EUCoM – Evaluating Uncertainty in Coordinate Measurement

National Session: UK

Presenter: Chris Smyth (NPL)

Meeting to be recorded

The team at NPL

Alistair Forbes	NPL Fellow in the Data Science department Work extensively on the development of algorithms and software for coordinate metrology
David Flack	40 years in Dimensional Metrology at NPL
James Norman	7 years experience in Dimensional Metrology including 2.5 years at NPL

Contents

- Background to project / technical details
- Implementation of measurement uncertainty analysis
- Review of NPL's role and experiences
- Questions to audience
- Questions from audience
- Results of questions to audience
- Open discussion

Acknowledgements

- This project has received funding from the EMPIR programme (17NMR03 EUCoM) co-financed by the Participating States and from the European Unions Horizon 2020 research and innovation programme.

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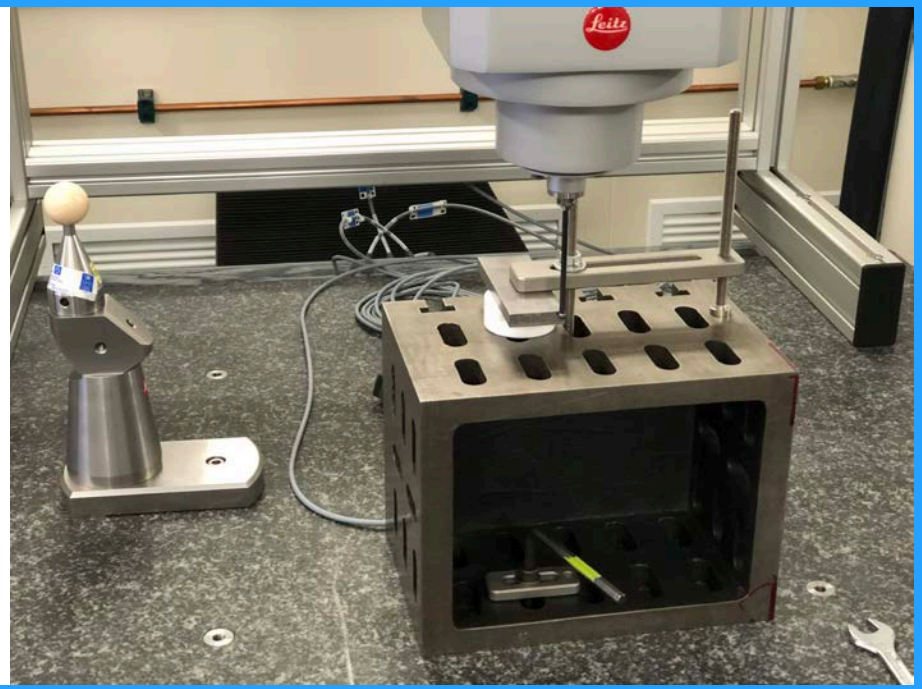
EUCoM
Evaluating Uncertainty in Coordinate Measurement

Overview of EUCoM project

- recap of this morning

Presenter: James Norman



https://www.hexagonmi.com/products/coordinate-measuring-machines/bridge-cmms/leitz-infinity

Plenary session

https://eucom-empir.eu/seminars/

Audience question

When ascertaining conformity/non-conformity of a product do you…

Current uncertainty evaluation methods

ISO 15530 series

Part 3:

- provides an a posteriori method based on measurements of a *calibrated workpiece*
- calibrated workpiece is required to be identical (nominally) to the *actual workpiece*

Part 4:

- evaluation of *task specific* measurement uncertainty using simulation
  - e.g. VCMM, PUNDIT CMM, other Monte Carlo methods

MPE vs measurement uncertainty

- Maximum permissible error (MPE) of length measurement
  - Extreme value of length measurement error, E_L, permitted by specifications (ISO 10360-2:2009)
  - NB: One dimensional
  - e.g. $E_L = A + L/B$

- Measurement uncertainty
  - A parameter, associated with the result of a measurement, that characterizes the *dispersion of the values* that could reasonably be attributed to the measurand
  - e.g. 1000 ± 3 mm ($k = 2$)

Where these methods fit in to the current methods availed?

1. 15530-3
2. 15530-4 e.g. VCMM
3. MPE
4. Do nothing

1. 15530-3
2. 15530-4 e.g. VCMM
3. ***EUCoM methods***
4. MPE
5. Do nothing

Audience question

- How do you currently consider the measurement uncertainty associated with your CMM measurements?
- Would simplified methods of ascertaining measurement uncertainty be useful to you?

Project aim

Deliver two ***industrially relevant*** methods for evaluating the uncertainty of coordinate measurement:

1. Based on *prior knowledge*
   - of the coordinate measuring machine specification

2. Based on *learnt knowledge*
   - of the part to be measured and the specific measurement task

These methods will feed into new standards – ISO 15530 series

Project objectives

- To develop *traceable* and *standardised* methods for evaluating the uncertainty of coordinate measurement a posteriori using type A evaluation.
  - *Remove* need for calibrated workpiece
  - Use workpiece under investigation

- To develop a *simplified* and *validated* method for predicting the uncertainty of coordinate measurements a priori using type B evaluation.
  - *Mathematical models* using known information about a CMM (e.g. MPE) and known information about a workpiece (e.g. nominal shape)

NPL's role in EUCoM

- Took a *leading role* in development of mathematical models for a priori method
  - Such as the models presented by Alistair Forbes (morning session)
- Fed back into development and design of experiments for testing the method based on a posteriori information
  - Uncertainty estimates via measurement data (performed on workpiece)
- Took part in the *selection of workpieces* used for round robins
- Measured both a *prismatic* workpiece and a *freeform* workpiece on our CMMs

A note on the impact of COVID19

- NPL lab shutdown in March 2020
- Lab restart for some CMM was not trivial!
- Subsequent bubbling systems have had significant impact on speed of measurement delivery
- CTC environment in labs: great for CMM… not so great for SARS COV 2

Questions

- Before we move onto more specific technical details, are there any questions?

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Experience with the methods using learnt knowledge

Presenter: James Norman

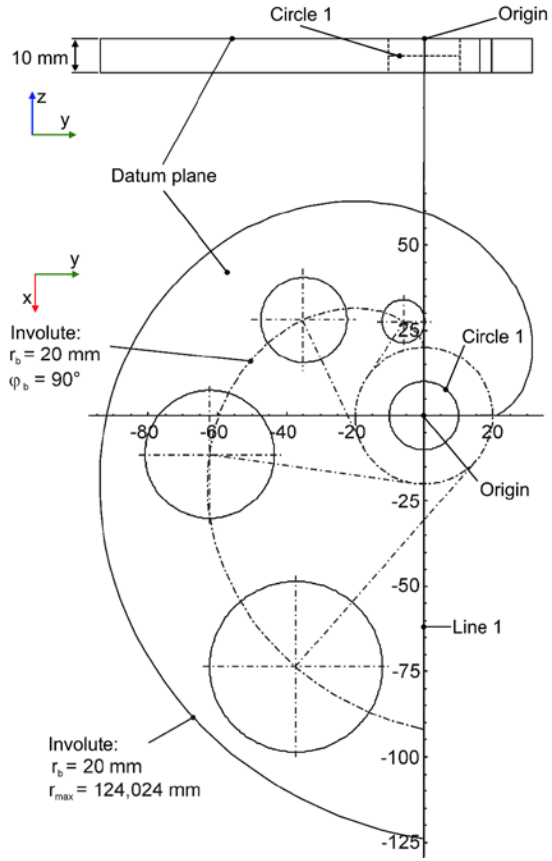
Workpiece selection

- Seven of workpieces were selected
  - Aimed to make these workpieces *industrially relevant*
  - Relatively simple workpieces
  - Some *prismatic*, some *freeform*

Artefact	Provided by	Calibrated by
Connecting rod	CMI	CMI
Multi-feature check (HQ)	ATH	CUT
Multi-feature check (LQ)	PTB	PTB
Steering knuckle	ATH	CUT
Hyperbolic paraboloid	CMI	CMI
Involute gear	PTB	PTB
Freeform plate	NPL	NPL

Description of the method (1)

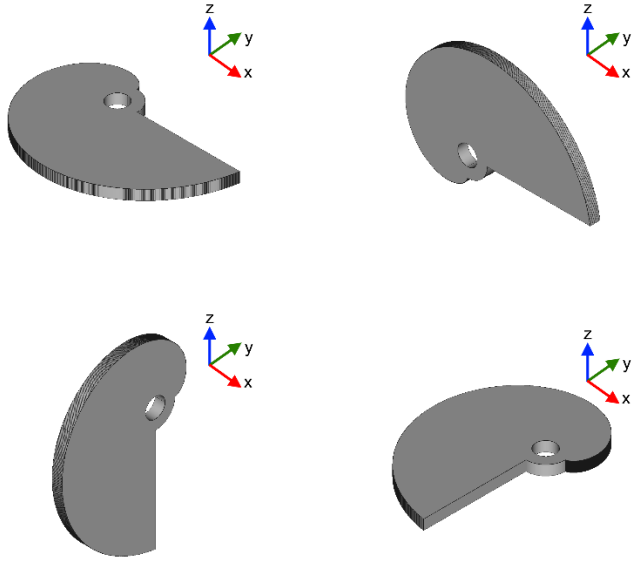
- Involute(s)
  - One wavey
  - One non-wavey
- Measured on two CMM
  - Leitz PMM-C infinity
  - Ziess UPMC 550



Description of the method (2)

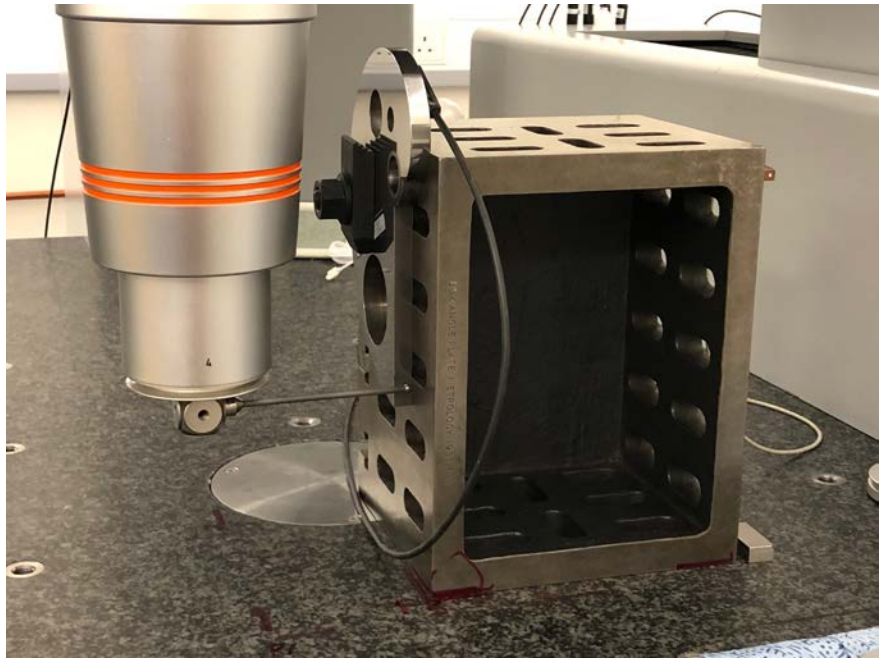
- Measurements of features
  - Four orientations
  - Five measurements (min 3)
  - Reset mounting between each measurement

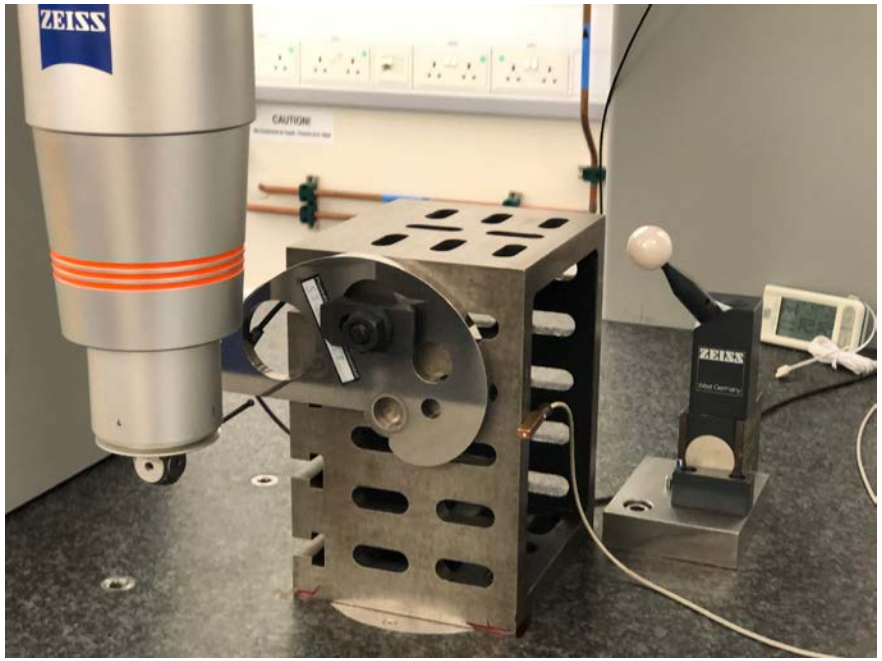
- Output coordinate data from critical features for uncertainty analysis



Involute on Zeiss UPMC

- Orientations 2 and 3
- May need specific stylus arrangements for different orientations





Sphere and gauge block

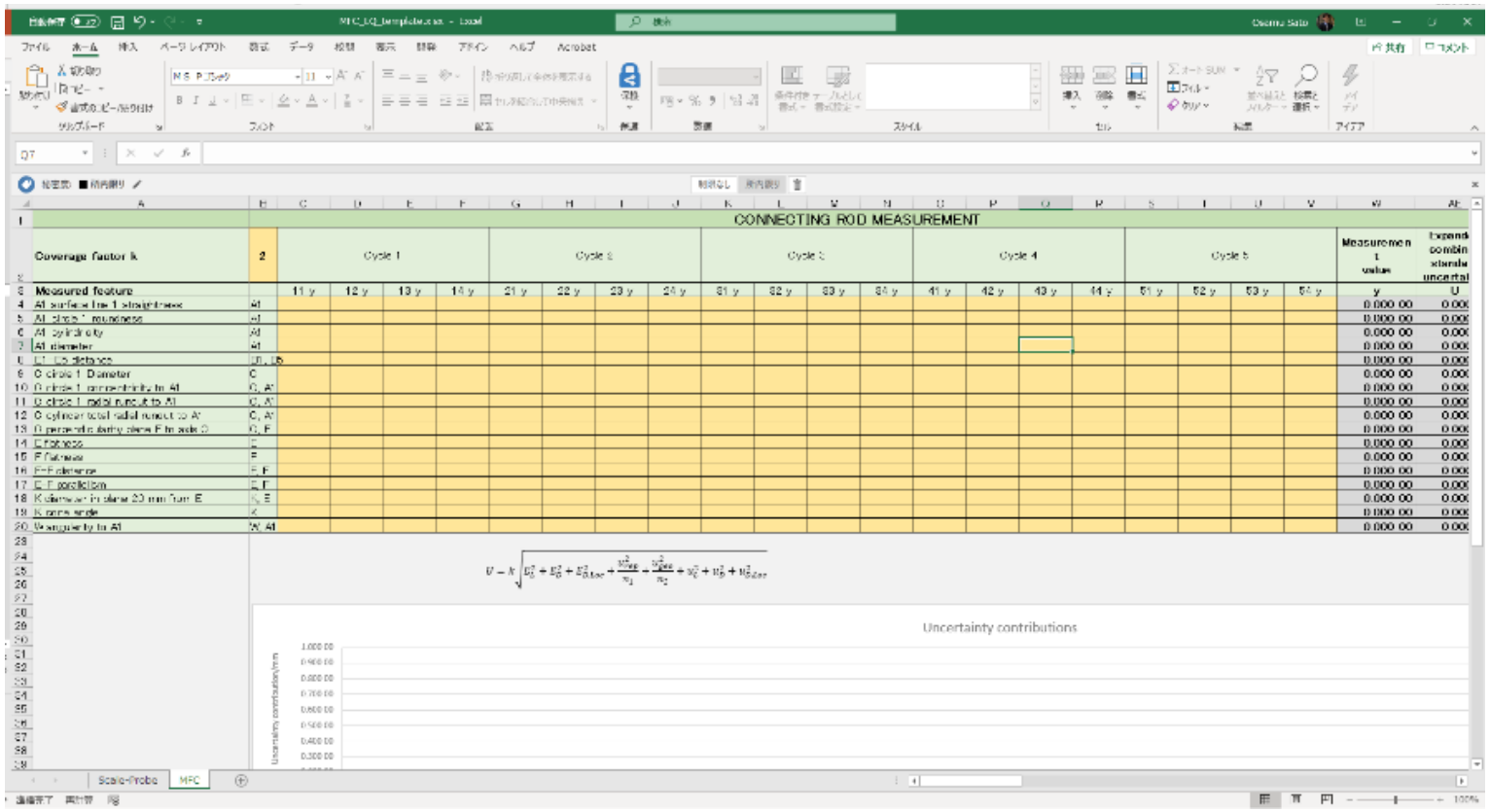
- Measurement of sphere and measurement of length gauge
  - Cannot use qualification sphere
  - Calibrated diameter (sphere) and length (gauge block)

Technical implementation

- Analysis of variance (ANOVA) technique

- Length gauge
  - Introducing scale
- Spherical measurement
  - Probe setup error

- Excel template for calculations (will be available)



NPL experience of using method

- Styli – may need *customised* setup
- Workpiece mounting – *not always easy to define orientations* on CMM (rotation)
- Scanning vs single points – need to replicate real scenario but consider point measurements as a standard

- Once setup is defined and tested, remaining work is trivial to carry out and repeat
- Up front cost but minimal costs thereafter

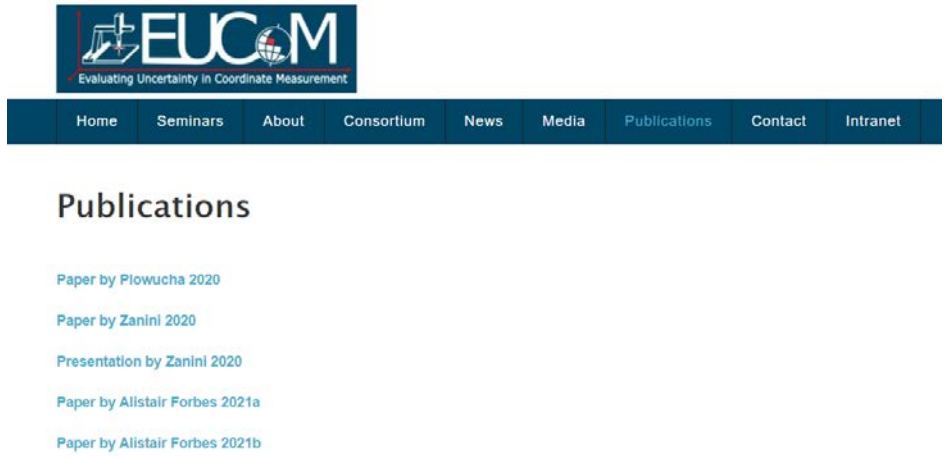
Audience question

- What are the benefits to you of the methods we have outlined?
- What are the barriers to using the methods outlined?

Section specific questions

EUCoM website and publications

https://eucom-empir.eu/



M4R funding refresh

https://www.npl.co.uk/measurement-for-recovery

- Consultancy to bring you up to speed with these methods
- This could be used to help with implementation of methods

Open discussion

- Results from polls

How often do I need to repeat measurements?

- After ISO 10360
- Significant change in workpiece features
- Significant change in measurement environment
- Change in CMM
- After a long time

- Basically after anything that might change the uncertainty in measurement

How long did measurements take?

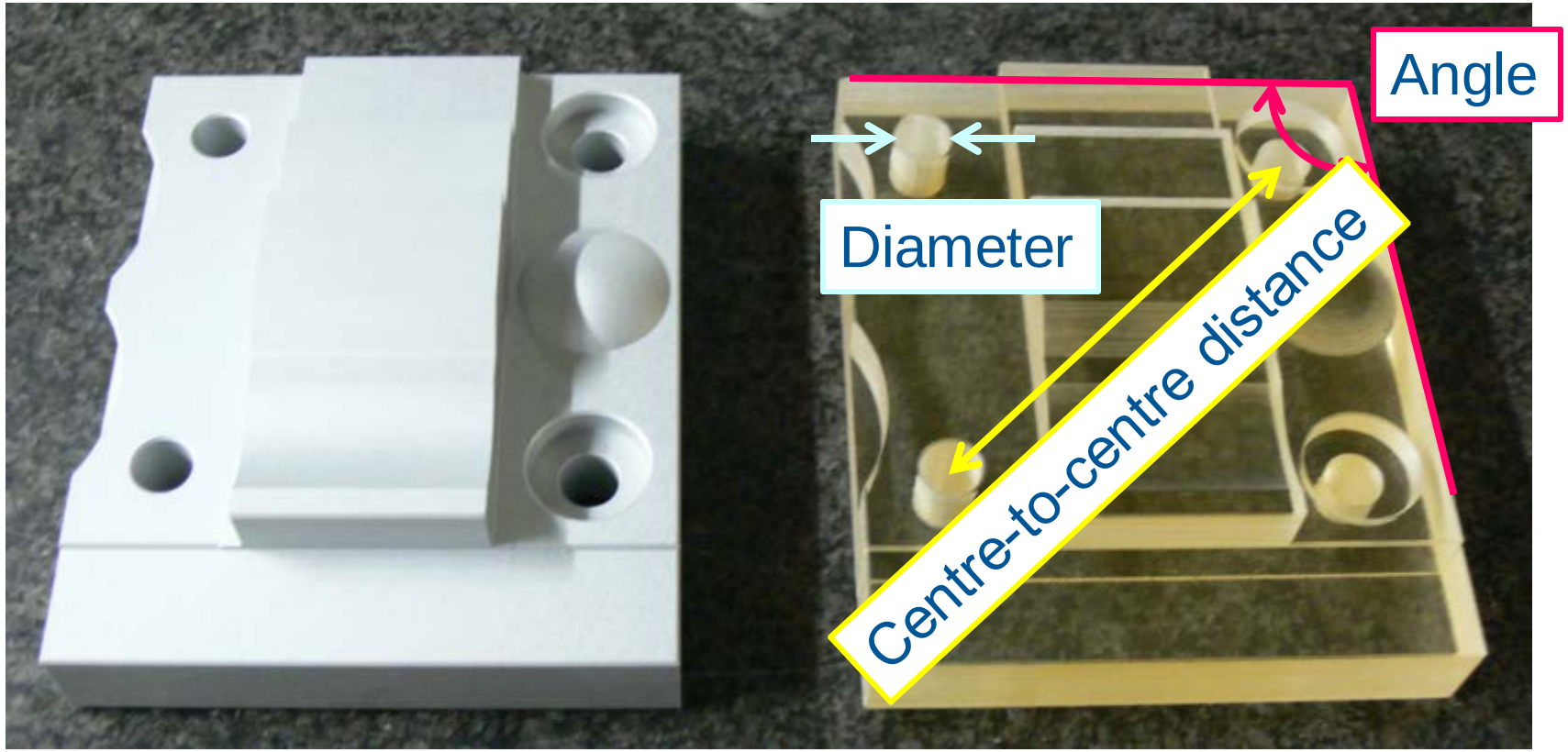
- Dependent on rigour of analysis
  - Number of repeat measurements
  - Is mounting reset

- Approx. 40 mins per involute measurement

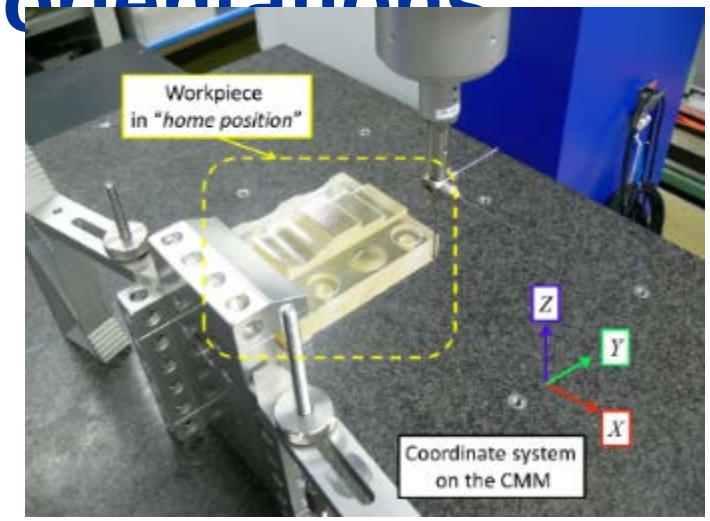
- 4 orientations × 5 repeat measurands = ~13 hrs per workpiece per CMM

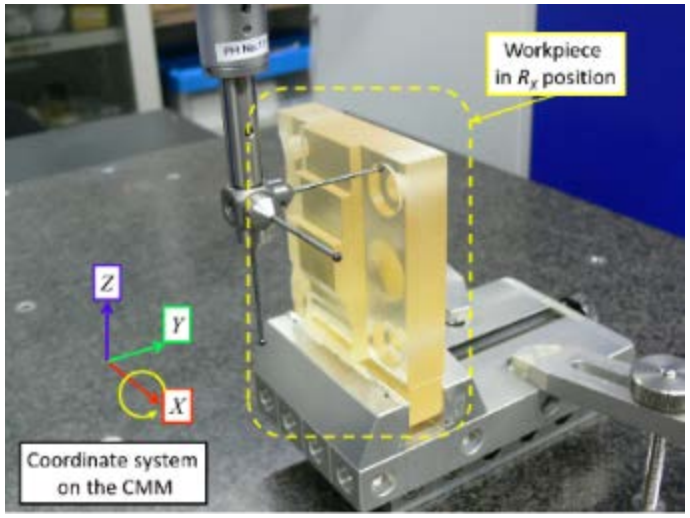
Practice

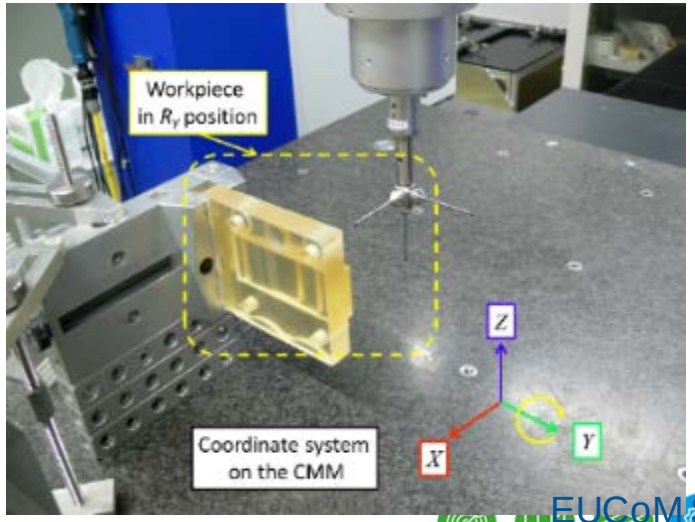
- Angle and distance/size measurement



3 repetitive measurements in 4 orientations







4-orientation is sufficient

Measurement results

	Orientation 1 (home position)	Orientation 2 (R_X position)	Orientation 3 (R_Y position)	Orientation 4 (R_Z position)
Cycle 1	89.9859	90.0140	90.0159	89.9848
Cycle 2	89.9853	89.9860	90.0166	90.0148
Cycle 3	89.9853	89.9862	90.0162	90.0144
$\overline{{}^{j}y}$	89.9855	89.9954	90.0162	90.0047
$\bar{\bar{y}}$	90.0005			

Variation by random errors and short-term system variation

Variation by global errors and long-term system variation

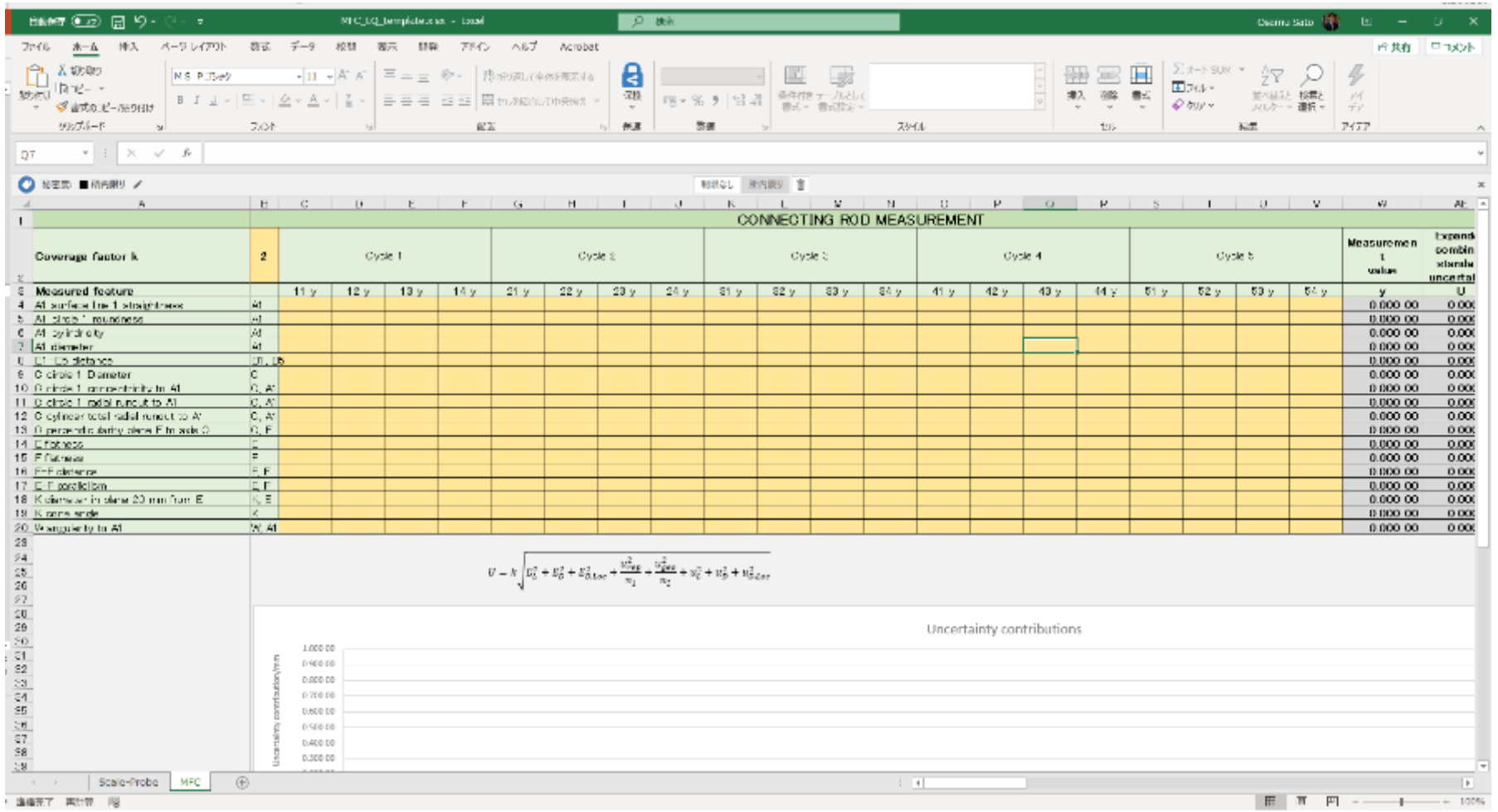
Uncertainty evaluation

S	DOF	Variance	Expectation of the variance
$S_A = \sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\left(\overline{{}^{j}y} - \overline{\overline{y}}\right)^2 = 0.001548$	$f_A = n_2 - 1 = 3$	$V_A = S_A/f_A = 0.000516$	$u_{rep}^2 + n_1 \cdot u_{geo}^2 = u_{rep}^2 + 3u_{geo}^2$
$S_e = \sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\left({}^{ij}y - \overline{{}^{j}y}\right)^2 = 0.001112$	$f_e = (n_1 - 1)\cdot n_2 = 8$	$V_e = S_e/f_e = 0.000139$	u_{rep}^2
$S = \sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\left({}^{ij}y - \overline{\overline{y}}\right)^2 = 0.002659$	$f = n_1 \cdot n_2 - 1 = 11$		
$u_{rep}^2 = V_e = 0.000139$			
$u_{geo}^2 = (V_A - V_e)/n_1 = 0.000126$			
$U = k \cdot \sqrt{\frac{u_{rep}^2}{n_1} + \frac{u_{geo}^2}{n_2}} = 3\sqrt{\frac{0.000139}{3} + \frac{0.000126}{4}} = 0.0264$			

Do I need to execute such a complicated computation?

No!

Calculation with spread sheet software



Excellent template provided by EUCoM project

- Introduction of people
- Recap/intro of project overall (max 5 mins)
  - Industrially relevant evaluation of uncertainty on CMM
  - General – partners across Europe and industrial stakeholders
  - Covid
- ISO 15530 – explanation of existing methods, too complicated/time consuming
  - Get audience opinion of existing parts of this ISO
  - Online quizzes during meeting
- Experience of using method
  - Photos, discussion of practicalities, appropriate styli for orientations, mounting in orientations, one off percase of setup, once in place no need to buy more
- How this project feeds into future standardisation work
  - ISO 15530 part 2 (a priori) and part 5 (a postiori)
- Highlight publications and EUCoM website
  - Future conference and publications
- Open discussion