0.299
5	0.324	0.298
6	0.303	0.299
7	0.317	0.334
8	0.333	0.303
9	0.340	0.353
10	0.338	0.309
Average *RONt*	0.323	0.314



a) First orientation b) Second orientation

Figure 6: First roundness profile



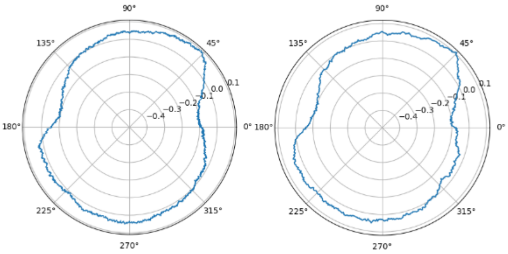
a) First orientation b) Second orientation

Figure 7: Repeated roundness profiles

The results of the *RONt* after filtering data using Fourier reduction and Random component exclusion methods are presented in Table 2, and roundness profiles are given in Figures 8 and 9.

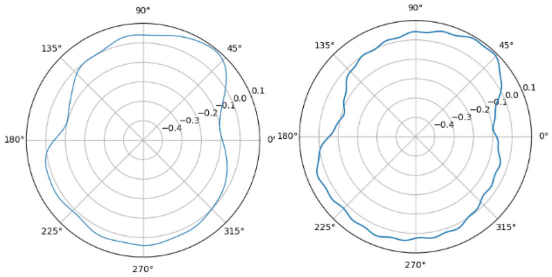
Table 2: *RONt* values on precise sphere after noise reduction

Filtering method	*RONt* - First orientation, µm	*RONt* - Second orientation, µm
Fourier reduction method	0.211	0.217
Random component exclusion	0.191	0.203



a) First orientation b) Second orientation

Figure 8: Roundness profiles after Fourier reduction method



a) First orientation b) Second orientation

Figure 9: Roundness profiles after Random component exclusion

5. CONCLUSION

This paper presents results of roundness measurement of the precise sphere at FSB using a noise reduction algorithm. Used noise reduction toolset employs functions for Fourier reduction and random component exclusion methods based on Haitjema and Morel's work.

As noise is the limiting factor in roundness measurement, the first part of this paper deals with the determination of static noise. It is determined that the static noise with spindle rotation turned on is in the range of ± 0.03 µm, which mainly comes from electrical and mechanical sources. Additional noise components resulting from the contact between the probe and the measuring object and spindle rotation errors were not examined.

In the second part of the work, two sets of measurements were carried out where the sphere was rotated by 90 degrees concerning the spindle. The measurements were carried out with different numbers of measuring points. From the measurement results, it is evident that the different orientation has no influence on the roundness results, so the form of the profile can be attributed to the systematic error of the spindle rotation of the device, which is recognized as the most significant influence on the measurement.

Given that the deviation from the *RONt* of the sphere from the Calibration certificate equals 14 nm, the measured *RONt* of 323 nm in the first orientation and 314 nm in the second orientation is primarily the result of a spindle rotation error and electrical noise in the measurement signal.

After noise reduction using the Fourier reduction method, the *RONt* value has been reduced to 211 nm in the first orientation and 217 nm in the second orientation. A similar level of noise reduction was found using Random component exclusion where the *RONt* value was reduced to 191 nm in the first orientation and 203 nm in the second orientation. The difference in the number of points taken in different orientations did not significantly affect the measurement results.

Given that the reduction of *RONt* value is greater than the determined level of static noise, it can be concluded that the random noise component resulting from the spindle rotation and contact of the probe with the measurement object has also been reduced.

Future research will be dedicated to eliminating the systematic error of the spindle rotation using the error separation technique (multistep, reversal method) or the randomization method proposed by Hatjama and Morel, which will be the continuation of this research.

Acknowledgement

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