Misure a contatto con evolventimetri e CMM applicate alla misura di ingranaggi ed elementi complessi

Outline

- the project “DriveTrain”
- case study: a large ring segment
- case study: gear roughness measurements

EMRP
European Metrology Research Programme
Programme of EURAMET
The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union

Traceable Measurement of Drivetrain Components for Renewable Energy

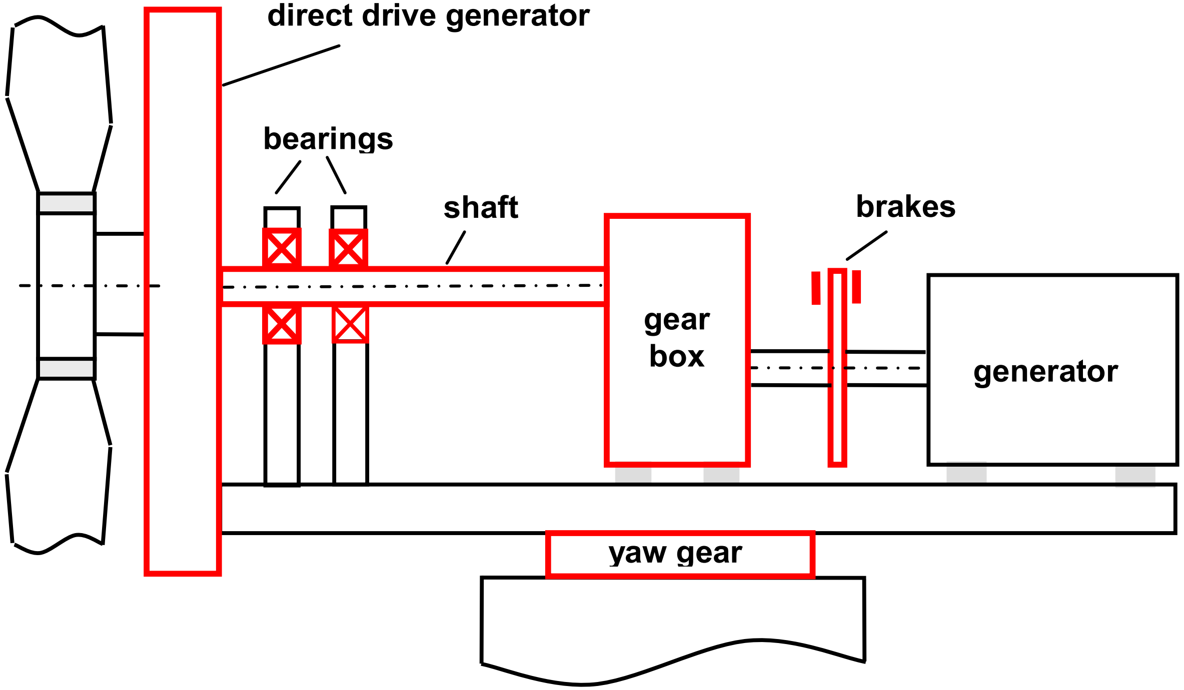
Ensure Reliable Quality Assurance for Less Failures and Enhanced Efficiency

www.ptb.de/emrp/drivetrain.html

- **7 national metrology institutes (NMI, coord. PTB);**
- **3 universities;**
- **4 partners from industry;**
- **19 collaborators/stakeholders**
- **09/2014 – 08/2017 Run-time**

Technical / Economical needs

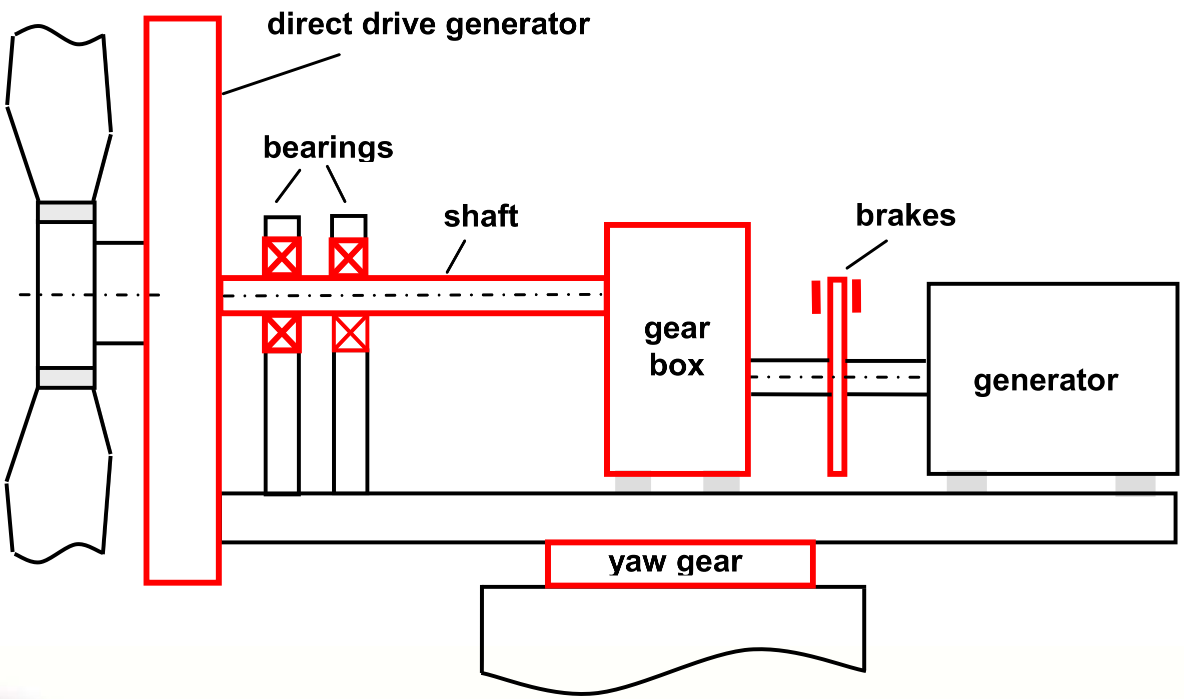
- ✓ EU industry doubling wind energy systems (WES) every 3-4 years
- ✓ maximum power per WES is now 7 MW, 20 MW is already predicted
- ✓ high operation costs



Technical needs

Study the metrological needs for

- ✓ shafts up to 3 m in length and Ø 1 m
- ✓ large bearings up to Ø 2 m
- ✓ internal and external gears up to Ø 3 m
- ✓ brakes up to Ø 1 m



Implementation

- ***Network of European NMIs***

✓ Metrological infrastructure for drivetrain components

✓ Product-like measurement standards for size, form, waviness, and roughness

✓ Determination of the measurement uncertainty in typical harsh environmental conditions in industry

✓ compliance with ISO 14253 to be established

- ***Equipment***

✓ Modern measurement systems (GMMs and CMMs)

✓ Sophisticated software and algorithms

✓ Certified standards

Implementation

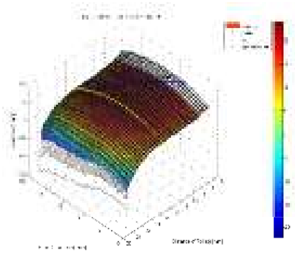
2D and 3D measurement strategies

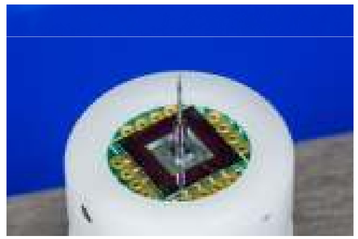
The aim is to provide candidate 2D and 3D solutions for drivetrain component roughness waviness and form characterisation compliant with GPS methodology

Designed and manufactured
test gears for evaluating characterisation parameters;
CAD model links

Issued
a platform for gear profile evaluation;
evaluation of ISO 1328-1 filter specification;
report on existing 3D gear measurement methods;
Gear 2D harmonic profile content;
Gear flank and root roughness and waviness dataset;
test gear measurement strategy recommendations;
a good practice guide (draft) for shaft measurements;
metrology strategies for braking system components;

Measured
test gear samples;
gear replication method assessment;





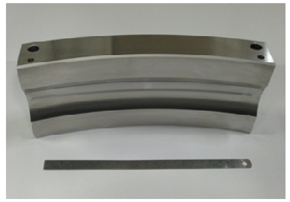
Implementation

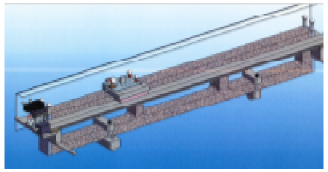
novel measurement standards

The aim is to research and develop measurement standards and calibration procedures for establishing traceability and estimate measurement uncertainty for drivetrain components.

Designed and manufactured
involute artefacts;
a large ring with thermo sensors;
a segment of a large ring;
a novel interferometric step gauge and
test gears

Measured
selected gear samples





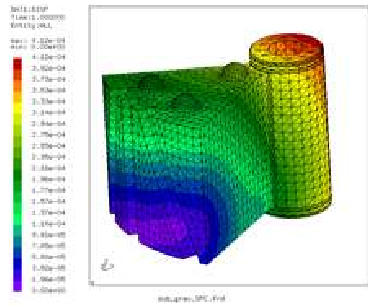
Implementation

virtual measuring process

The aim is to develop a virtual measuring process to include all the significant uncertainty contributions from the workpiece, environment, measuring strategies and measuring instrument.

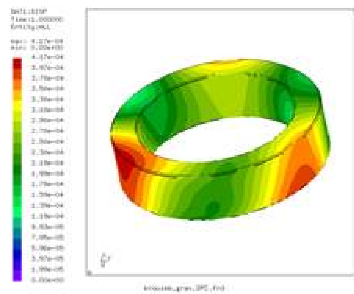
Development

Model (FEM, Kriging theory) for simulation of representative large drivetrain components allowing estimation of temperature, gravity, surface form and roughness influence to numerical value of measurement uncertainty contribution.



Application

Input data for model: 3D geometry, environmental condition, coefficient of thermal expansion, etc. Simulation: geometrical changes, acclimatization time, deformation. Result: estimation of measurement uncertainty contribution.



Validation

Validation of virtual measurement process model using the experimental measurement. Case studies of comparison of the values obtained by simulation with the measured ones.

Implementation

meas. strategies and uncertainty

The aim is to test the developed measurement standards in industry and to establish and quantify the key additional sources of uncertainty that influence industrial measurement capability, with particular reference to environmental effects.

Protocols

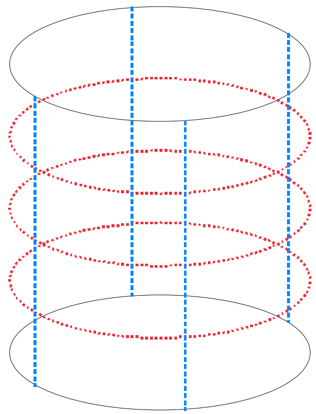
Measurement procedures are under discussion with industrial partners and other industrial users to find optimal and cost effective realisations for practical purposes.

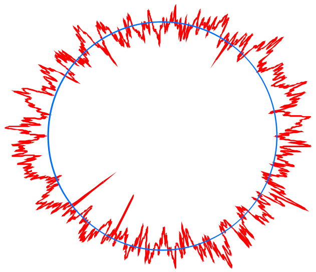
Established measurement strategies have been transfered to large scale metrology and are under test.

The results are discussed with industry to analyse their performance.

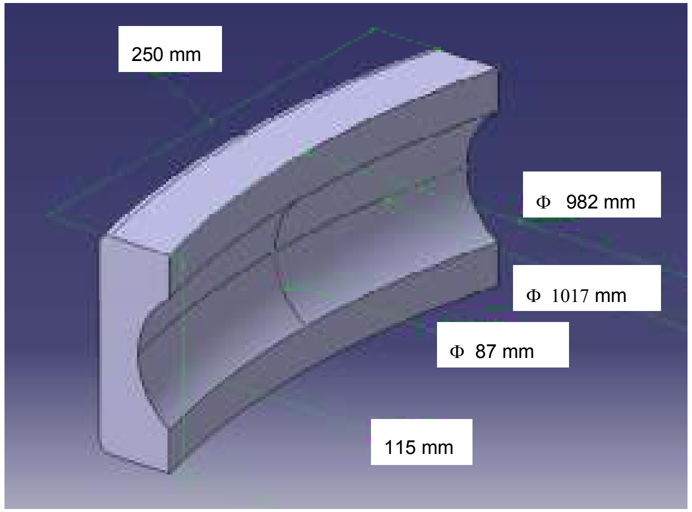
Training

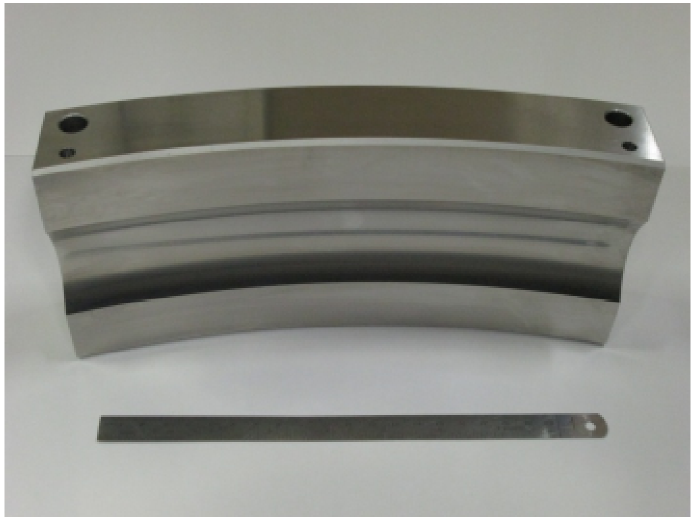
on measurement of gears





Large ring segment





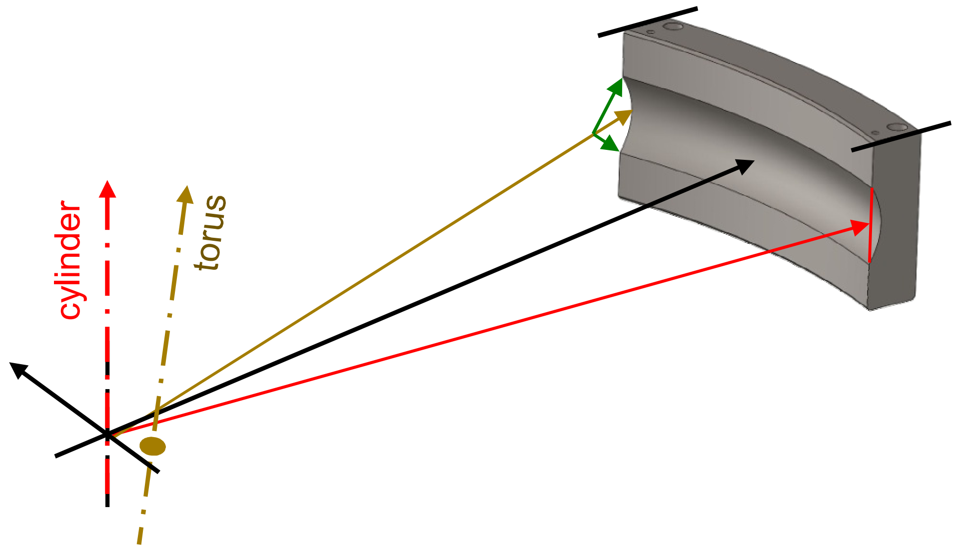
feasibility of using a ring segment primarily to quantify the influence of the workpiece surface and form, which are generally the largest sources of noise and vibrations of critical rolling surface;

measurements of form, sizes and texture of cylindrical- and torus-shape surfaces are needed to qualify raceway conformity and geometries of large bearings cups.

Large ring segment

Measurands

- Two (coaxial) geometrical features:
  - A cylinder
  - A torus
- Intrinsic parameters
  - Radius of the cylinder
  - Torus
    - Radius of the ring
    - Radius of the tube



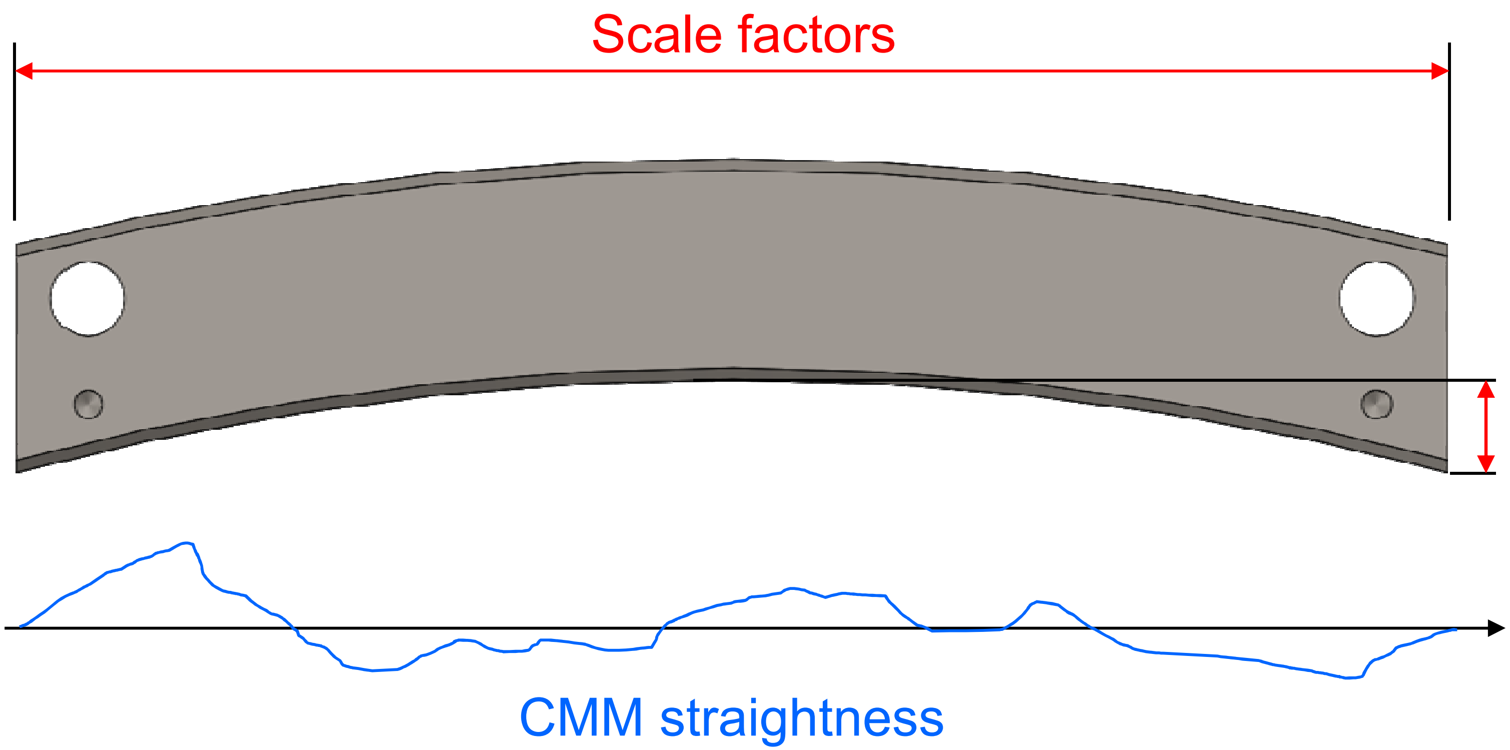
- Location parameters (axes)
  - Orientation
  - Location

Large ring segment

- The measurand features are very partial
  - Cylinder: about its axis
  - Torus: about its axis *and* about its ring
- Mathematically, a partial element poses an ill-conditioned problem
  - The CMM errors are magnified
  - Extreme care in compensating the CMM errors
  - Non trivial uncertainty evaluation (by Monte Carlo)

Large ring segment

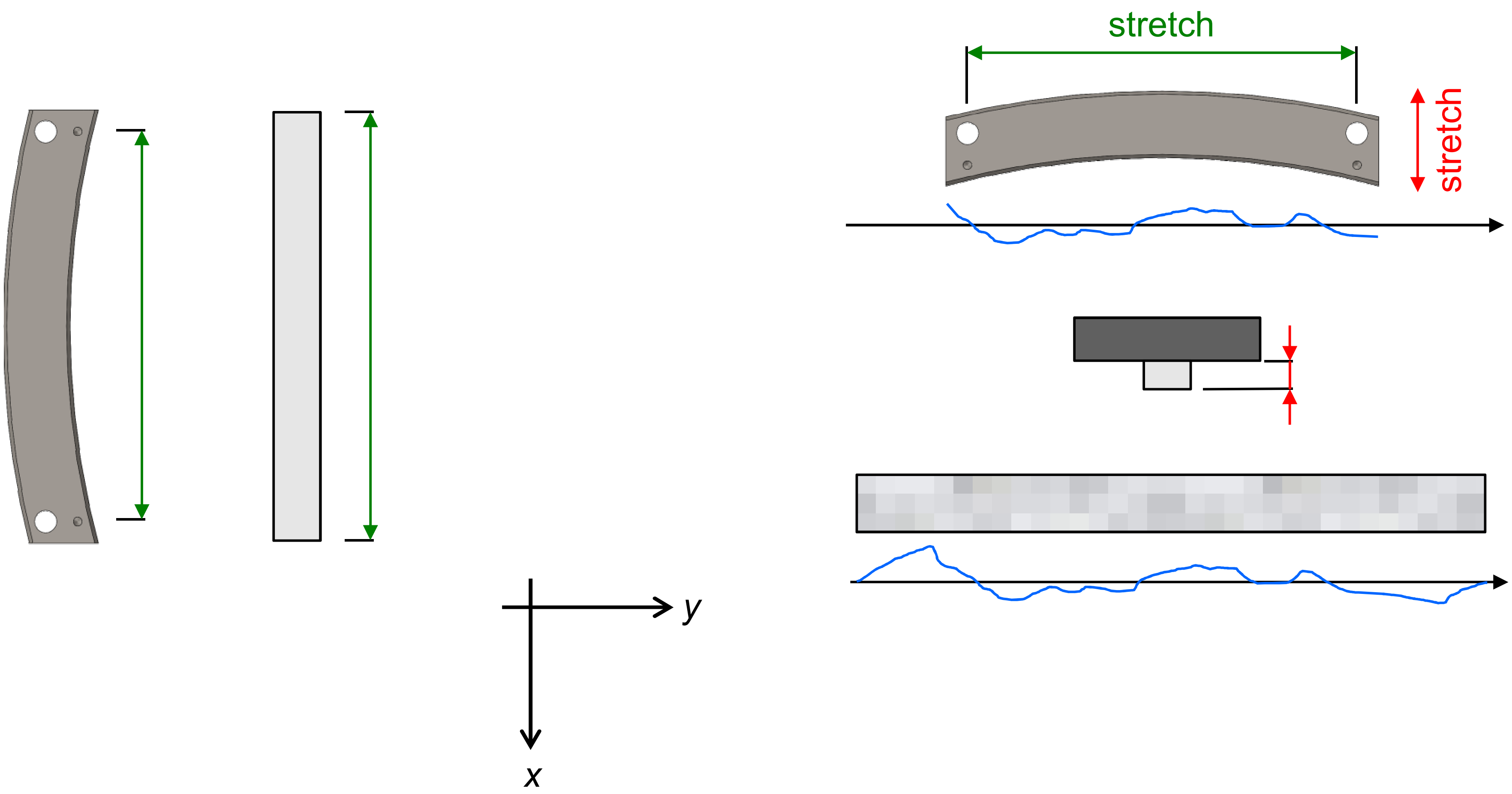
What affects the measurement most?



Comparisons with three calibrated standard to correct as much of these errors as possible

Large ring segment

Comparisons



Large ring segment

Experimental set up

Large ring segment

results

- significantly different in the tangential and radial directions
  - the tangential is much more affected by the partiality of the features
  - this affects both the measurement and the machining
- uncertainty evaluation still to do

Cylinder	
Radius (DfN)	0.16 mm
Form	9.2 µm
Torus	
Tube radius (DfN)	0.58 mm
Overall radius (DfN)	-0.10 mm
Coaxiality torus - cylinder	
Radial	6.15 µm
Tangential	0.51 mm
Angle torus - cylinder axes	
Radial plane	-69 µrad
Tangential plane	-0.43 mrad

DfN = Deviation from nominal

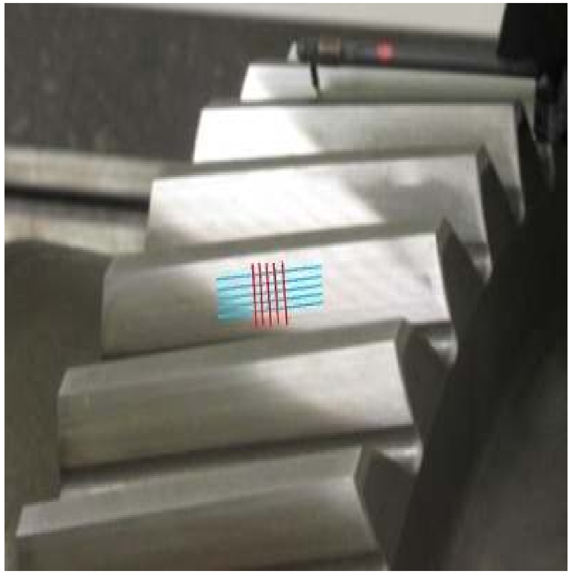
A Balsamo, R Frizza, GB Picotto, D Corona, *Design, manufacturing and calibration of a large ring segment,* Proc. EUSPEN2016, Nottingham, UK, May 2016

motivation

- surface texture as a source of vibration generation and wearing during normal gear operation;
- relation between roughness and micropitting;
- selection of roughness parameters for the evaluation of gear texture;
- prediction of gear noise from roughness analysis.

gear → waviness/roughness

2D tooth profiles were taken from three helical gears of different surface finish



hobbed

ground

lapped

sample gear and gear teeth provided by MDM and NCL

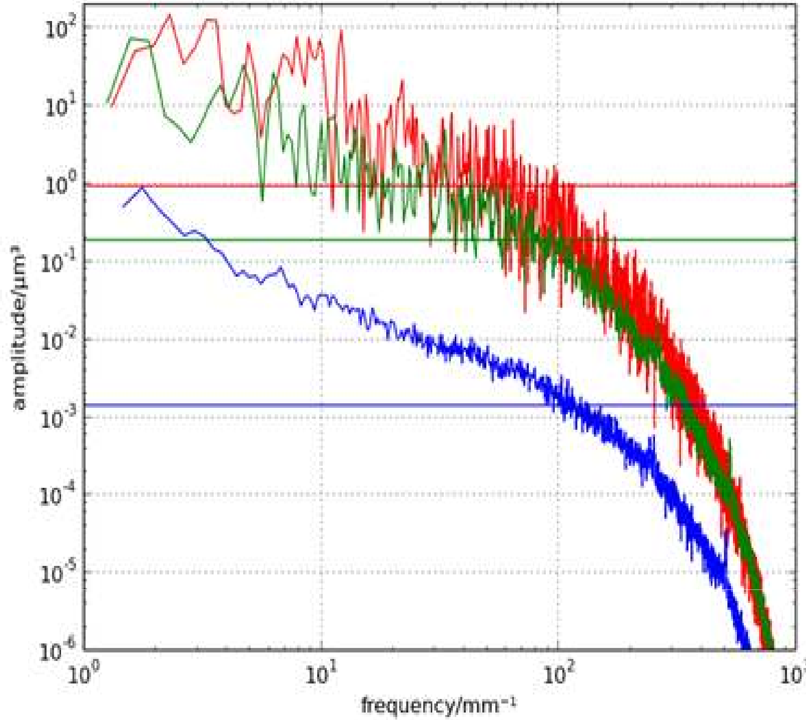
gear → waviness/roughness

PSD graphs _ involute path

The graphs are truncated at the cutoff frequency (1/λc) on the X-axes and at 10^{-6} amplitude on the Y-axes:

Straight lines represent an empirical threshold level of energy, 95% of the whole area below the PSD.

Mean of the PSDs calculated from 20 profiles taken on parallel scan paths of 5 mm length along the **involute** direction



(red) hobbed, (green) ground, and (blue) lapped.

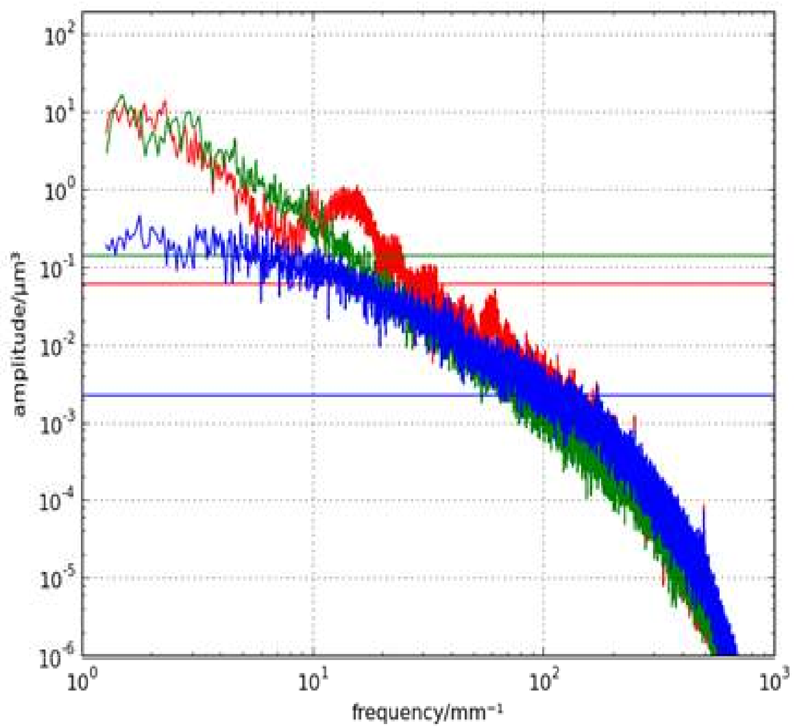
gear → waviness/roughness

PSD graphs _ helix path

The graphs are truncated at the cutoff frequency (1/λc) on the X-axes and at 10^{-6} amplitude on the Y-axes:

Straight lines represent an empirical threshold level of energy, 95% of the whole area below the PSD.

Mean of the PSDs calculated from 10 profiles taken on parallel scan paths of 25 mm length along the **helix** direction



(red) hobbed, (green) ground, and (blue) lapped.

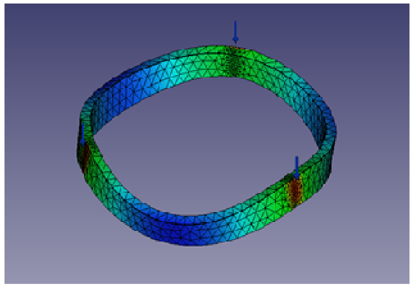
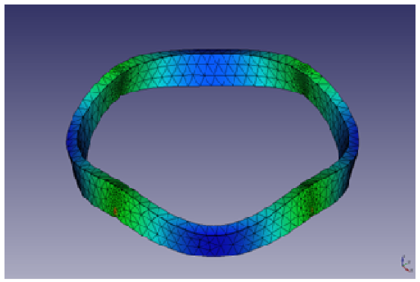
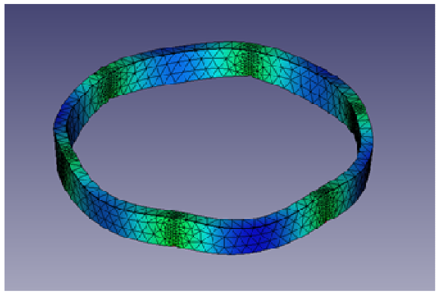
F. Pollastri, GB Picotto, *Surface texture measurements of gear tooth,* Proc. EUSPEN2016, Nottingham, UK, May 2016

large ring deformation

Motivation

understanding the influence of typical supports and clamping fixtures as used in industry for large rings.

the influence of self-weight of large rings by the deformations along axial and radial directions were calculated by assuming three, four and six support points of two rings :
- diameter 1 m , and 2 m;
- height 115 mm, width   40 mm, AISI 440C;
- horizontal laying on flat supports with a contact area of 20 mm x 40 mm

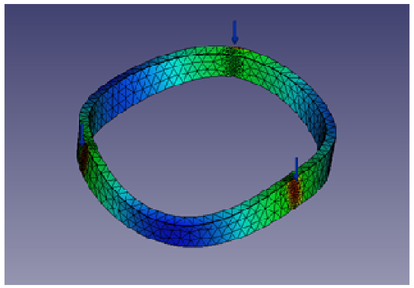
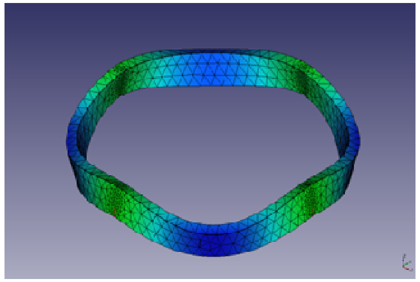
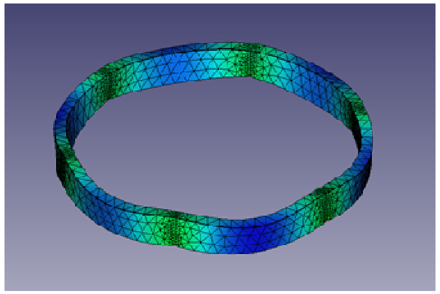




large ring deformation

Results

Nr of support points	Max axial deformation Δz /µm			
	FreeCAD-Calculix FEM simulation		Comsol FEM simulation	
	Diameter 1 m	Diameter 2 m	Diameter 1 m	Diameter 2 m
3	1,88	27,68	1,88	28,07
4	0,60	7,99	0,53	7,55
6	0,13	1,50	0,12	1,36

Nr of support points	Max radial deformation Δr /µm			
	FreeCAD-Calculix FEM simulation		Comsol FEM simulation	
	Diameter 1 m	Diameter 2 m	Diameter 1 m	Diameter 2 m
3	0,44	3,60	0,59	4,24
4	0,18	1,37	0,19	1,50
6	0,05	0,30	0,04	0,33

Impact

Direct

- ✓ Reduction of production and maintenance costs
- ✓ Improvement of the performance of drivetrains
- ✓ Extension of the lifetime of renewable energy systems

Technological

- ✓ Reduction of scrap
- ✓ Reworking of expensive large scale workpieces on shop floor
- ✓ FEA based prediction of failure modes and functional performance of drivetrain components

Indirect

- ✓ Knowledge transfer and service for other fields e.g. ship and aerospace industry
- ✓ International harmonization of trade
- ✓ Competitiveness of EU renewable energy industry

Basal

- ✓ ISO working groups TC 60 (gears) and TC 213 (GPS)
- ✓ National guidelines such as UNI, BSI, DIN and VDI
- ✓ Best practice guides

Thanks for your attention!

A. Balsamo, D. Corona, A. Egidi, G.B. Picotto, F. Pollastri, M. Pometto