58th ILMENAU SCIENTIFIC COLLOQUIUM
Technische Universität Ilmenau, 08 – 12 September 2014
URN: urn:nbn:de:gbv:ilm1-2014iwk:3

NEW MATERIAL STANDARDS FOR TRACEABILITY OF ROUNDNESS MEASUREMENTS OF LARGE SCALE ROTORS

T. Widmaier[1] / P. Kuosmanen[1] / B. Hemming[2] / V.-P. Esala[2] / D. Brabandt[3] / J. Haikio [4]

[1] Aalto University School of Engineering, Department of Engineering Design and Production
[2] MIKES Centre for Metrology and Accreditation, Finland
[3] Karlsruhe Institute of Technology, wbk Institute of Production Science
[4] RollResearch Int. Ltd.

ABSTRACT

Large scale rotors in the paper and steel industry are called rolls. Rolls there are periodically reground and roundness measurements are made throughout the machining process. Dimensional measurement systems for large rolls (diameter < 2000 mm) are available on the market. They are typically based on the roundness measurement algorithm from Aoki and Ozono. This method can separate roundness of the rotor from its movement. For reliable measurement results, every measurement should be traceable with an estimation of measurement uncertainty. Therefore, three different material standards in the form of discs (diameter > 500 mm) with different roundness profiles were and will be made during this research. They will be measured at least in the laboratories of two national metrological institutes. Later the discs can be used to calibrate measurement devices. In first tests with one of the discs measurement results of two different measuring devices were compared with measurement results from the coordinate measurement machine of the Finnish national metrology institute. They showed deviation in amplitudes of the harmonics to be 2.3 µm or less. This shows that reliable roundness measurements of rolls are possible.

Index Terms **–** Material standard, roundness, paper machine roll, steel mill roll, measurement uncertainty

1. INTRODUCTION

Roundness is an important feature for all rotating machines where smooth rotation of the rotors or even surface quality and even thickness of the end product is needed, such as paper machines, printing machines, engines and generators etc. In length measurements diameter is often measured as a two point measurement which is affected by out of roundness of the part. Therefore measurements of roundness are also useful when the specific diameter is critical or important.

Fig. 1. Four point roll measuring device of a grinding machine.[1]

[1] Photo by RollResearch Int. Ltd.

In paper mills the roundness measurements are commonly carried out when the roll is located on a lathe or on a grinding machine, see Fig. 1. There the heavy rolls are rotating with their own bearings or they are supported by sliding pads. With this measurement setup it is difficult to avoid a rotational error of the centreline of the roll, and thus one or two point measurement methods cannot separate the rotational error movement of the workpiece from its geometry. This is the reason for the usage of multi point measurement devices in the paper industry [1]. Most of them are based on the Ozono method, where the roundness is calculated from weighted sensor signals in a given configuration around the rotor [2].

In the steel industry the roundness tolerances of the rolls are not as tight as in the paper industry, and thus the common measurement device there is a two point measurement device, which is well suited for diameter variation profile measurement. The diameter and diameter variation profiles are more important than the roundness. [3][4][5][6]

The reliability of the measurement is naturally important for machined workpieces in production. Competitive production needs reliable information about the geometry of the workpiece or some specific dimension or feature of the workpiece, e.g., roundness error. In the modern machine tools for the large scale rotors, i.e., paper mill or steel mill rolls, the reliability of the onsite measurement device is needed also for the error compensation of the roll grinder or lathe. For the error compensation control systems of the machine tools use the geometry information measured by the measurement device. Thus the measured geometry error must be accurate to be compensated correctly. [4][5][6][7]

The reliability of a measurement instrument is ensured by calibration. Ideally the calibration is performed using traceable calibrated measurement standards. This gives the possibility for the end user to make traceable measurements with a known measurement uncertainty. As a part of an EMRP project "Traceable in-process dimensional measurement" calibration discs are developed and manufactured. The design of these discs is presented in this paper. The evaluation of measurement uncertainty will be presented in future papers. The tests will be carried out in at least two national metrology institutes and with a four-point roll geometry measurement device at the Aalto University or at an industrial plant of an industrial partner.

It is not in the scope of this paper to explain all concepts, terminology and filters in roundness measurements. It is also assumed that the reader is aware of the written standards such as ISO 12181 for roundness and understands the idea of material standards for roundness.

2. BACKGROUND

2.1. Material roundness standards

Roundness material standards are useful when calibrating a roundness measuring device. There are two main categories of standards:

- standards with nearly zero roundness error,
- sensitivity standards or magnification standards with intended form error.

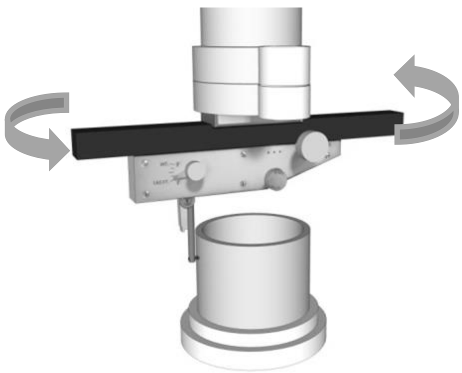

Fig. 2. Measurement of roundness in laboratory with a roundness measuring machine.

Typically the sizes of parts which need to be measured at high accuracy have diameters in the range 1 to 500 mm. This means that most measurement equipment is built for this range and as a result from this is that roundness standards have nominal diameters in the range 20 to 100 mm. In Fig. 2 a typical laboratory roundness measurement setup is shown. These standards used in metrology laboratories are too small to be used to calibrate large roundness instruments intended for diameters at several meters. Therefore the needs of industry are not met by existing roundness standards.

2.1.1. Hemispheres

In roundness metrology glass hemispheres are manufactured to be as round as possible (Fig. 3). Typically they have roundness errors in the range of some tens of nanometres. They reveal radial errors in the rotation or axial reference for the roundness measurement.

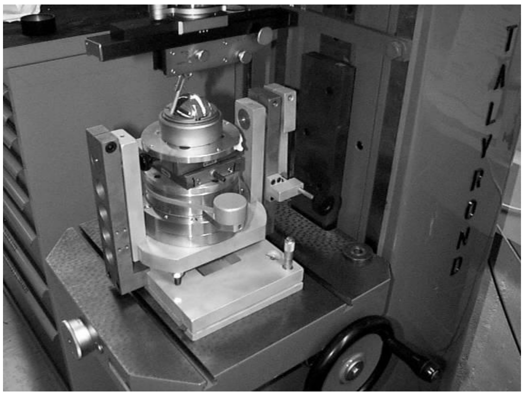

Fig. 3. A hemisphere at a roundness measurement instrument.

2.1.2. Flick standards

Flick standards are cylinders with a flat part (Fig. 4). The flat feature of the otherwise round cylinder makes an inward out of roundness. The magnification error or sensitivity of a roundness instrument can be calibrated by measuring the flick standard. Flick standards can be compared to gauge blocks. Similarly to the typical use of gauge blocks, one or two standards is not enough and quite a large set of flick standards is needed to check the magnification error of a roundness instrument. The flick standard is also versatile as it can be calibrated by several instruments such as roundness instrument, form measuring machine, length measuring machine (two point diameter) and coordinate measuring machine. Naturally questions of different measurand and profile distortion depending on radius of probe tip arise, depending on selected instrument. These questions have been discussed in a recent paper from METAS and PTB [8]. Although the geometry of a flick looks simple it is non-trivial to calibrate [8].

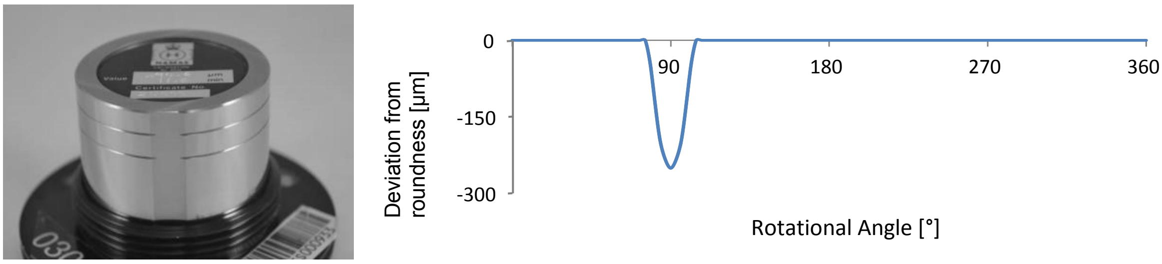

Fig. 4. Left-hand side: Flick standard[2] and right-hand side: deviation from roundness.

All flick standards are of plug-type intended for external measurement. In all roundness measurements the selection of filter affects the results and this is especially true for flicks. As roundness is a measurement of form, short-wave roughness is usually filtered out. In a roundness plot the flick area appears as a deep valley and is therefore reduced by any filtering. The frequency content of a flick makes it probably not ideal for equipment relying on the Ozono method where analysis is done in frequency domain.

2.1.3. Ellipse standards, single wave

As mentioned the drawback of flick standards is that the linearity error of the transducer at a roundness machine cannot be characterized by a limited amount of flicks, for example two or three. Therefore cylinders with an elliptical form error have been manufactured. The form error linearly depends on the height (Fig. 5). At MIKES two standards are used. First one is with roundness error in range 5 to 25 µm and another one with roundness

[2] Photo by V-P Esala

error in range 35 to 300 µm. If the roundness instrument is able to measure at different heights automatically, a large amount of roundness results can be plotted quickly. A drawback is the critical dependence between position (height) and magnitude of elliptical form. The uncertainty in the height produces an uncertainty in the correct reference value.

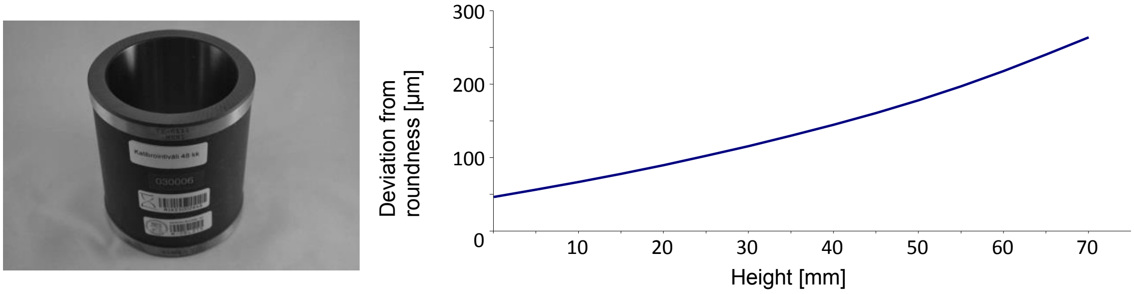

Fig. 5. Left-hand side: Ellipse standard with internal cylinder. Right-hand side: its deviation from roundness.

2.1.4. Multi-wave standards

The standards discussed in previous sections have one measurand, which is the peak to peak value of centred roundness profile. This peak-peak value is named RONt in ISO 12181. Another result which can be calculated from roundness plots are the harmonics which give the magnitude of the theoretical waves.

Recent examples of multi-wave standards are those developed by Fraunhofer Institute for Production Technology (IPT). Their profiles contain a superposition of sinusoidal waves with wave numbers 5, 15, 50,150 and 500 UPR (undulations per revolution) [8]. The advantages of MWS compared to flicks are better signal to noise ratio and low sensitivity to noise in measured profiles [8]. Also in the paper of Jusko et. al. [9], where a Euramet comparison of a flick standard and MWS were analysed, is shown that the spectral analysis (harmonics) of MWS leads to good agreement and stability.

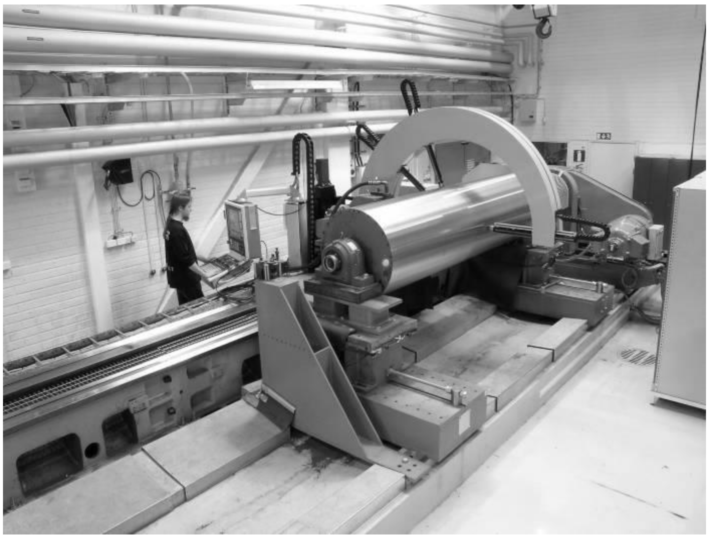

Fig. 6. Four-point roll geometry measurement instrument at the Aalto University.

2.1.5. Asymmetric multi-wave standards

The asymmetric multi-wave standards (AMWS) have been developed to calibrate large roundness measuring machines based on the Ozono-method. These machines are used when grinding rolls in paper- and steel industry (Fig. 6). There the grinding process is often controlled according to the measured geometry data. The measuring range for diameter is 300 to 2000 mm, meaning that typical roundness standards cannot be used. Instead, calibration discs (Fig. 7) have been used. As with MWS these discs have waves but the shape is not symmetric. The shape and the waves are found suitable for the Ozone method. Because of the large size typical roundness measuring machines cannot be used for calibration. Instead either coordinate measurement machine (CMM) or specially built setups for roundness measurement must be used.

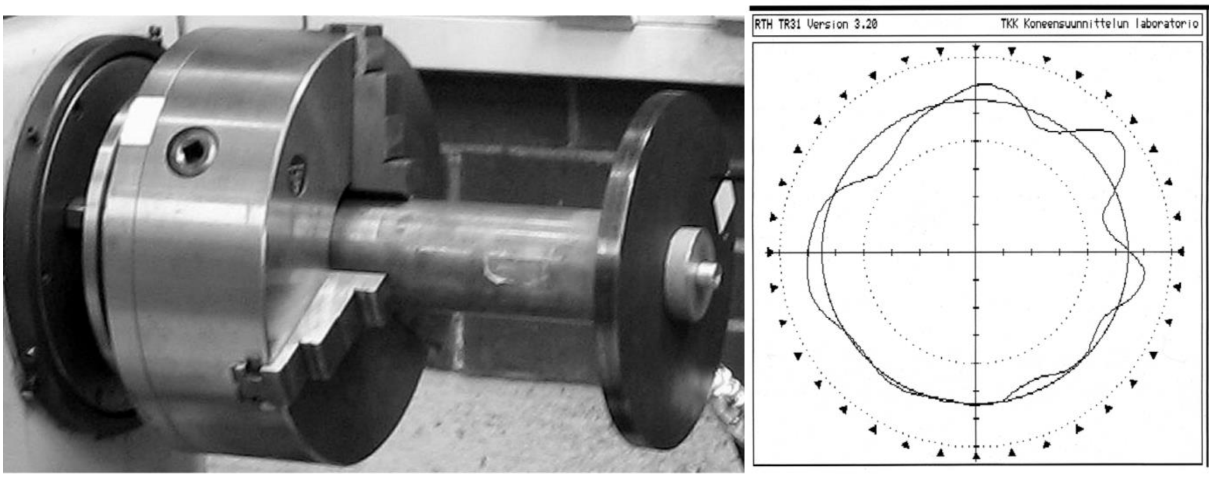

Fig. 7. Disc (left) and roundness plot (right). [1]

2.2. Four-point roll measurement devices

2.2.1. Hybrid four-point roundness measurement

One of the multi-point methods commonly used in the roll geometry measurement devices is the so called Hybrid four-point method. The method behind the Hybrid four-point measurement device is based on the three-point Ozono method [2], but in a combination with the two-point (diameter) measurement method. The two-point measurement method (when only using sensors S1 and S4 in Fig. 8) suffers from a harmonic filtration, and thus making it unsuitable for the measurement of the odd numbered harmonic lopes of a roundness profile [10][3], but the even numbered harmonic lopes are measured accurately by this method. The Hybrid four-point method presented originally by Väänänen [11] uses the Ozono method to measure the odd numbered harmonic lopes and combines the result with the even numbered lopes measured with the two-point method. This ensures an overall better accuracy than with Ozono or two-point method alone.

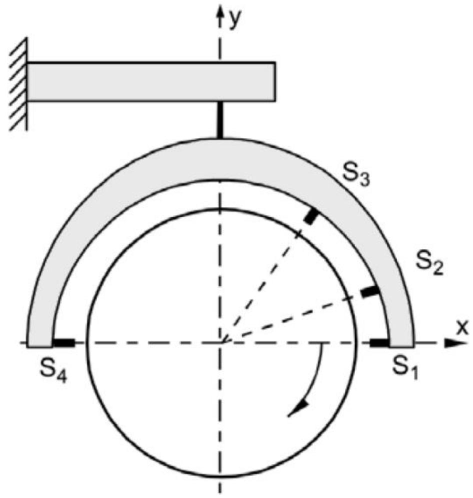

Fig. 8. Typical orientation of probes [S1-S4] in a four-point measurement system.

The evaluation of the uncertainty for the roundness measurement method will be carried out during this research project.

2.2.2. Sensors

Commonly used displacement sensors are from the MT12xx series from Heidenhain. The xx denotes the different output signal types, e.g., MT 1281 has 1Vpp sinusoidal signal output. Other displacement sensors can be use also, e.g., LVDT or for non-contacting applications eddy-current or optical sensors.

The reported accuracy for the Heidenhain MT 12xx is ±0.2 µm. This accuracy has been verified also in the calibration report by the Finnish national metrology institute MIKES (Certificate of calibration M-08L056, 2008).

Fig. 9. Heidenhain MT1281 digital micrometre.[3]

3. PROPOSED ROUNDNESS STANDARDS

The measurement standards are intended to quantify error sources found in large measurement systems that are based on the Ozono method (Fig. 1). The developed measurement standards are also useful for calibration of two-point and one-point measurement systems. The error sources which are expected to be found are errors of the transducers, angular orientation error and positioning error of transducers. Thermal expansion and vibration of the measurement frame (Fig. 8) are other possible error sources. The algorithm of the measurement systems have already been validated by simulation, but functional testing is possible and valuable to perform with the developed discs.

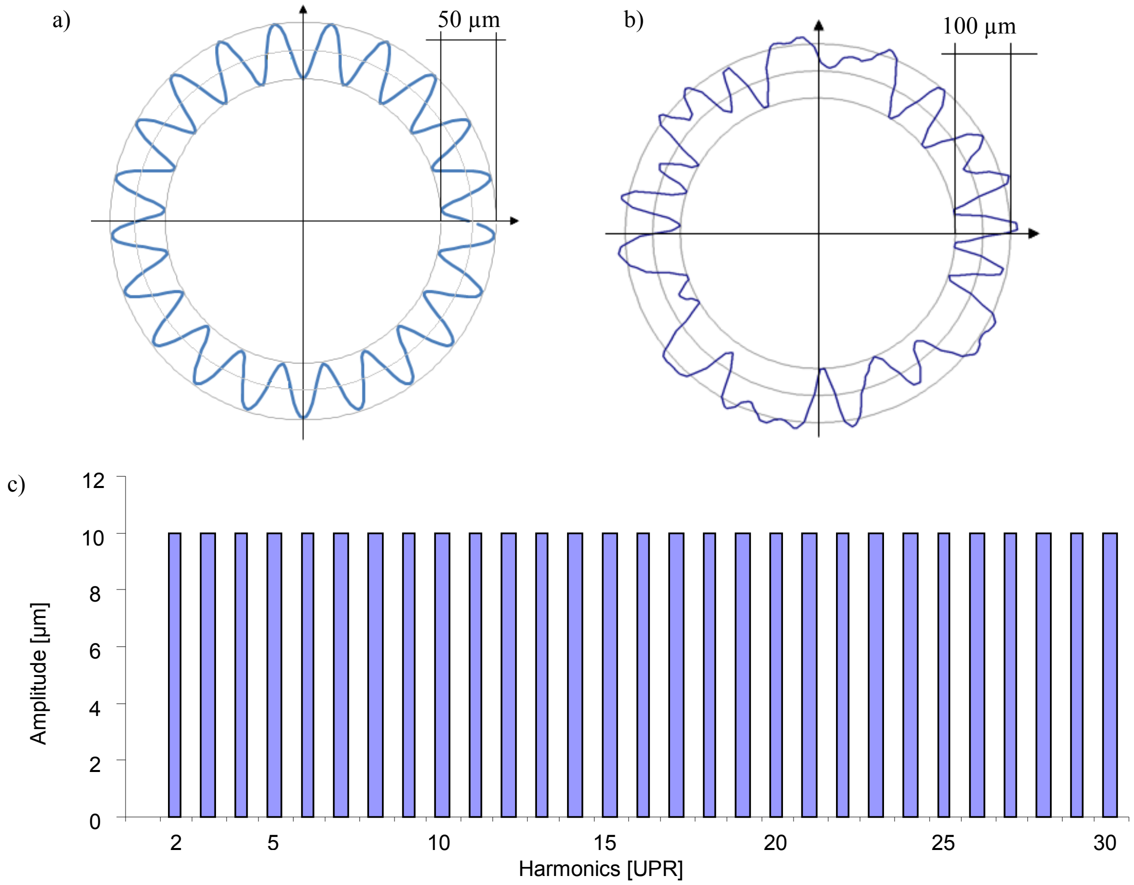

Fig. 10. a) Designed profile of the type B disc with 21 UPR. b) Designed profile of the type C disc with 2 – 30 UPR. c) Designed wave amplitudes of the type C disc profile.

[3] http://positionfeedback.com/heidenhain-length-measurement/mt-1315.html

All standards are discs with the diameter of 503 mm. This is the largest diameter that can be easily measured in both laboratories and not too small to be measured by in process roundness measurement systems in industry. Larger discs were also considered but weight and handling would lead to problems. The thickness of the discs will be 50 mm which is enough for robustness and yet not too heavy to handle. The types and requirements of the selected standards are shown in Table 1.

The type A standard is almost perfectly round. With a roundness error below 2 µm this standard helps to reveal errors like noise and thermal drift.

Table 1. Requirements for the measurement standards.

Name	Form	Deviation from roundness [µm]
Type A	round	< 2 µm
Type B	21 UPR	25 µm
Type C	extended multiwave, 2 – 30 UPR	10 µm / undulation

Type B is selected as it has one characteristic form of a 21 UPR wave. The propagation of error of single probes at in process roundness measurement systems is expected to be revealed by this disc. The type C, extended multi wave, consists of several waves. Standards of this type have previously been used and they are expected to work as overall test standard. Type B and C profiles are shown in Fig. 10.

All standards will be calibrated by roundness measuring instrument with a rotary table. Additional measurements to get other form errors like cylindricity will be done in a CMM. In this paper the preliminary comparison results for the disc type C are presented.

4. RESULTS

Preliminary comparison tests with the first manufactured calibration disc type C were carried out on three sites: with the four-point roll geometry measurement device (RollCal 3) at an industrial partner (IP), with the four-point laboratory measurement device at Aalto University and with the CMM (Legex 9106) at MIKES.

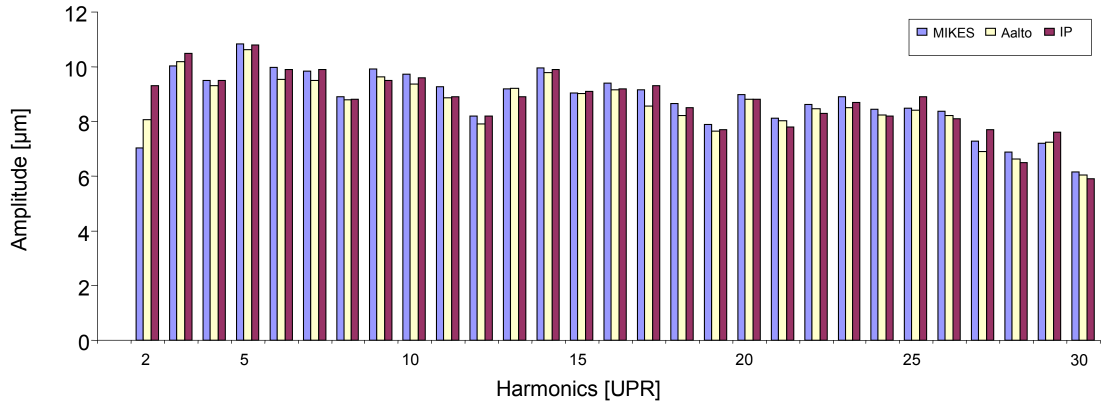

Fig. 11. Comparison of the measurement results of the harmonics of the calibration disc type C made on three different sites.

The amplitudes of the waves (harmonics) of the measured profile are shown in Fig. 11. The deviation of the harmonics 3 to 30 between the different measurement devices are less than 1 µm. The deviation of the second harmonic between the measurement devices is 1 µm and 2.3 µm (amplitude of the 2nd harmonic: MIKES 7 µm, Aalto 8.1 µm and IP 9.3 µm). The cause for this could be tracked down to the coupling between the disc and its shaft. A cure for this has already been designed and manufactured, but its effect has not yet been tested.

5. CONCLUSIONS

The flick standard is the most used type of magnification standard for one-point roundness instruments, but not efficient with multi-point instruments.

The diameters of the most roundness standards are well below 500 mm and are intended for use in metrology laboratories and are not suitable to ensure traceability for measurement of large parts in industry. Some asymmetric multi-wave standards are large and are already used in paper- and steel industry. Other standards proposed in this paper were and will be manufactured. The analysed results from measurements with the type C disc made with the roll geometry devices showed that a deviation of the amplitude of the individual waves from the disk was 2.3 µm or less from the results of the CMM of MIKES. The complete uncertainty assessment is still required, but these first results show that the reliable roundness measurements of the large scale rotors in the industry are possible.

6. ACKNOWLEDGEMENT

This work was funded through the European Metrology Research Programme (EMRP) Project IND11 MADES. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union. We also wish to thank all the people at UPM Kaipola paper mill in Finland who were involved in the grinding and measuring of the first calibration disc for their support and help.

7. REFERENCES

[1] Kiviluoma, P. 2009. Method and device for in situ runout measurement of calender thermo rolls. Doctoral dissertation. Helsinki University of Technology, Espoo. ISBN 978-952-248-259-4.

[2] Ozono, S. (1974). On A New Method Of Roundness Measurement On The Three Point Method, Proceeding of the ICPE, pp 457-462, Tokyo, Japan, 1974

[3] Juhanko, J. 2011. Dynamic Geometry of a Rotating Paper Machine Roll. Aalto University Publication Series Doctoral Dissertations 117/2011. 172 p. ISBN 978-952-60-4363-0.

[4] Kotamäki, M. 1996. In-situ measurement and compensation control in external grinding of large cylinders. Helsinki: Acta Polytechnica Scandinavica, Mechanical Engineering Series No. 121. 123 p.

[5] Kuosmanen, P. 2004. Predictive 3D roll grinding method for reducing paper quality variations in coating machines. Helsinki University of Technology Publications in Machine Design 2/2004, Espoo. ISBN 951-22-7014-5.

[6] Widmaier, T. 2012. Optimisation of the roll geometry for production conditions. Aalto University Publication Series Doctoral Dissertations 156/2012. 184 p. ISBN 978-952-60-4878-9.

[7] Haikio J. (1997). A turning system to minimize the geometrical error of a roll. Master's thesis. Helsinki University of Technology, Espoo. 78 p.

[8] Thalmann, R., Spiller, J., Küng, A. and Jusko, O., 2012 Meas. Sci. Technol. 23. Calibration of Flick standards.

[9] Jusko, O., Bosse, H., Flack, D., Hemming, B., Pisani, M., Thalmann, R., 2012 Meas. Sci. Technol. 23. A comparison of sensitivity standards in form metrology—final results of the EURAMET project 649.

[10] Whitehouse, D. (1994). Handbook of surface metrology. Institute of Physics Publishing for Rank Taylor Hobson Ltd. pp. 139-142.

[11] Väänänen P. (1993). Turning of flexible rotor by high precision circularity profile measurement and active chatter compensation. Licentiate's thesis. Helsinki University of Technology, Espoo. 104 p.

CONTACTS

D.Sc. (Tech) Thomas Widmaier
Prof. Petri Kuosmanen
Aalto University School Engineering,
Department of Engineering Design and Production,
Otakaari 4, P.O.Box 14100
FI-00076, Aalto, Finland
Phone: +358 50 5609515
E-mail: Thomas. Widmaier@aalto.fi

D.Sc. (Tech.) Björn Hemming
M.Sc. (Tech.) Veli-Pekka Esala
Centre for metrology and accreditation
(MIKES), P.O. Box 9,
FI-02151 Espoo, Finland
bjorn.hemming@mikes.fi

Dipl.-Ing. Daniel Brabandt
Karlsruhe Institute of Technology,
wbk Institute of Production Science,
Kaiserstraße 12,
D-76131 Karlsruhe, Germany
daniel.brabandt@kit.edu

M.Sc. (Tech.) Janne Haikio
RollResearch Int. Ltd.
Luoteisrinne 4D
FI-02270 Espoo
janne.haikio@rollresearch.fi