The Influence of Scanning Parameters on CMM Measurements

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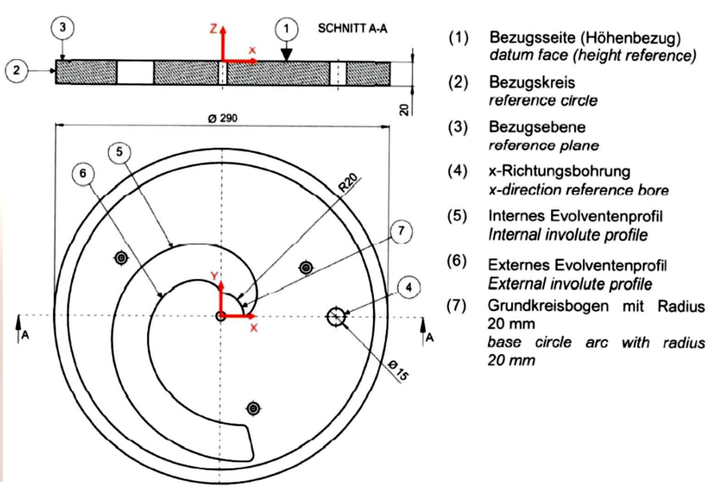
Introduction

This work shows the results of Deliverable 5.2.3 - **JRP ENG56 DriveTrain** about "*validation of measurement strategies and determination of achievable measurement uncertainty in industrial environment*". Deliverable refers to investigation of dynamic behavior of probing systems due to scanning measurement at CMM of two standard involute profiles, both superposed with a certain waviness. INRIM investigated the influence of scanning parameters such as different **scanning speeds**, **workpiece orientations** inside the measurement volume and **stylus lengths**. Measurement results have been analyzed in order to evaluate the **profile deviations** (F_a, f_{fa} and f_{Ha}) according to ISO 1328-1:2013 and the influence due to the scanning measurement parameters on these results. Moreover, a **spectral analysis** has been performed using FFT method and the three main components of the spectrum have been calibrated in terms of wavelength and amplitude.

The measurement standard SAFT 2w

The standard SAFT 2w is a plate with a diameter of 290 mm and a thickness of 20 mm, with 2 polished references on the border (a circle and a plan) in order to determine the reference axis of the workpiece. The standard embodies an internal and an external involute profile both superposed with a certain waviness. The profiles have been manufactured with a wire-cut EDM machine. The machining data points have been obtained by using a parametric function.

SAWT 2W artefact



Technical drawing of the internal involute waviness scanning measurement standard

Geometry parameters	
Outer diameter	290 mm
Face width	20 mm
Involute parameters:	
• Radius of base circle	20 mm
• Range of involute function inv(α)	
Int. involute: ----------	0°- 270°
ext. Involute: ----------	0°- 200°
Nominal wavelength and amplitude:	
• $\lambda_1; A_1$ ----------	8 mm; 5 µm
• $\lambda_2; A_2$ ----------	2.5 mm; 3 µm
• $\lambda_3; A_3$ ----------	0.8 mm; 1 µm

Waviness parameters

Parametric definition :

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} r_e \cdot \cos(inv\alpha) \\ r_e \cdot \sin(inv\alpha) \end{pmatrix}$$

rb : *basis radius*
ly: *roll length*
A_n: *amplitude of wave n*
λ_n: *wave length of wave n*

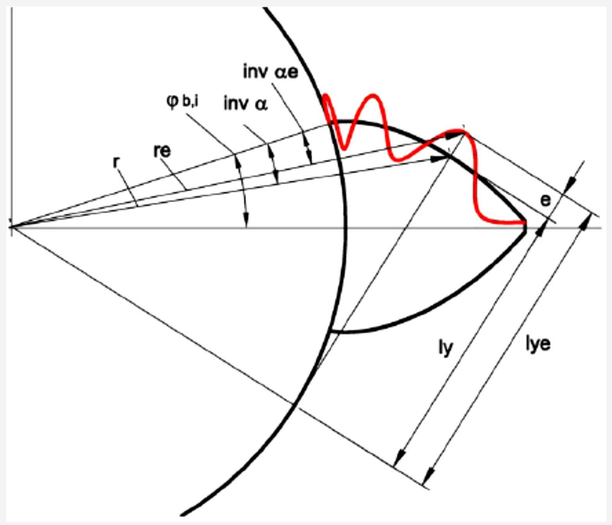
with

$$inv\alpha(ly) = \tan\left(\cos^{-1}\left(\frac{rb}{r}\right)\right) - \left(\cos^{-1}\left(\frac{rb}{r_e}\right)\right)$$

$$r_e(ly) = \sqrt{rb^2 + ly_e^2} \qquad r(ly) = \sqrt{rb^2 + ly^2}$$

$$ly_e(ly) = ly + \sum_{n=1}^{3}\left(A_n \sin\frac{2\pi \cdot ly}{\lambda_n}\right)$$

Parametric function



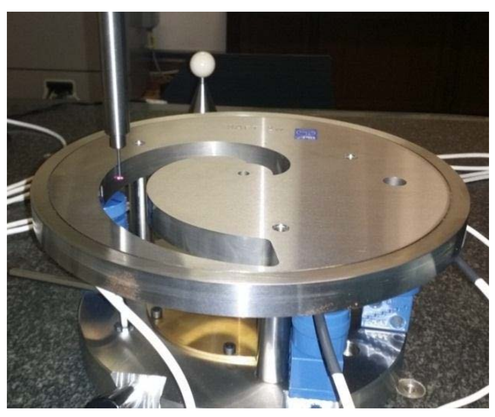
Sketch of the involute with waviness

Experimental setup and plan of measurement

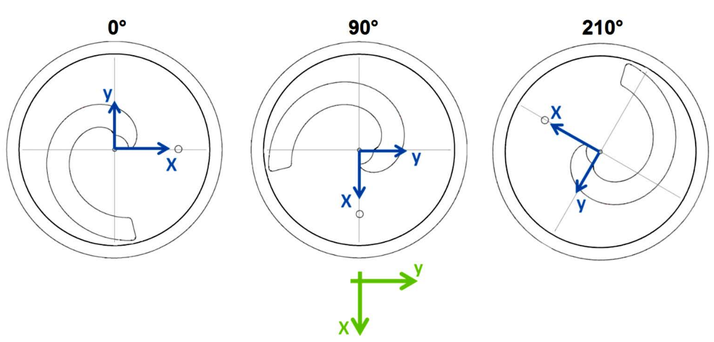
- Measuring volume: 12 x 10 x 7 dm^3 ;
- EMP_E = 0.6 µm + 1.7·10^{-6} L ;
- P_{FTU} = 0.6 µm;
- Resolution= 0.05 µm (20 points/mm);
- Stylus model: Leitz trax (tip diameter : 3 mm).

One face of SAFT 2w was equipped with 4 PT100 probes for temperature compensation. Measurement was performed, for both profiles, according to the following scanning measuring parameters:

- 3 Workpiece Orientations (WO): 0°, 90° and 210°;
- 5 Scanning Speed (SS): 2, 8, 14, 20, 24 mm/s;
- 3 Stylus Length (SL): 35, 135 and 235 mm;
- 3 scanning measure repetitions for each parameter set.



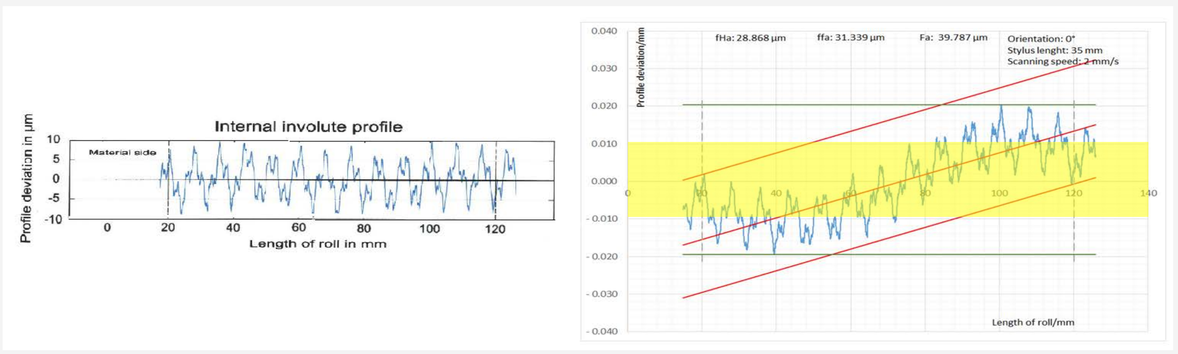
Example of internal involute measurement scanning



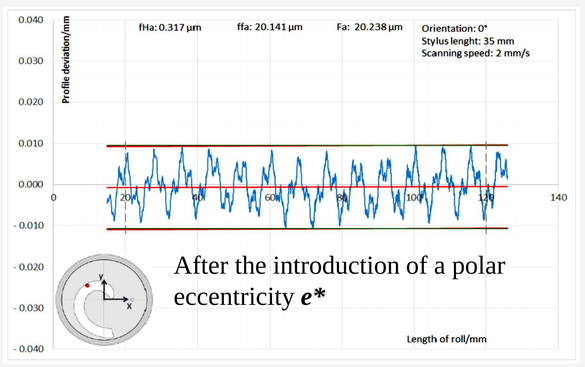
WO with respect to machine x-axis and y-axis (green)

Scanning measurement results and data analysis

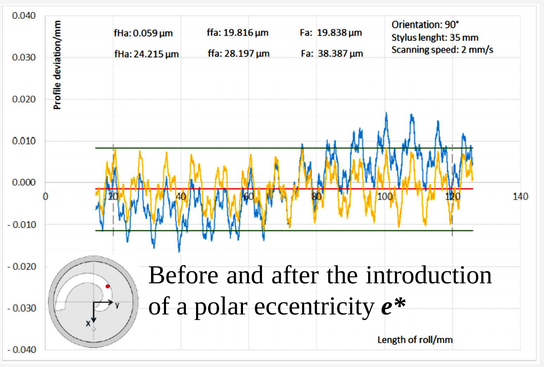
A total of 270 measurement profiles have been performed. From the measurement data the profiles have been calculated as function of roll length, then the theoretical involute was subtracted from data. A first evaluation of computed data evidenced the presence of an unexpected periodic deviation of the profile that seemed to reveal some eccentricity. in particular a **polar eccentricity e*** has been introduced in order to eliminate the sinusoidal behaviour and its application has been observed at different workpiece orientations.



Profile deviation: from PTB certificate (left), from INRiM scanned data points (right)



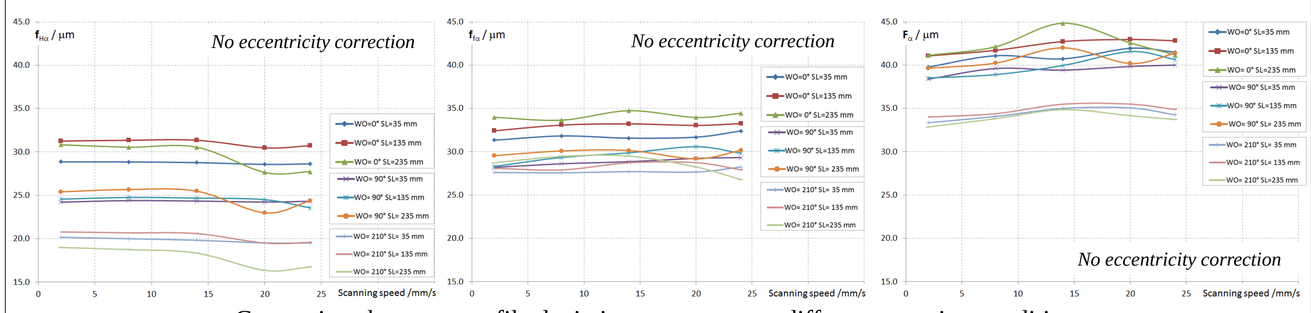
After the introduction of a polar eccentricity e^*



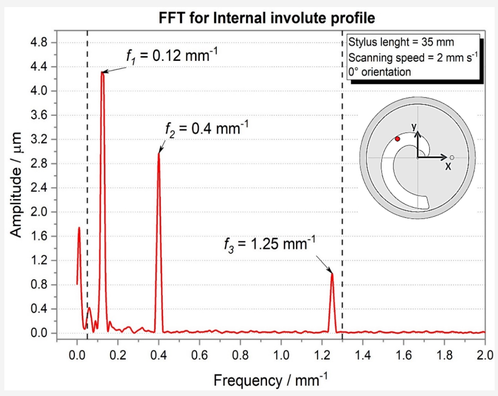
Before and after the introduction of a polar eccentricity e^*

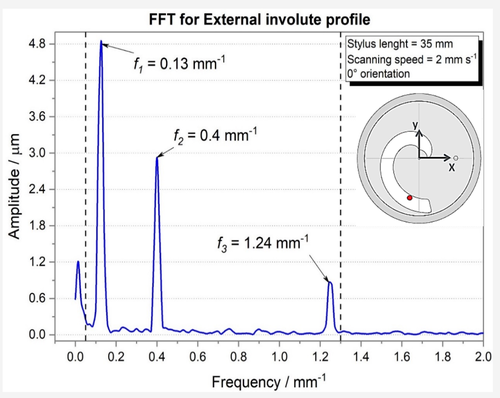
Profile	Mean profile deviations (SS = 2 mm/s; SL = 35 mm)		
internal	$\overline{f_{Ha}} = 0.008\ \mu m$	$\overline{f_{fa}} = 21.028\ \mu m$	$\overline{F_a} = 22.184\ \mu m$
external	$\overline{f_{Ha}} = -2.532\ \mu m$	$\overline{f_{fa}} = 19.149\ \mu m$	$\overline{F_a} = 19.827\ \mu m$

Internal and external profile deviations variability with respect to mean profile deviations at best scanning conditions



Comparison between profile deviation parameters at different scanning conditions





SL= 35mm, WO= 0° - EXTERNAL INVOLUTE PROFILE										
SS / mm s^{-1}	f_1 / mm^{-1}	λ_1 / mm	A_1 / µm	f_2 / mm^{-1}	λ_2 / mm	A_2 / µm	f_3 / mm^{-1}	λ_3 / mm	A_3 / µm
2	0.1286	7.777	4.799	0.4001	2.500	2.928	1.2430	0.804	0.857
8	0.1286	7.779	4.806	0.4000	2.500	2.935	1.2570	0.796	1.063
14	0.1286	7.776	4.799	0.4001	2.500	2.970	1.2574	0.795	0.993
20	0.1286	7.776	4.767	0.4001	2.499	3.069	1.2432	0.804	0.890
24	0.1286	7.777	4.779	0.4001	2.500	3.142	1.2430	0.804	0.873

External profile FFT results as function of SS

SS = 2 mm/s, WO= 0°- EXTERNAL INVOLUTE PROFILE									
SL / mm	f_1 / mm^{-1}	λ_1 / mm	A_1 / µm	f_2 / mm^{-1}	λ_2 / mm	A_2 / µm	f_3 / mm^{-1}	λ_3 / mm	A_3 / µm
35	0.1286	7.777	4.799	0.4001	2.500	2.928	1.2430	0.804	0.857
135	0.1286	7.777	4.799	0.4001	2.500	2.936	1.2430	0.804	0.871
235	0.1286	7.777	4.806	0.4001	2.500	2.932	1.2430	0.804	0.880
SS = 2 mm/s, WO= 90°- EXTERNAL INVOLUTE PROFILE									
SL / mm	f_1 / mm^{-1}	λ_1 / mm	A_1 / µm	f_2 / mm^{-1}	λ_2 / mm	A_2 / µm	f_3 / mm^{-1}	λ_3 / mm	A_3 / µm
35	0.1286	7.775	4.781	0.4001	2.499	2.927	1.2432	0.804	0.865
135	0.1286	7.776	4.770	0.4001	2.499	2.935	1.2432	0.804	0.873
235	0.1286	7.776	4.770	0.4001	2.499	2.938	1.2431	0.804	0.915
SS = 2 mm/s, WO= 210°- EXTERNAL INVOLUTE PROFILE									
SL / mm	f_1 / mm^{-1}	λ_1 / mm	A_1 / µm	f_2 / mm^{-1}	λ_2 / mm	A_2 / µm	f_3 / mm^{-1}	λ_3 / mm	A_3 / µm
35	0.1286	7.778	4.793	0.4000	2.500	2.934	1.2428	0.805	0.860
135	0.1286	7.776	4.782	0.4001	2.500	2.930	1.2431	0.804	0.862
235	0.1286	7.776	4.772	0.4001	2.500	2.924	1.2431	0.804	0.891

External profile FFT results as function of SL and WO

Uncertainty source	significance level	
	high	low
Measurement repeatability		v
Measurement reproducibility	N	
CMM geometrical error (uncompensated)	N	
Sample centering	v	
Probing effect		v
Algorithm of analysis	v	v
Scanning speed		v
Stylus length		v
Sample fixturing		v
Thermal drift		v

Sources to be taken into account for uncertainty budget evaluation

Remarks/Conclusions

Freeform scanning on an internal involute profile measurement standard designed and manufactured by PTB has been conducted. Points to be outlined:

- the presence of unsuspected effects as **eccentricity** and some plausible thermal effects not deeply investigated, yet;
- a barely significant trend of the dependence of f_{Ha} f_{Ha} F_a, parameters as a function of SS,SL or WO;
- high and stable performances of the machine from spectral analysis of data: evaluations of wavelength and amplitude are very repeatable and not influenced by WO, SS or SL; maintenance of high performances also at the most critical measuring conditions.

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https://www.ptb.de/emrp/eng56-home.html

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