Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

3D METROLOGY CONFERENCE

Holistic thread gauge calibration with a 2-D contour scanner: A concept

3DMC|2022
Automation | Digitization | Data Intelligence
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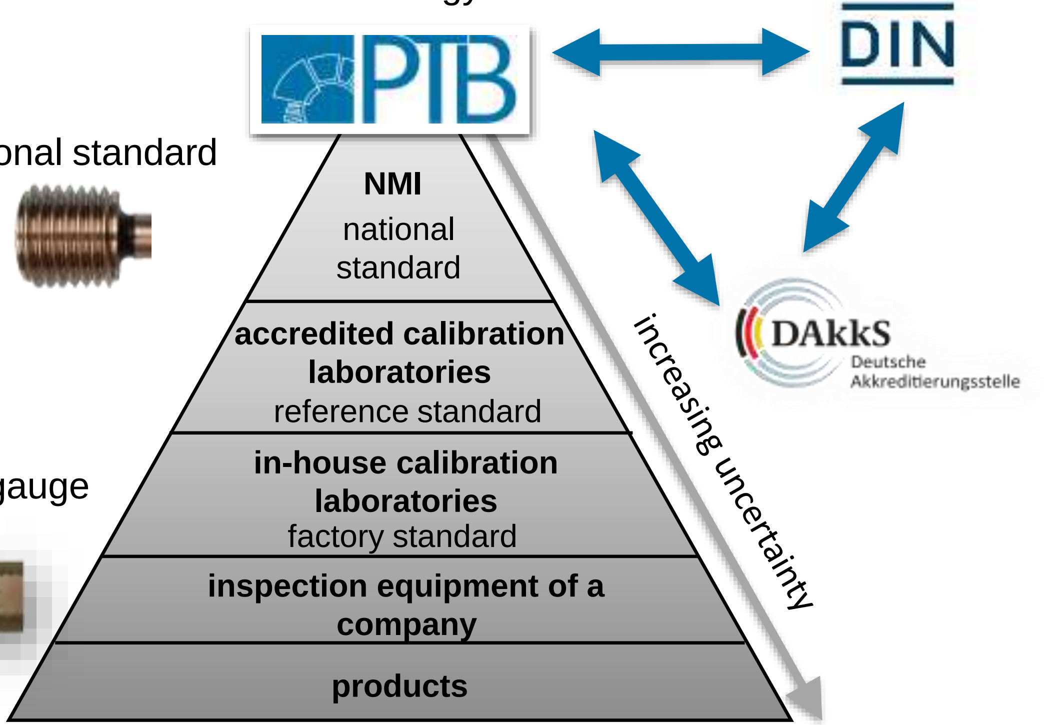
Division „Precision Engineering“
Department 5.3 „Coordinate Metrology“
Working Group 5.33 „Gears and Threads“

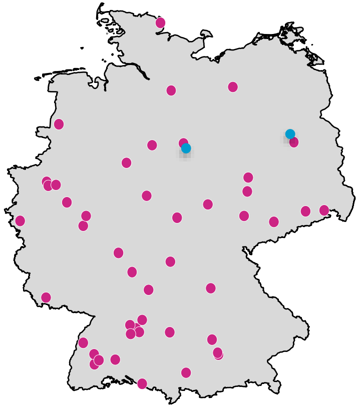
National quality infrastructure „threads“

National metrology institute

national standard



„go“- thread gauge



Credits: A. Przyklenk

- 47 accredited laboratories for thread calibration in Germany (DAkkS)
- approx. 50 manufacturer of threads, nuts and rivets

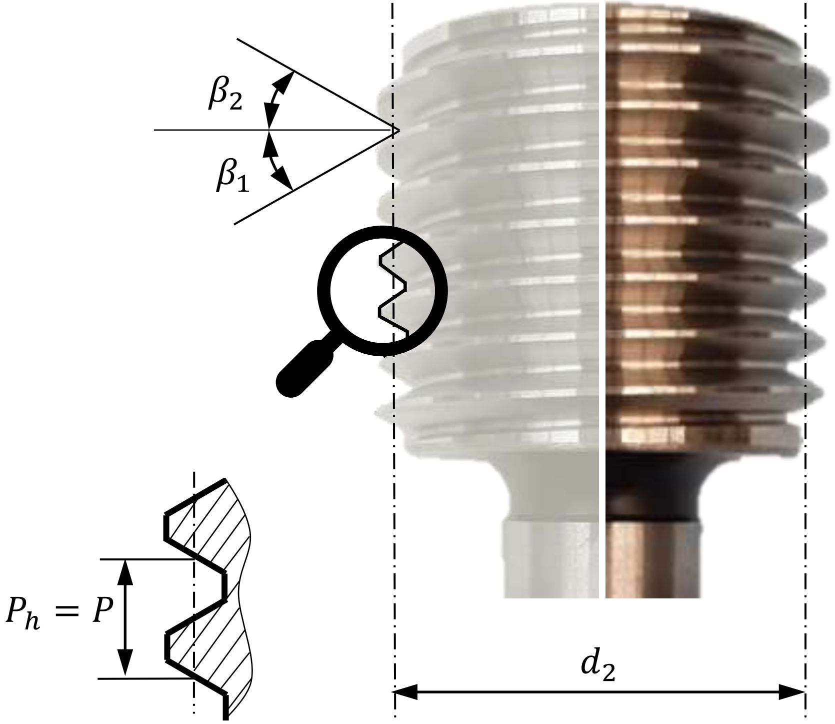
Thread determinants (ISO 5408:2009)

Cylindrical thread

- pitch diameter d_2, defined by pitch cylinder
- pitch cylinder:

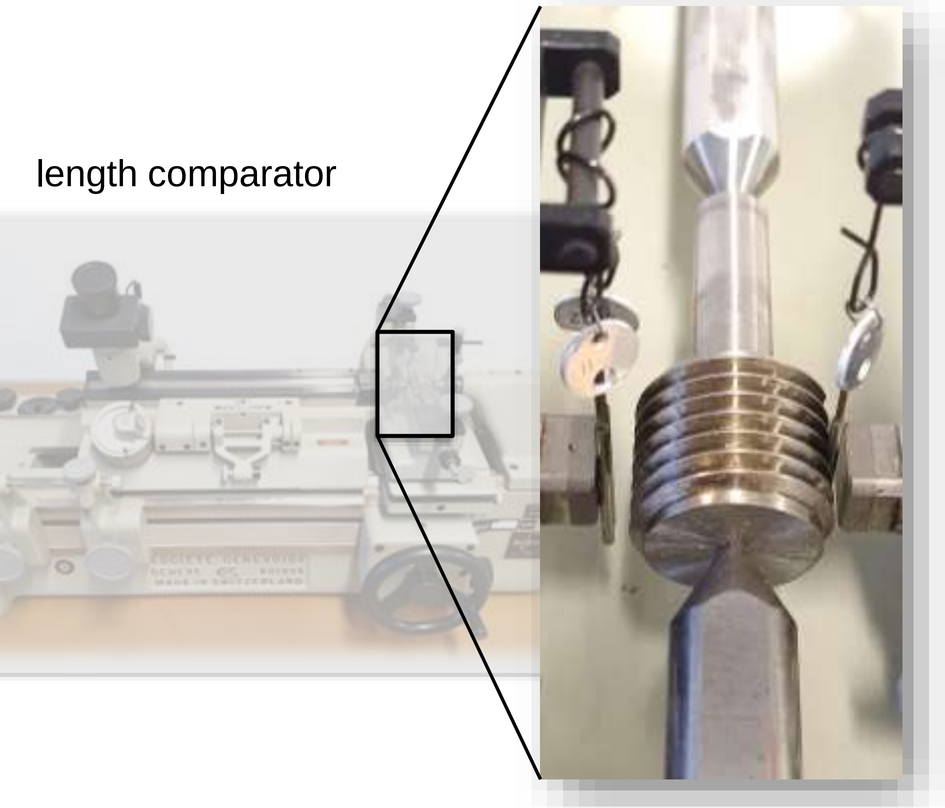
„imaginary cylinder whose surface cuts a parallel screw thread where the widths of the ridge and the groove of the thread are equal“*
(*ISO 5408:2009)

- lead of helix P_h (equals pitch P for single start threads)
- flank angles β_1, β_2



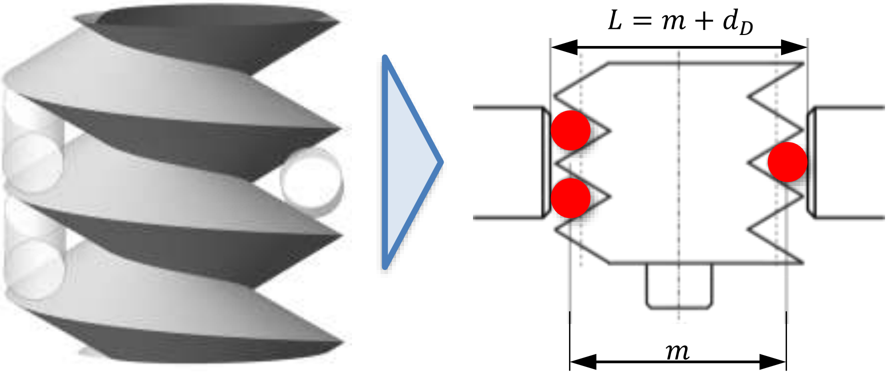
„Status quo“ thread calibration

length comparator



Euramet cg-10 (2012), DIN 2244 (2002), ISO 5408 (2009)

thread cross section

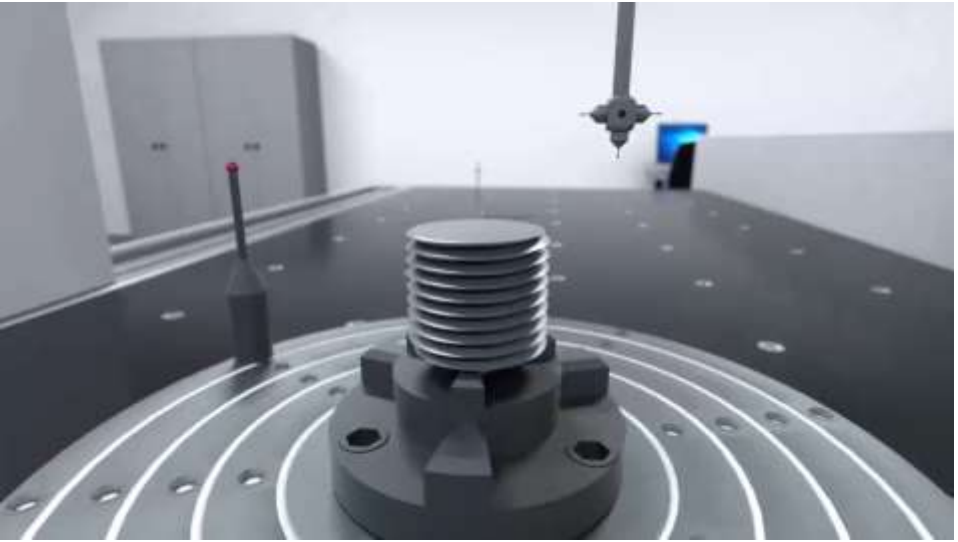


- three wire method
- can also be e[x]ecuted on contour scanners and CMMs, which [a]dditionally allow the determination of other paran[mete]rs (e
- potential of th[e] [appro]ach even if 3D-CM[M] use[d] performed alo[ng] 2D a[x]

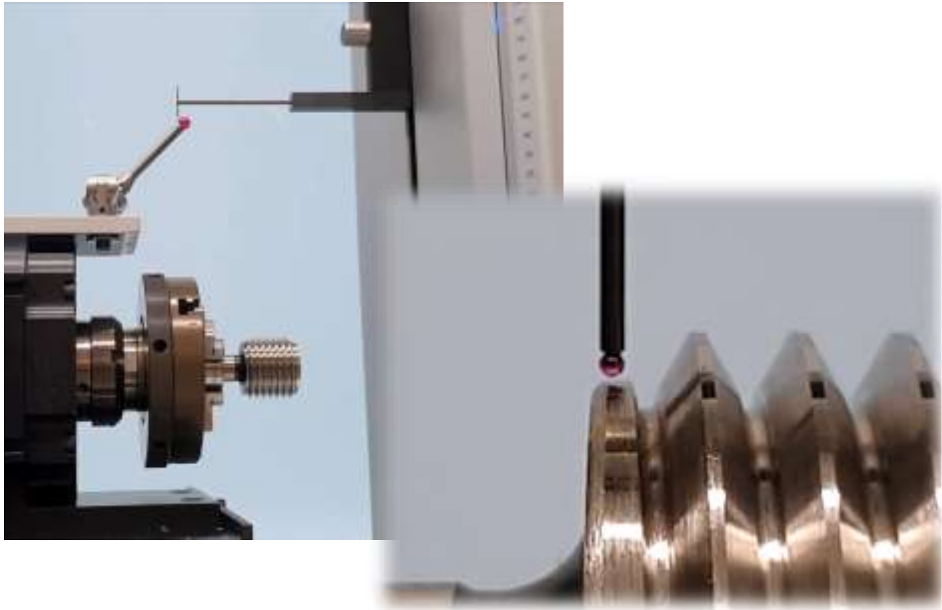
no full thread model

3D thread characterization at PTB

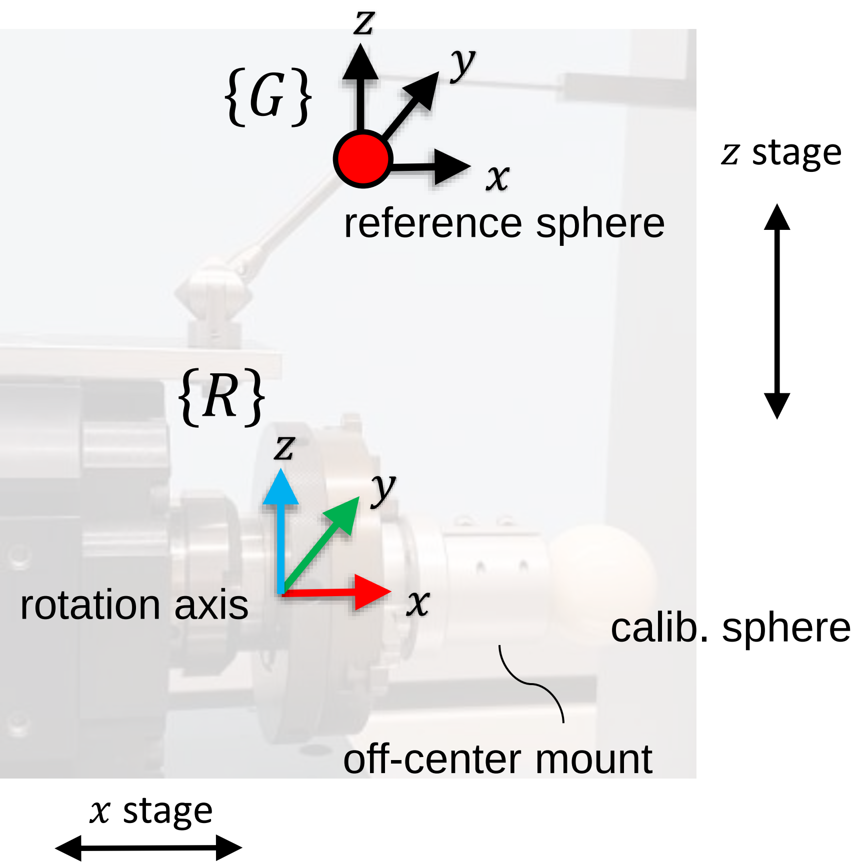
CMM with rotary table



New approach:
2-D Contour scanner with rotation axis



Axis calibration approach



Idea

- Standard scanner:
  2-D data points (x, z)
- Standard scanner plus rotation axis:
  3-D data points (x, y, z)

Task

- equip device with additional rotation axis (not commercially available)
- find pose of axis (in 3-D) in scanner coordinate frame (based on 2-D scanner data)

Approach

- multiple scans of calibrated sphere (in off-center mount)
- reconstruction of 3-D sphere yields axis in $\{G\}$

Measurement procedures

Scanner (V1)

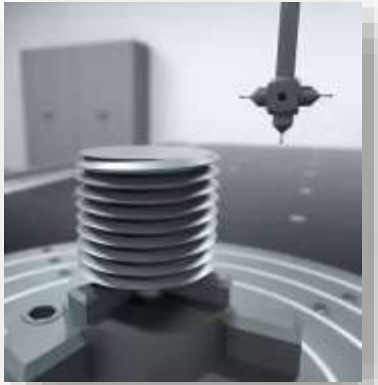
- axis calibration
- thread calibration

Scanner (V2)

- axis parameters are estimated in thread optimization (!)

- axial, from above and below (9x2 scans)
- scanning speed $1.5\ {}^{mm}/_{s}$
- ruby styli $r \approx 500\ \mu m$

CMM (reference)



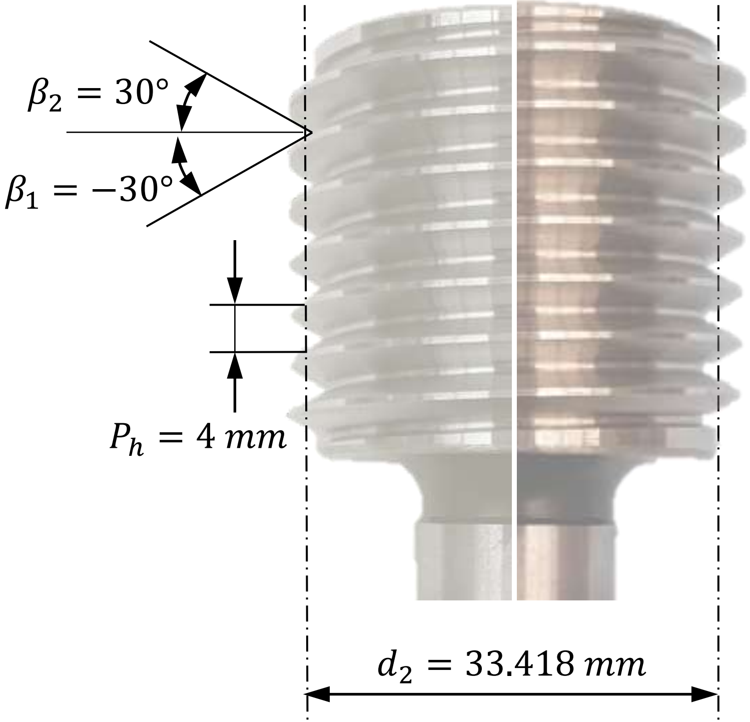
- helix, single flank contact, reversal measurement, substitution measurement to correct pitch diameter
- scanning speed $4\ {}^{mm}/_{s}$
- ruby stylus $r \approx 500\ \mu m$

Results: thread determinants

„go“-thread gauge / GD M 36 – 6H
nominal values

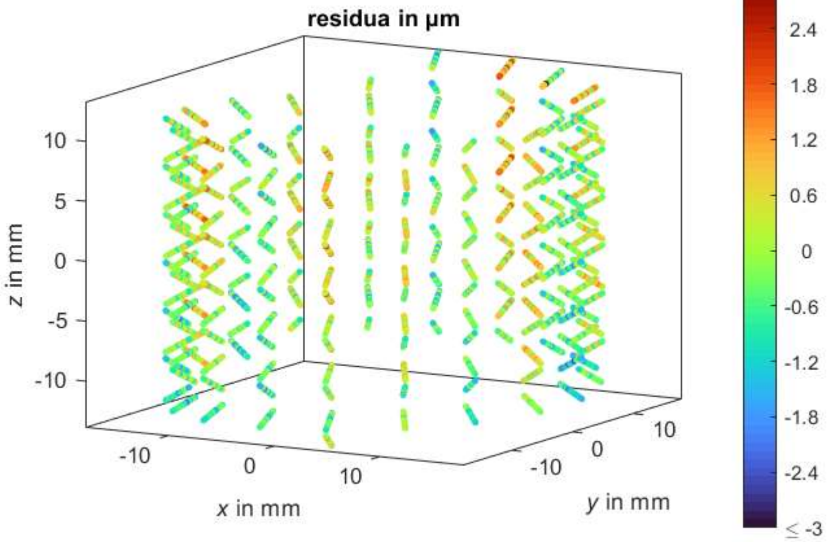
First exemplary measurement results

	CMM
d_2 in mm	
P_h in mm	
β_1 in °	
β_2 in °	



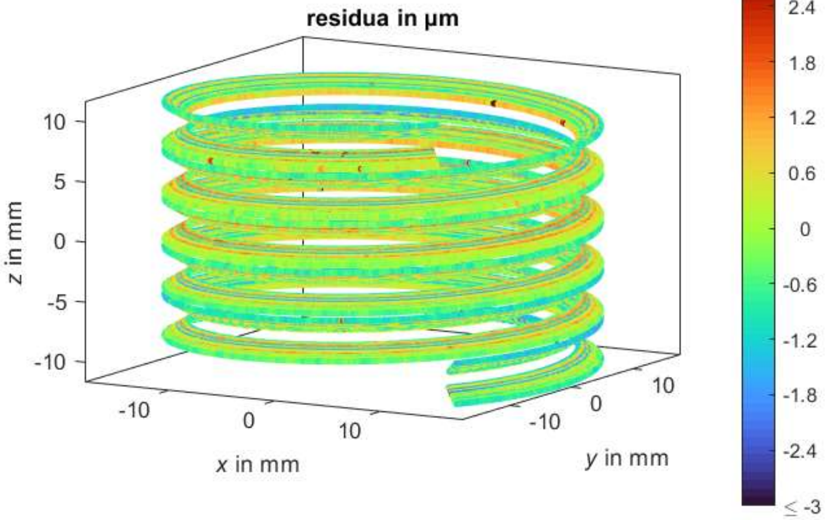
Results: 3D point clouds

Scanner (V1)



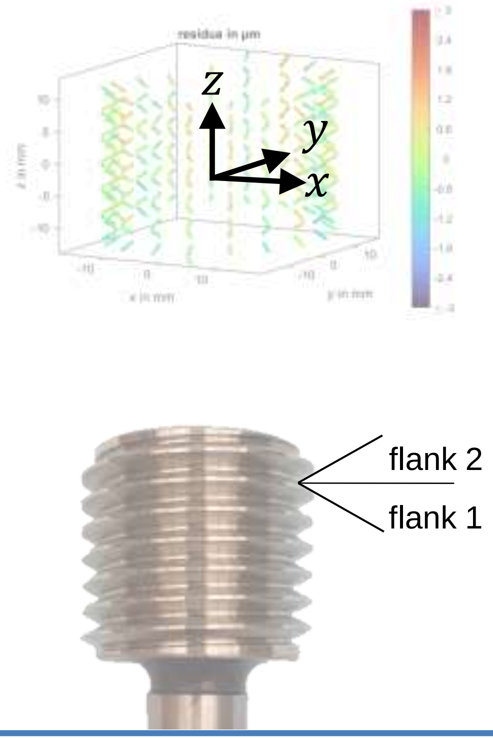
$\hat{\sigma} = 0.824\ \mu m$
$n = 106155$

CMM

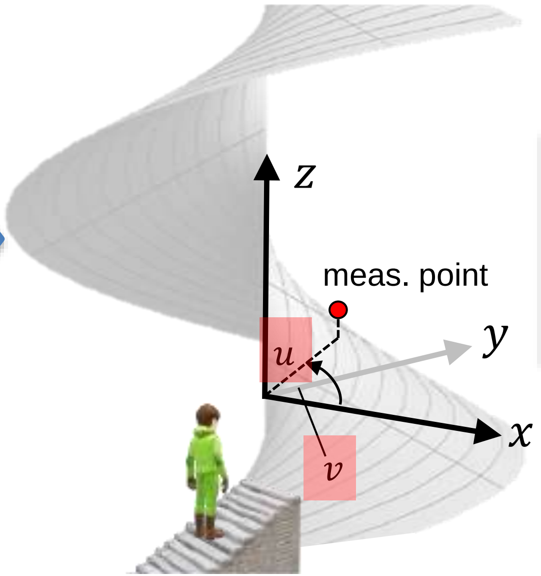


$\hat{\sigma} = 0.837\ \mu m$
$n = 178308$

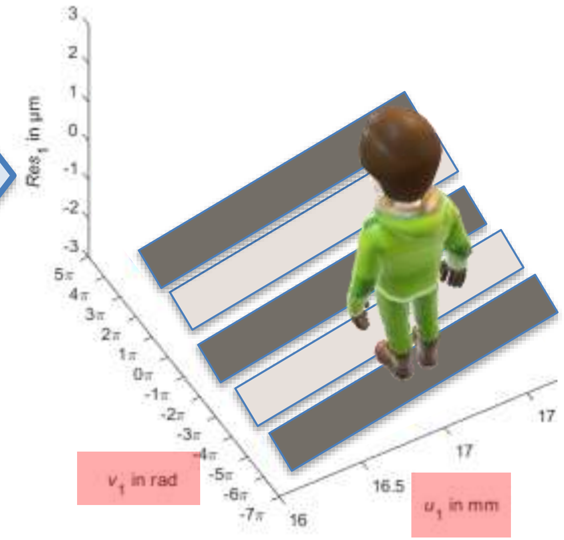
Results: Unwound residua



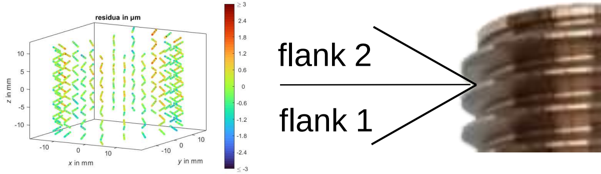
helix surface (flank 1)



flank 1

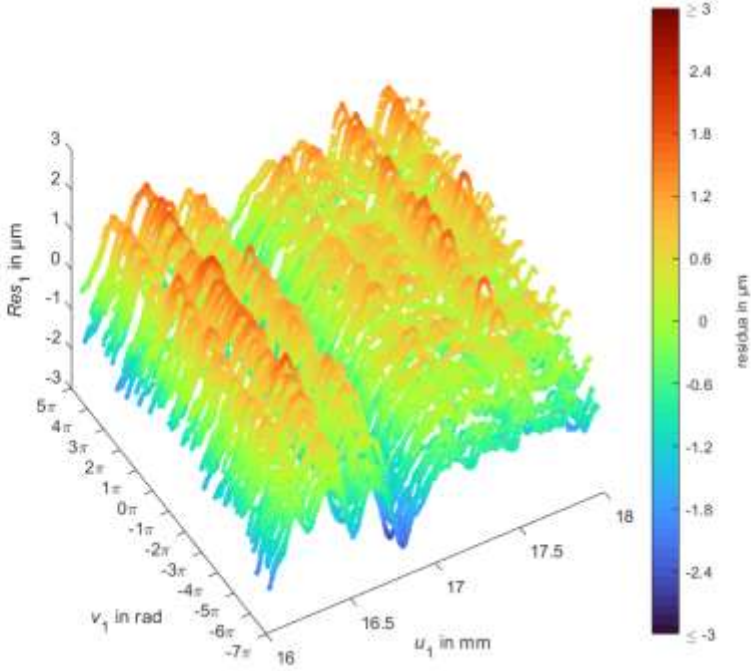


Results: Unwound residua

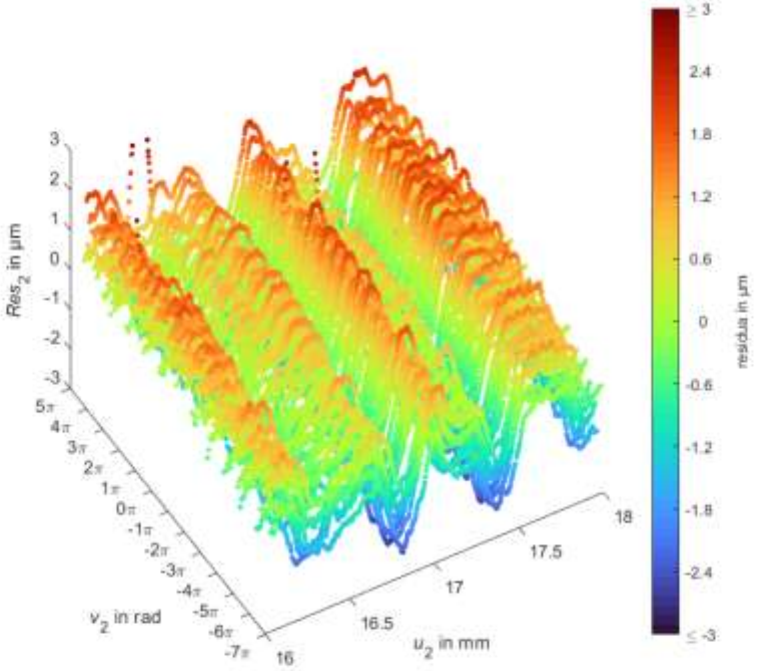


Scanner (V1)

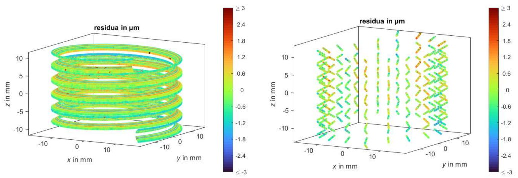
flank 1

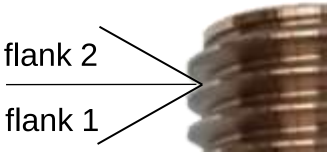


flank 2



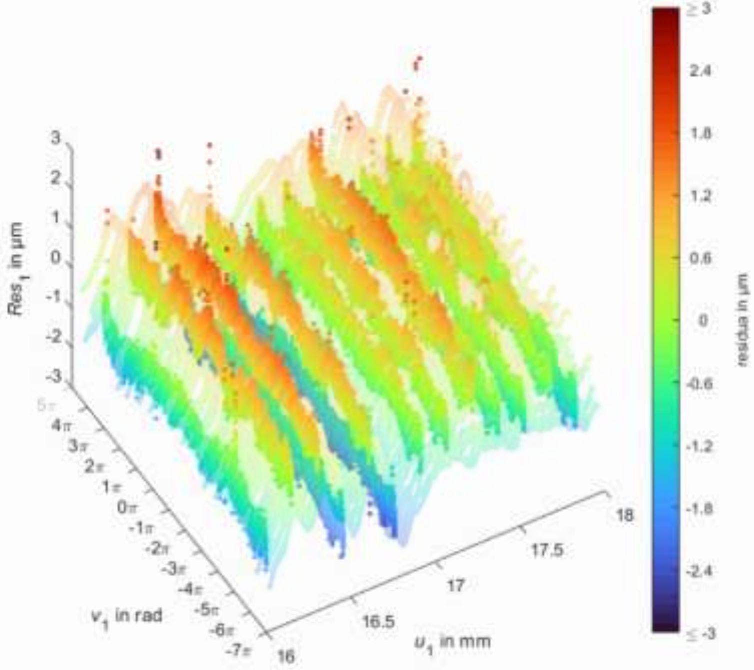
Results: Unwound residua



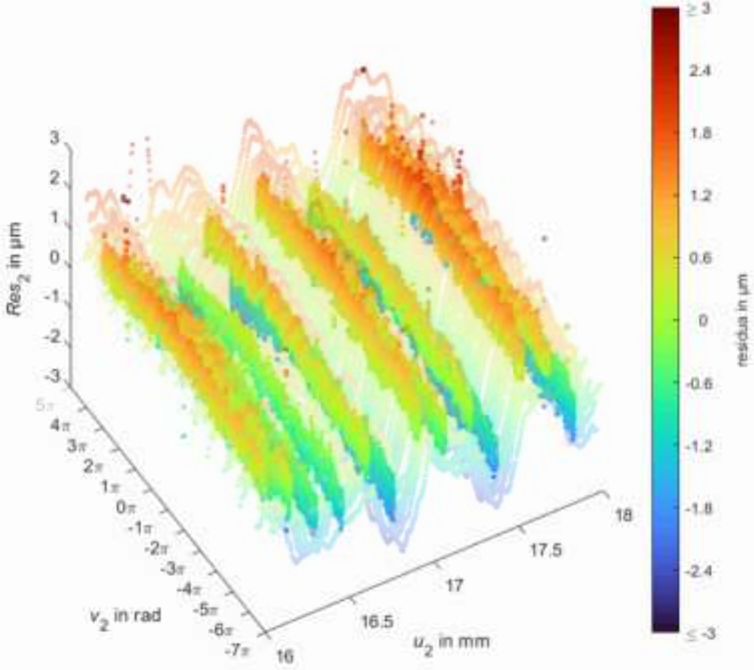


Scanner (V1) + CMM

flank 1

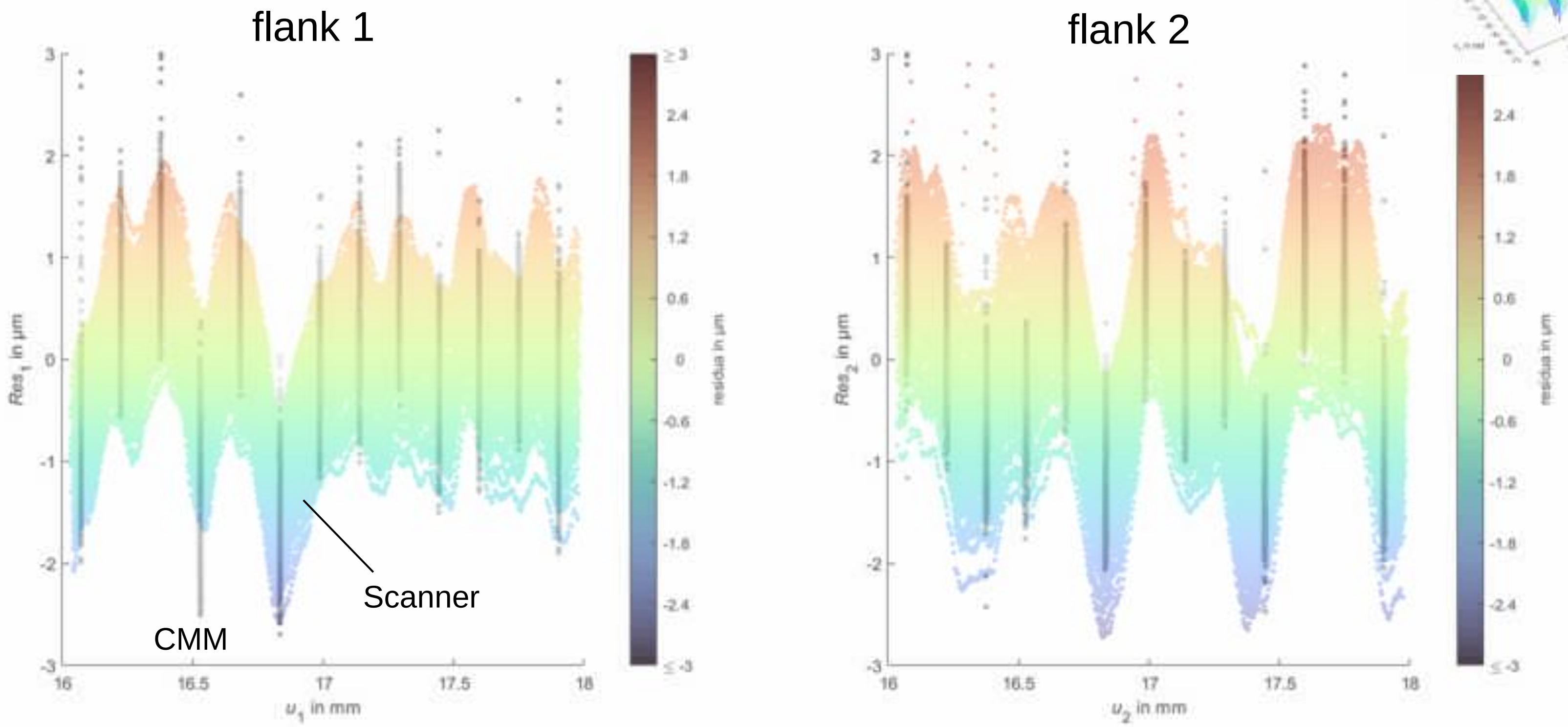


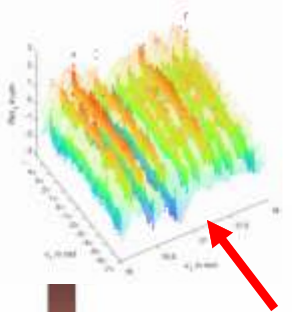
flank 2



Results: Unwound residua

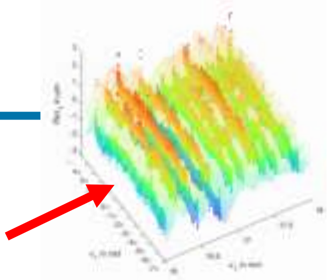
Scanner (V1) + CMM



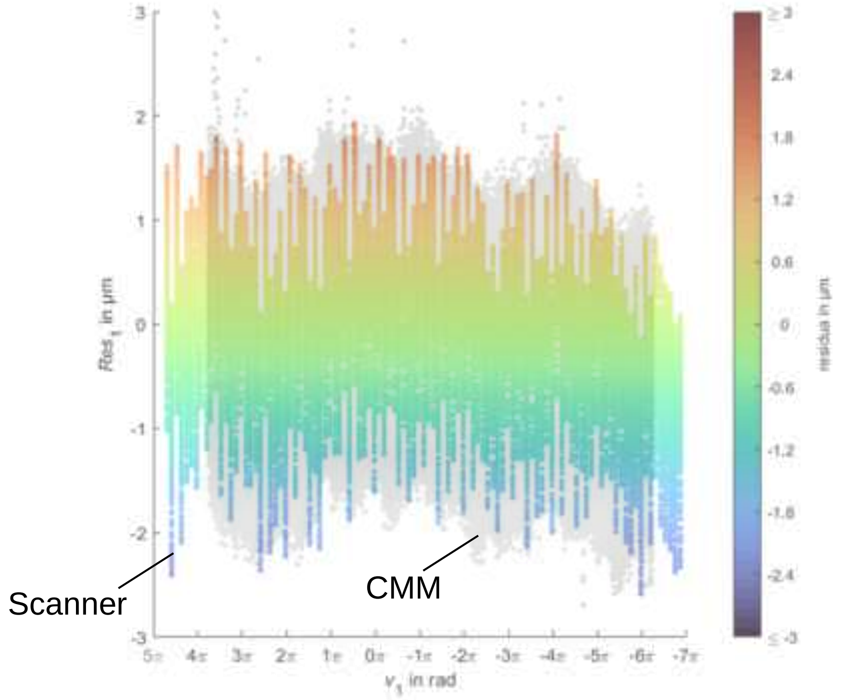


Results: Unwound residua

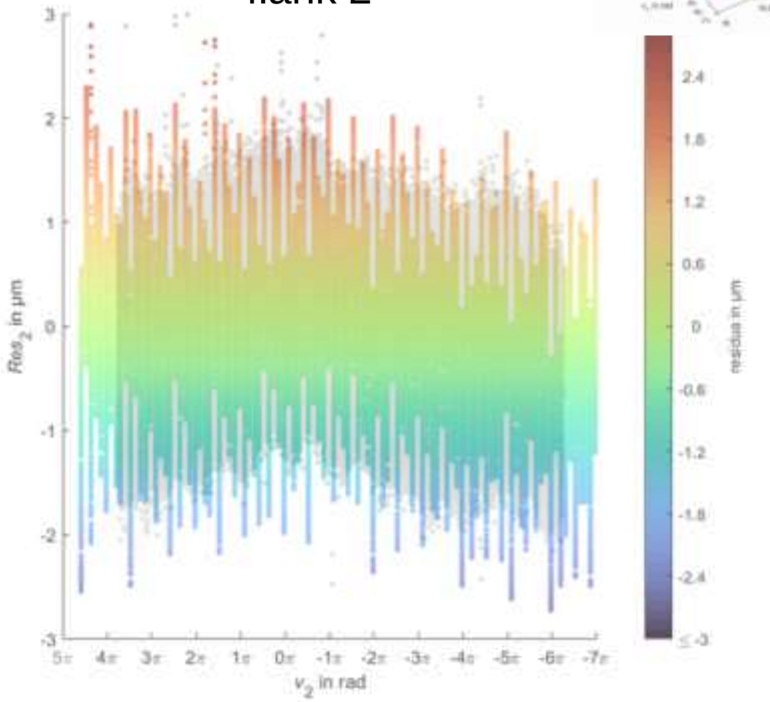
Scanner (V1) + CMM



flank 1

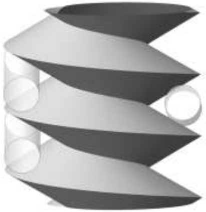


flank 2



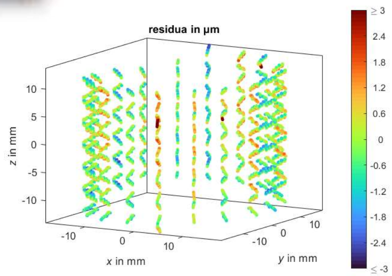
Summary

- „Status quo“ of thread calibration
  - 2-D data evaluation procedure
  - no 3-D thread model considered



- 3D thread characterization at PTB
  - CMM / 2-D contour scanner with rotation axis
  - holistic data evaluation

- First scanner measurement results
  - promising axis optimization approaches
  - good agreement with CMM measurement

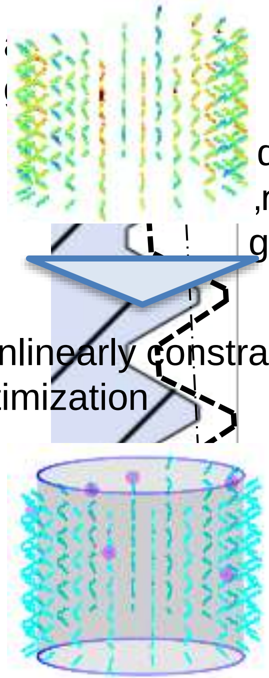


Outlook

- Parameter studies
  - axis optimization
  - thread calibration
- Determination of virtual pitch diameter
  - 3-D data required
  - complex to derive as ideal “mating” geometry is required (“envelope thread”)
  - potentially via SQP* with boundary conditions

*Sequential quadratic programming

Gaussian optimization



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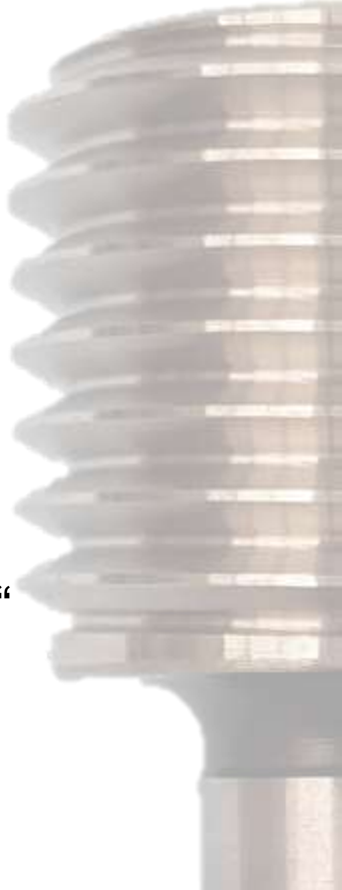


Mathematical thread model / optimization

helix surface for flank $j = 1,2$

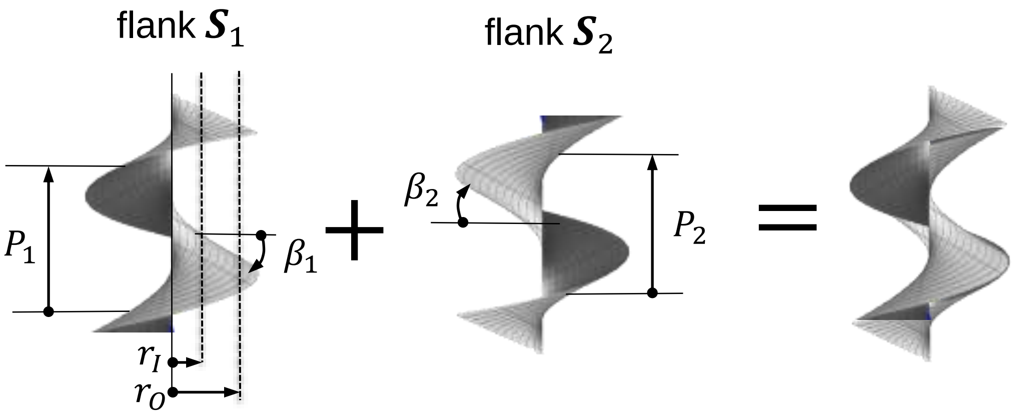
$$S_j^*(u, v, p_{j1}, p_{j2}) = \begin{pmatrix} u \cdot \cos(v) \\ u \cdot \sin(v) \\ u \cdot p_{j1} + v \cdot p_{j2} \end{pmatrix}$$

- geometrical parameter

  $p_{j1} = \tan(\beta_j) \quad p_{j2} = P_j / 2\pi$

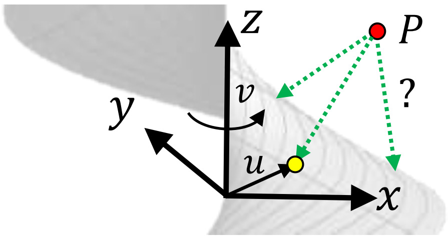
- boundary condition

  $r_I \leq u \leq r_O$



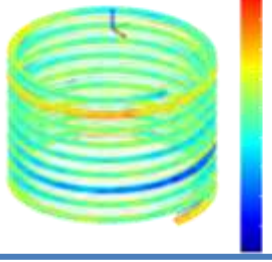
FUNKE-algorithm (Sourlier, 1995)

- (weighted) least squares optimization
- separation of geometry and pose
- derivation of global thread determinants



bestfit via foot point iteration

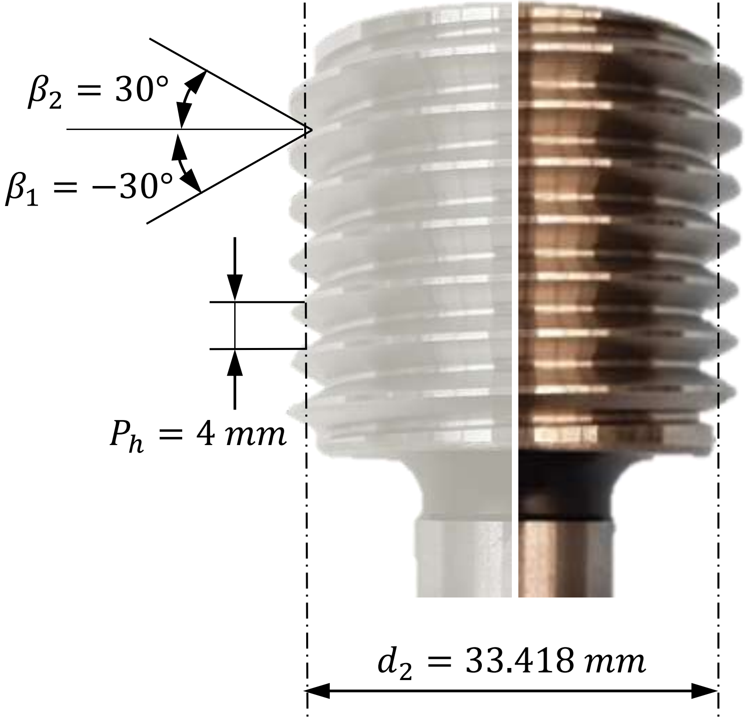
deviation



Mesurand: Nominal values

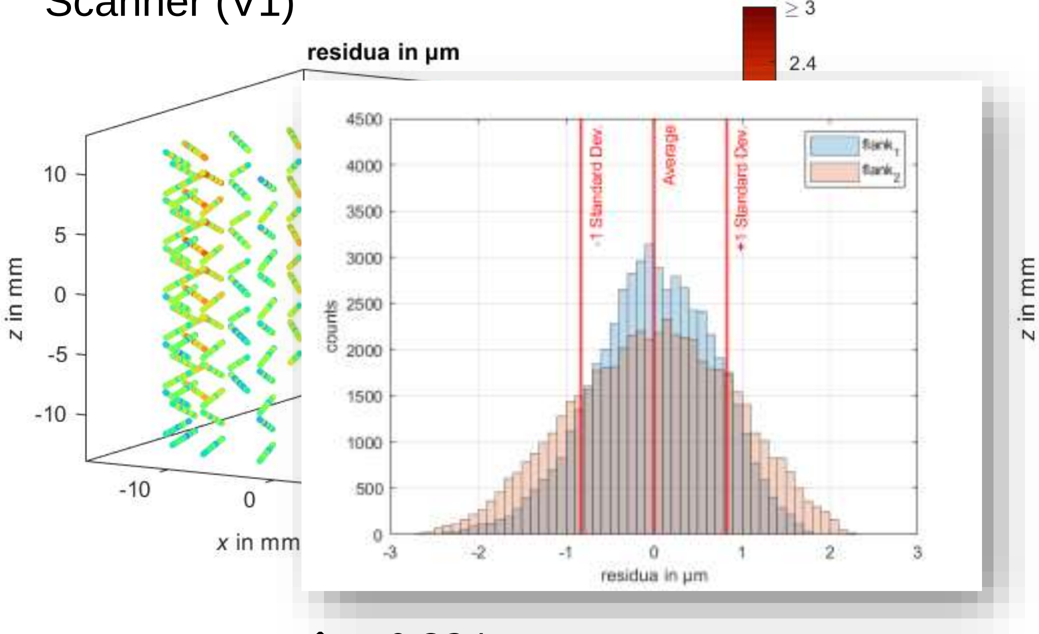
„go“-thread gauge / GD M 36 – 6H

Parameter		Tolerance
outer diameter in mm	36.0160	$\pm 0.0140\,mm$
pitch diameter d_2 in mm	33.4180	$\pm 0.0070\,mm$
core diameter in mm	max. 31.0930	
lead of helix P_h in mm	4	$0.005\,mm$
flank angles β_1, β_2 in °	$-30/30$	$\pm 8'$ ($\pm 0.1\bar{3}$°)
thread angle $\alpha = \lvert\beta_1\rvert + \beta_2$ in °	60	



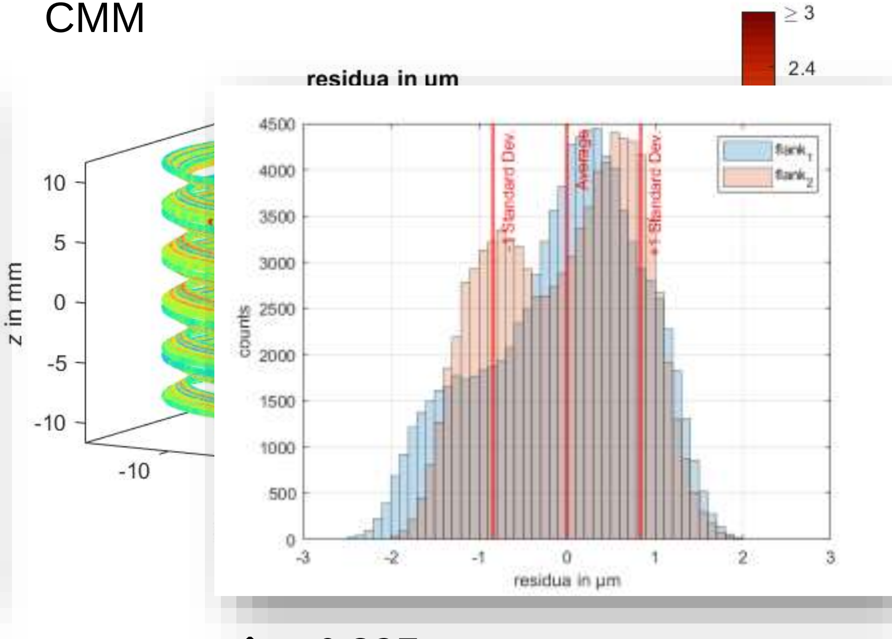
Results: 3D point clouds / histograms

Scanner (V1)



$\hat{\sigma} = 0.824\ \mu m$
$n = 106155$

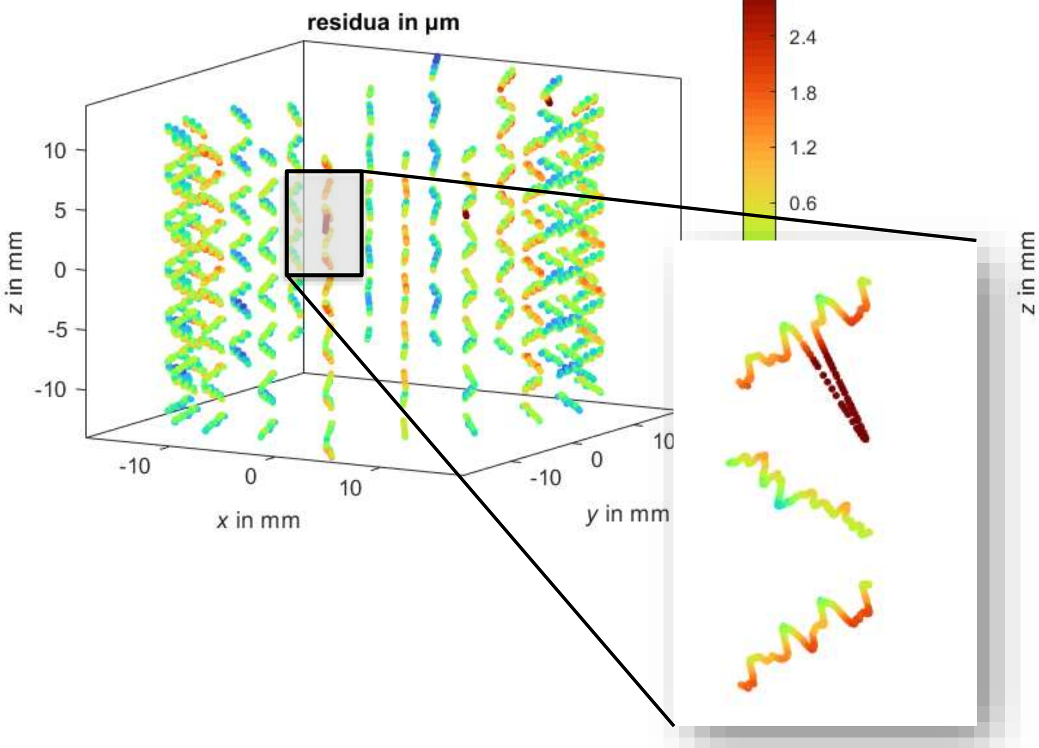
CMM



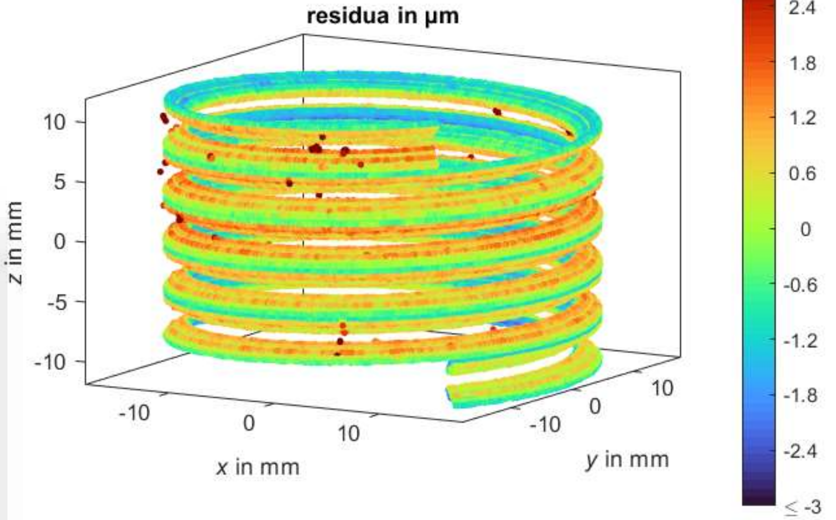
$\hat{\sigma} = 0.837\ \mu m$
$n = 178308$

Results: 3D point clouds – „zoomed in“

Scanner (V1)

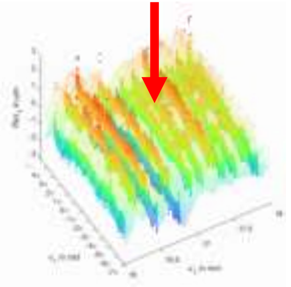


CMM

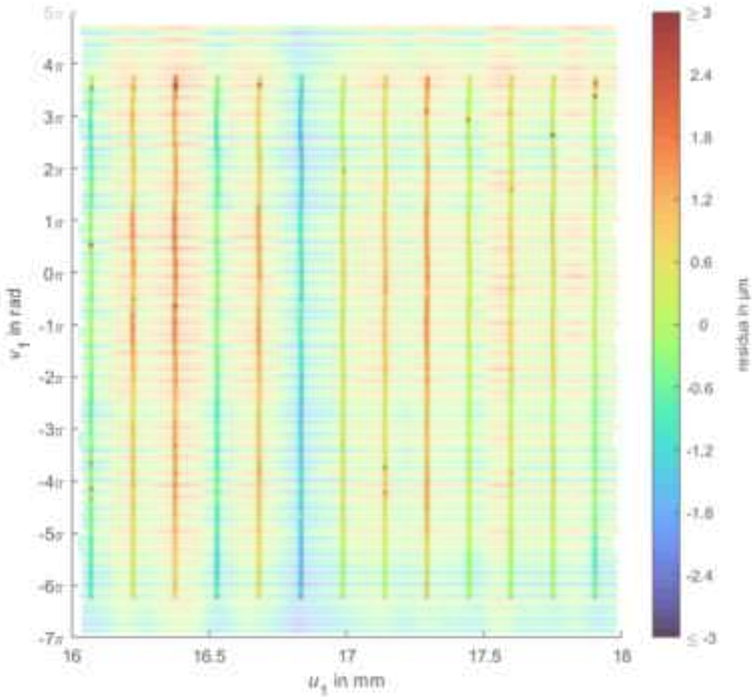


Results: Unwound residua

Scanner (V1) + CMM



flank 1



flank 2