Metrology for Advanced Manufacturing of the next Decade

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ZEISS Industrial Quality Solutions

23.06.2021

Agenda

1. Metrology for (Advanced) Manufacturing
2. Foresights and Roadmaps: The next Decade
3. Digitalization
4. Global Warming, Manufacturing and Metrology
5. The Task of NMI's: Confidence and Trust
6. Summary

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Manufacturing and Advanced Manufacturing

Manufacturing

The entirety of interrelated economic, technological, and organizational measures directly connected with the processing/machining of materials, i.e., all functions and activities directly contributing to the making of goods

T. Segreto, R. Teti, 2014, ***Manufacturing***. In: The International Academy for Production Engineering (**CIRPedia**), Laperrière L., Reinhart G. (eds) CIRP Encyclopedia of Production Engineering. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-20617-7_6561

Advanced Manufacturing

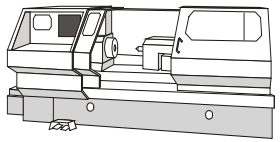
Branch of manufacturing that exploits evolving or emerging knowledge, technologies, methods and capabilities to make and/or provide new or substantially enhanced goods or services, or improve production efficiency or productivity, while ensuring environmental and societal sustainability

Source: Balsamo, A.: Definition of Advanced Manufacturing, AdvManuNet workshop, euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021

"System of Interchangeable Parts" for Manufacturing – Prerequisite for affordable technical Products

Source: ZEISS IQS

- **Unit System**
  for a unique specification of product characteristics



- **Machines**
  for manufacturing according to the product specification

- **Metrology**
  for determination and inspection of characteristics

The costs of metrology in manufacturing

Emerging challenges in the field

…

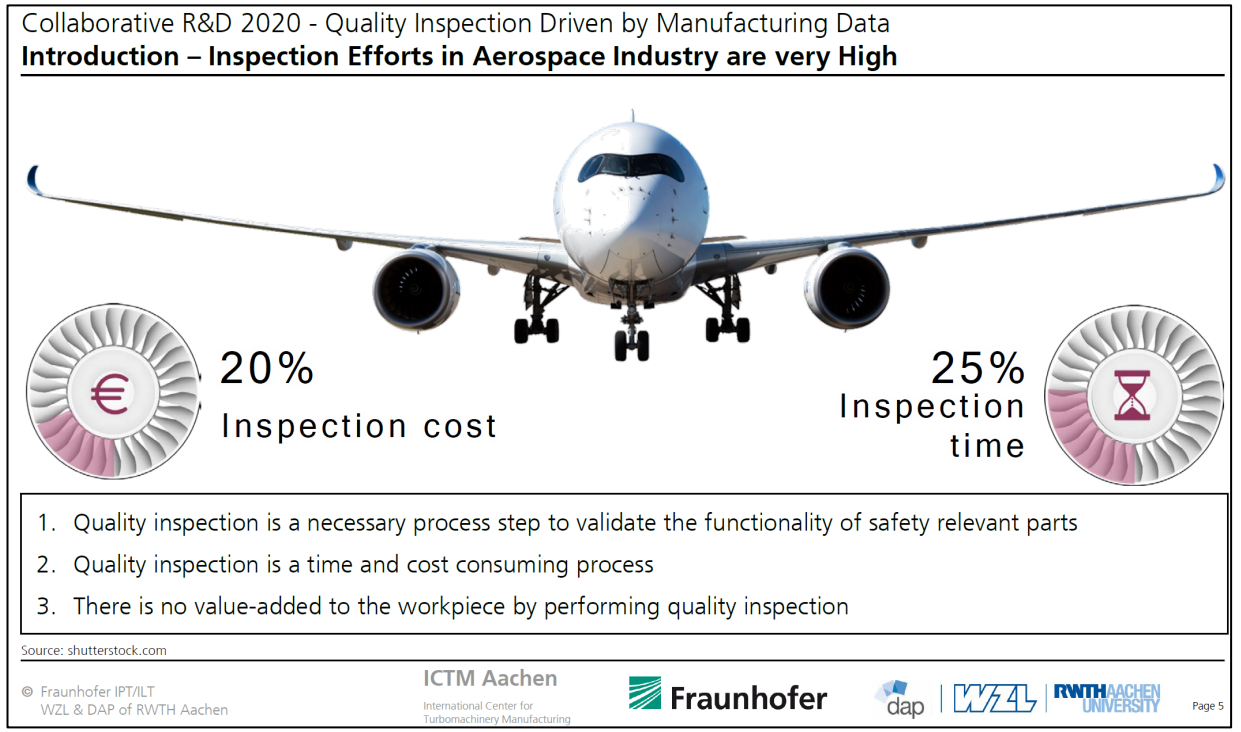
Advanced Manufacturing: Various digital concepts propose transformative improvements to production quality and efficiency, and therefore boost the competitiveness of Europe's manufacturing industries. While overall production quality has improved in recent decades, **the cost of quality issues still equates to between 5 and 40 % of total sales**. …

Source: The European Partnership on Metrology, Draft Proposal - June 2020 https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-metrology.pdf

Industrial Metrology

… Generally speaking, in most modern industries the costs bound up in taking **measurements** constitute **10-15% of production costs.**

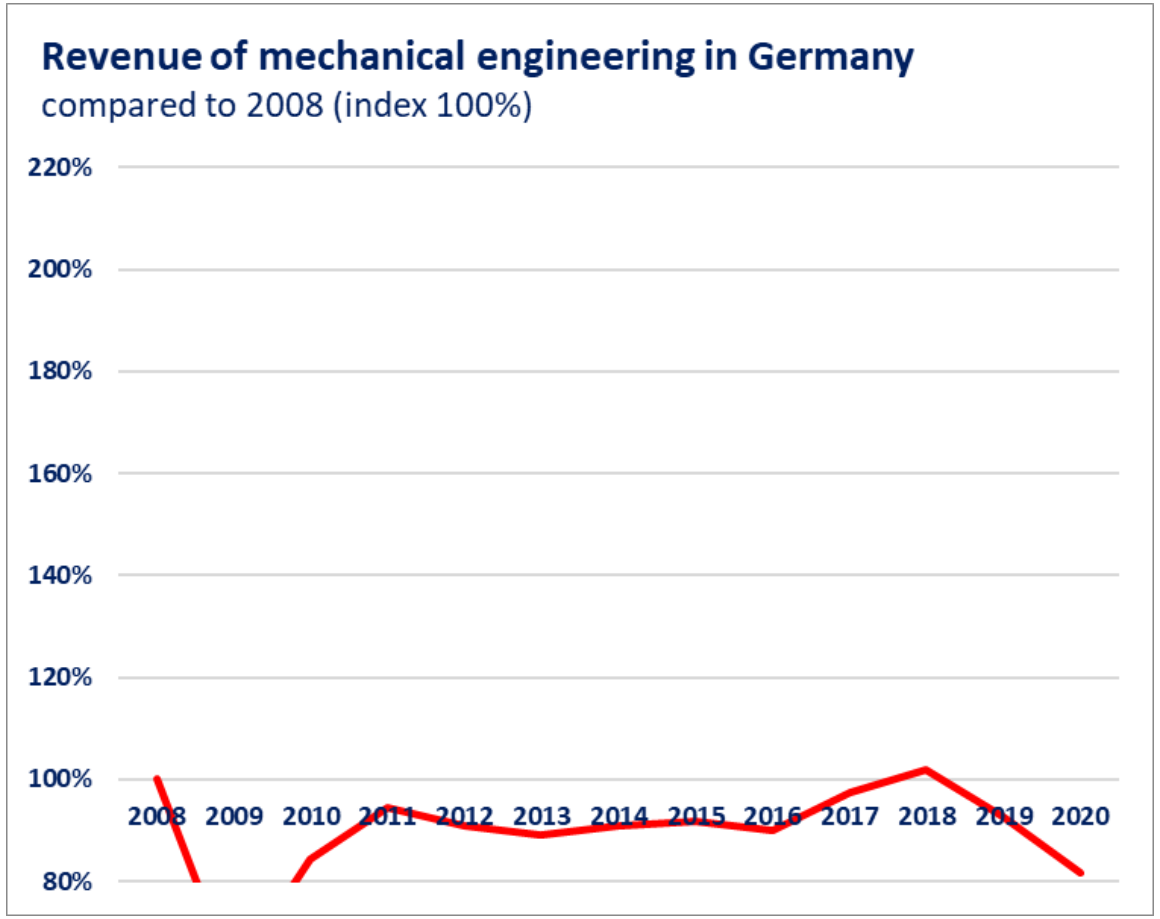
Czichos, H.: Introduction to Metrology and Testing, in: Czichos, H., et al. (Hrsg.): Springer Handbook of Metrology and Testing, Springer Verlag 2011.



Source: Gerretz, V., Venek, T.: Quality Inspection Driven by Manufacturing Data, Collaborative R&D 2020 –ICTM (International Center for Turbomachinery Manufacturing) Annual R&D Meeting, Aachen, Germany January 23th, 2020 (not published)

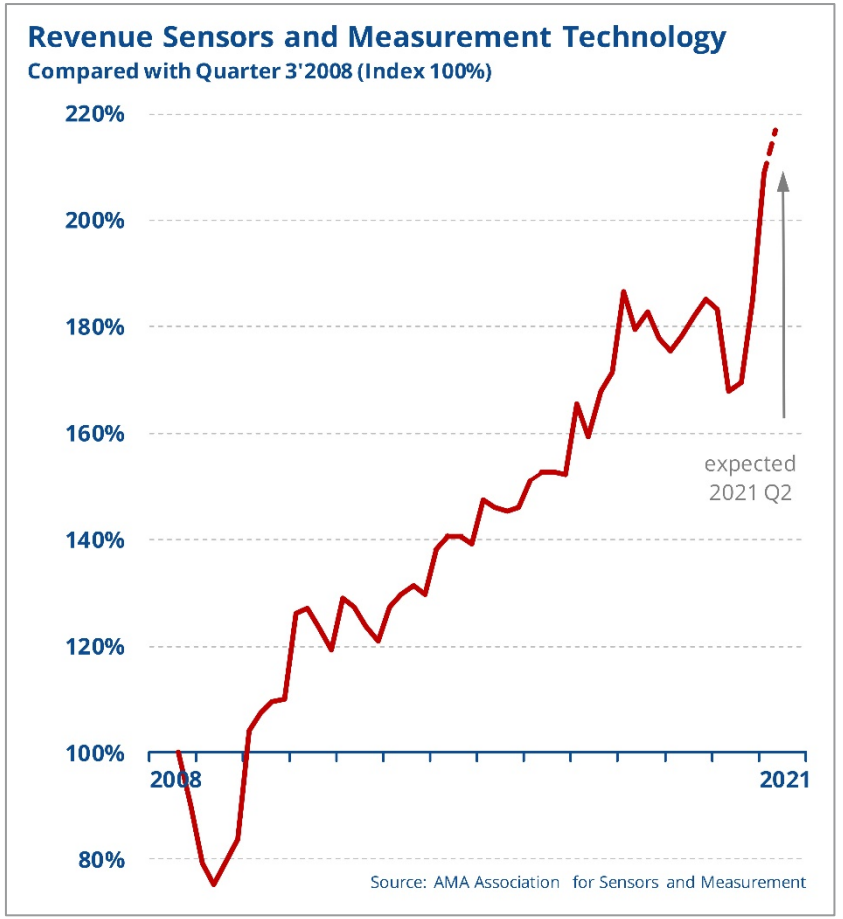
Revenue of Sensor and Measurement Technology Companies in comparison to Mechanical Engineering Companies

VDMA (Mechanical Engineering Industry Association) with approximately 3300 members in Germany



Source: own graphic based on: VDMA: Mechanical engineering – figures and charts 2021, https://www.vdma.org/documents/34570/6128644/MaBiZ_2021.pdf/bf9c7f0f-f094-3b99-d43a-d3b30a6e47a5?t=1617961887626
Statistical Handbook for Mechanical Engineering 2020, https://www.vdma.org/viewer/-/v2article/render/4090957

Association for Sensor and Measurement Technology e.V. (AMA) with approximately 450 members in Germany



Source: https://www.ama-sensorik.de/fileadmin/grafiken/2021Q1_Revenue.jpg

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Metrology for Advanced Manufacturing of the next Decade: Foresight and Roadmap Studies

https://hvm.catapult.org.uk/wp-content/uploads/2020/05/Integrated-Metrology-10-Year-Roadmap.pdf

NPL

https://doi.org/10.47120/npl.8948

Technology and Measurement Foresighting

A vision of the 2030s shaped by metrology

Manufacturing

Manufacturing will become more complex as supply chains become interdependent, digital and international.

Future manufacturing systems will be enabled by a large variety of digital solutions and intelligent data driven tools, which will result in the full digitisation of manufacture and sustainable resource management.

Responsive and agile manufacturing systems will emerge, which use innovative production techniques and rely on continuous measurement and product verification through digital or virtual methods.

Consumers will expect products and services to be personalised to their own needs and preferences.

CATAPULT High Value Manufacturing

NTEGRATED METROLOGY
0-YEAR ROADMAP FOR
OVANCED MANUFACTURING

VDI VDE VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik

Fertigungs-
messtechnik 2020

Technologie-Ro
für die Messte
in der industri
Produktion
2011

J. Sens. Sens. Syst., 2, 1–7, 2013
www.j-sens-sens-syst.net/2/1/2013/
doi:10.5194/jsss-2-1-2013
© Author(s) 2013. CC Attribution 3.0 License.

JSSS Journal of Sensors and Sensor Systems Open Access

https://doi.org/10.5194/jsss-2-1-2013

Looking at the future of manufacturing metrology: roadmap document of the German VDI/VDE Society for Measurement and Automatic Control

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[1]VDI/VDE GMA within VDI e.V., Dusseldorf, Germany
[2]Carl Zeiss Industrielle Messtechnik GmbH, Oberkochen, Germany

Correspondence to: J. Berthold (berthold@vdi.de)

Received: 22 October 2012 – Revised: 9 January 2013 – Accepted: 24 January 2013 – Published: 27 February 2013

Abstract. "Faster, safer, more accurately and more flexibly" is the title of the "manufacturing metrology roadmap" issued by the VDI/VDE Society for Measurement and Automatic Control (www.vdi.de/gma). The document presents a view of the development of metrology for industrial production over the next ten years and was drawn up by a German group of experts from research and industry. The following paper summarizes the content of the roadmap and explains the individual concepts of "Faster, safer, more accurately and more flexibly" with the aid of examples.

J. Sens. Sens. Syst., 5, 325–335, 2016
www.j-sens-sens-syst.net/5/325/2016/
doi:10.5194/jsss-5-325-2016
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JSSS Journal of Sensors and Sensor Systems Open Access

https://doi.org/10.5194/jsss-5-325-2016

Challenges and trends in manufacturing measurement technology – the "Industrie 4.0" concept

Dietrich Imkamp[1], Jürgen Berthold[2], Michael Heizmann[3], Karin Kniel[4], Eberhard Manske[5], Martin Peterek[6], Robert Schmitt[6], Jochen Seidler[7], and Klaus-Dieter Sommer[5]

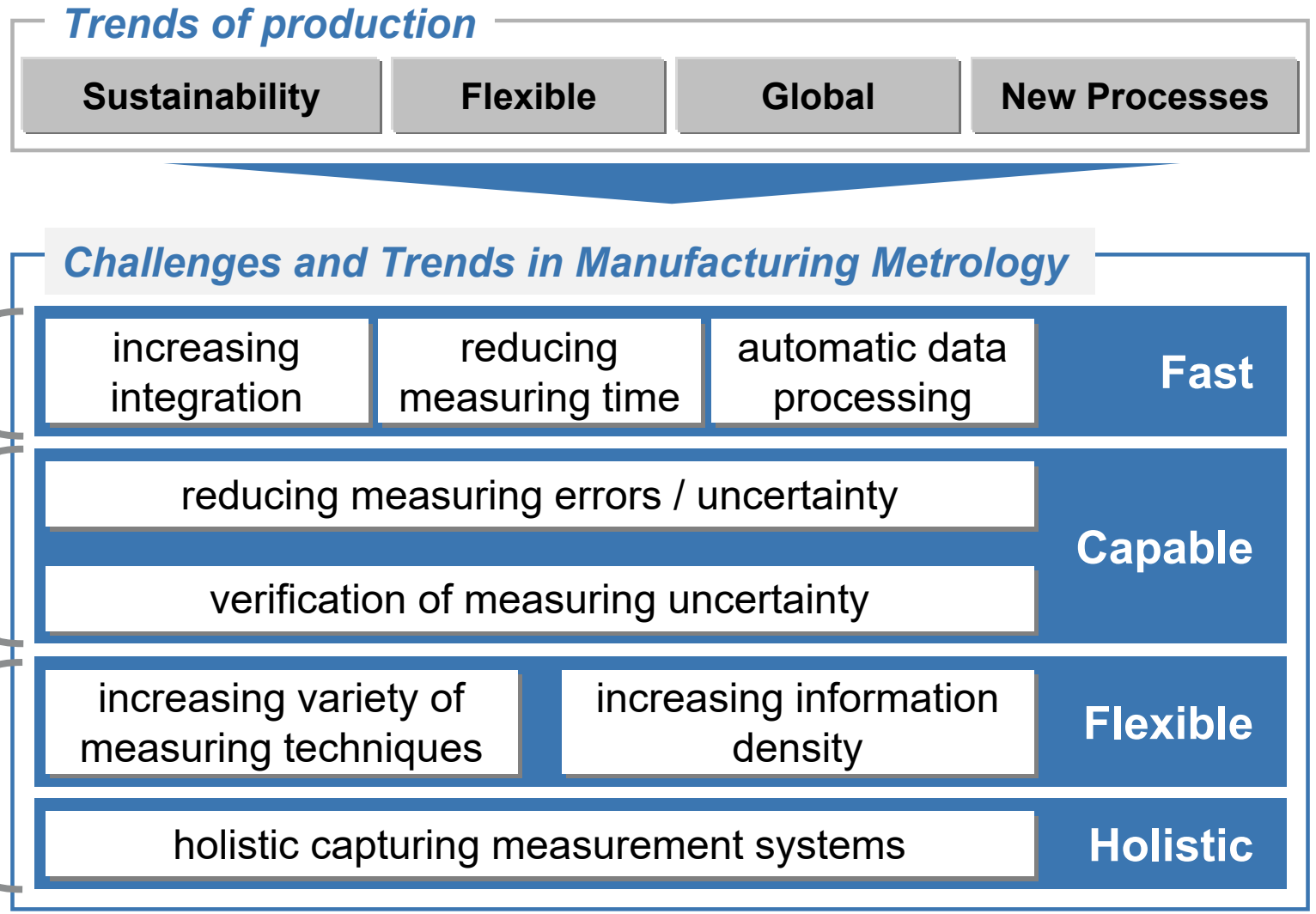
[1]Carl Zeiss Industrielle Messtechnik GmbH, Oberkochen, Germany
[2]VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (GMA), Düsseldorf, Germany
[3]Institut für Industrielle Informationstechnik IIIT, Karlsruher Institut für Technologie KIT and Fraunhofer IOSB, MRD, Karlsruhe, Germany
[4]Physikalisch-Technische Bundesanstalt, Braunschweig und Berlin, Germany
[5]Technische Universität Ilmenau, Institut für Prozessmess- und Sensortechnik, Germany
[6]Lehrstuhl für Fertigungsmesstechnik und Qualitätsmanagement, Werkzeugmaschinenlabor WZL der RWTH Aachen, University, Germany
[7]Mahr GmbH, Göttingen, Germany

Correspondence to: Dietrich Imkamp (dietrich.imkamp@zeiss.com)

Received: 23 May 2016 – Revised: 26 July 2016 – Accepted: 22 September 2016 – Published: 6 October 2016

Abstract. Strategic considerations and publications dealing with the future of industrial production are significantly influenced these days by the concept of "Industrie 4.0". For this reason the field of measurement technology for industrial production must also tackle this concept when thinking about future trends and challenges in metrology. To this end, the Manufacturing Metrology Roadmap 2020 of the VDI/VDE Society for Measurement and Automatic Control (GMA) was published in 2011 (VDI/VDE-GMA, 2011; Imkamp et al., 2012). The content of this roadmap is reviewed and extended here, covering new developments in the field of the Industrie 4.0 concept and presented with expanded and updated content.

Trends based on VDI/VDE-GMA Manufacturing Metrology Roadmap



- Unbroken trend
- More examples available as templates
- Application of Monte Carlo, AI, Machine Learning,…
- Comprehensive results

Source (Basic): Imkamp, D./ Berthold, J./ Heizmann, M./ Kniel, K./ Manske, E./ Peterek, M./ Schmitt, R./ Seidler, J./ Sommer, K.-D.: Challenges and trends in manufacturing measurement technology – The 'Industrie 4.0' concept, in: Journal of Sensors and Sensor Systems (JSSS), open-access peer reviewed journal published by the Copernicus GmbH (Copernicus Publications) on behalf of the AMA Association for Sensor Technology, doi:10.5194/jsss-5-325-2016, 2016. (Internet 04.11.2016: http://www.j-sens-sens-syst.net/5/325/2016/)

Trend: Fast
Accelerate metrology and integrate metrology

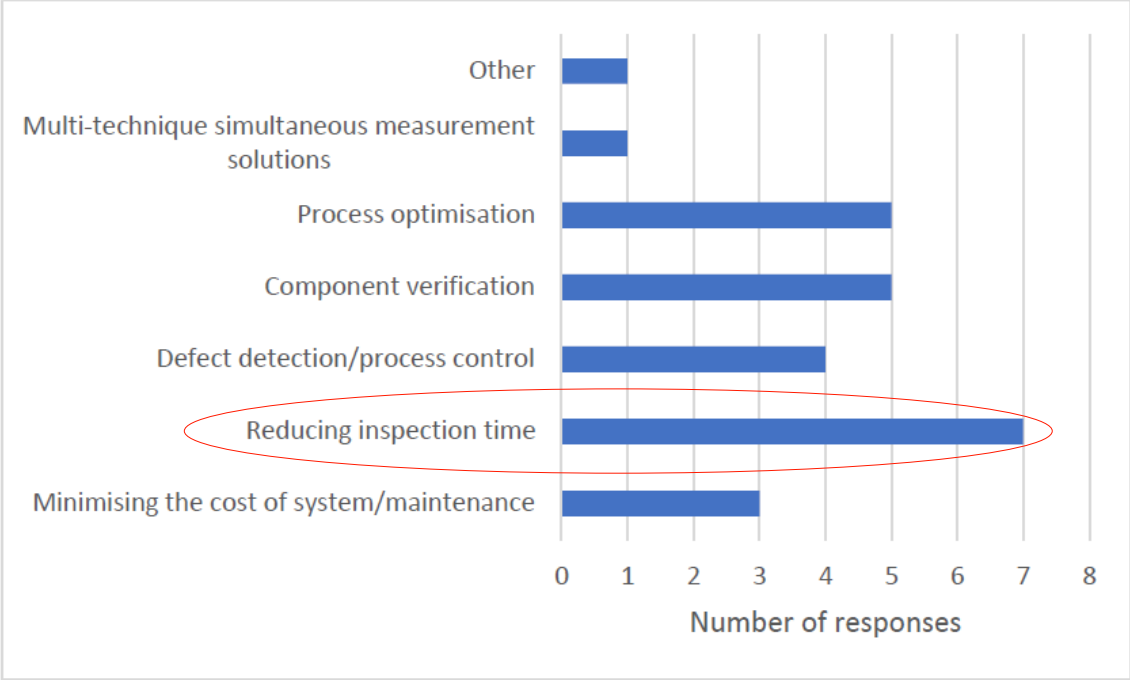


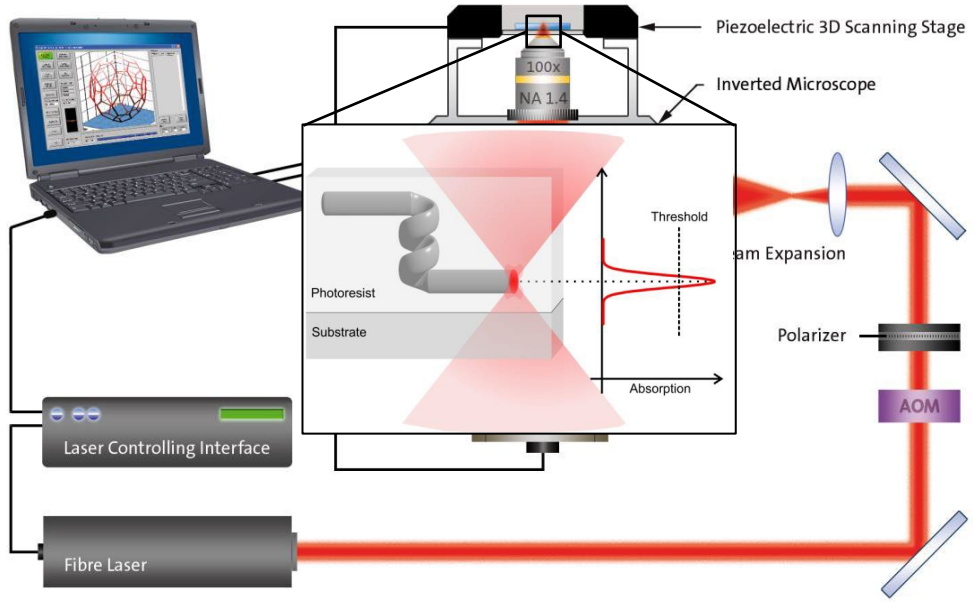
FIGURE 8. SURVEY PARTICIPANTS' PRIORITIES FOR THE FUTURE OF INTEGRATED METROLOGY.

Source: Leach, R.: Integrated Metrology – A 10 Year Roadmap For Advanced Manufacturing, High Value Manufacturing Catapult, UK, April 2020 (Internet, 06.12.2020: https://hvm.catapult.org.uk/wp-content/uploads/2020/05/Integrated-Metrology-10-Year-Roadmap.pdf)

faster measurement technology
(e.g. ZEISS Slogan: fast VAST scanning)

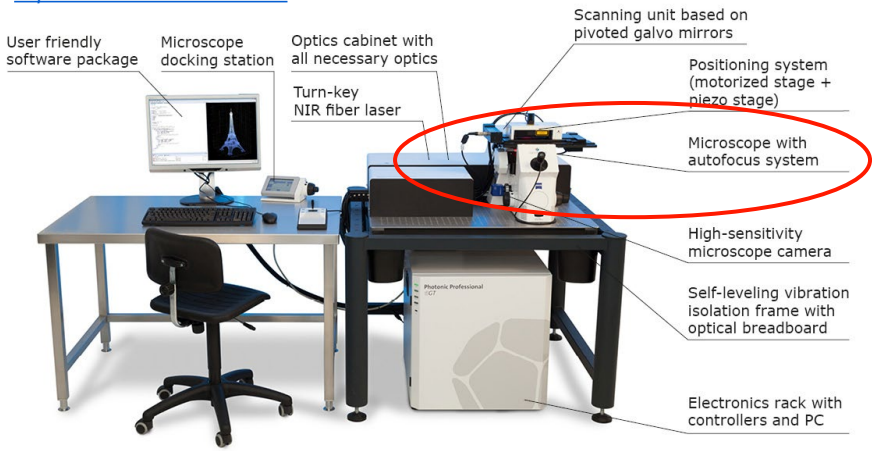
integration of metrology into manufacturing

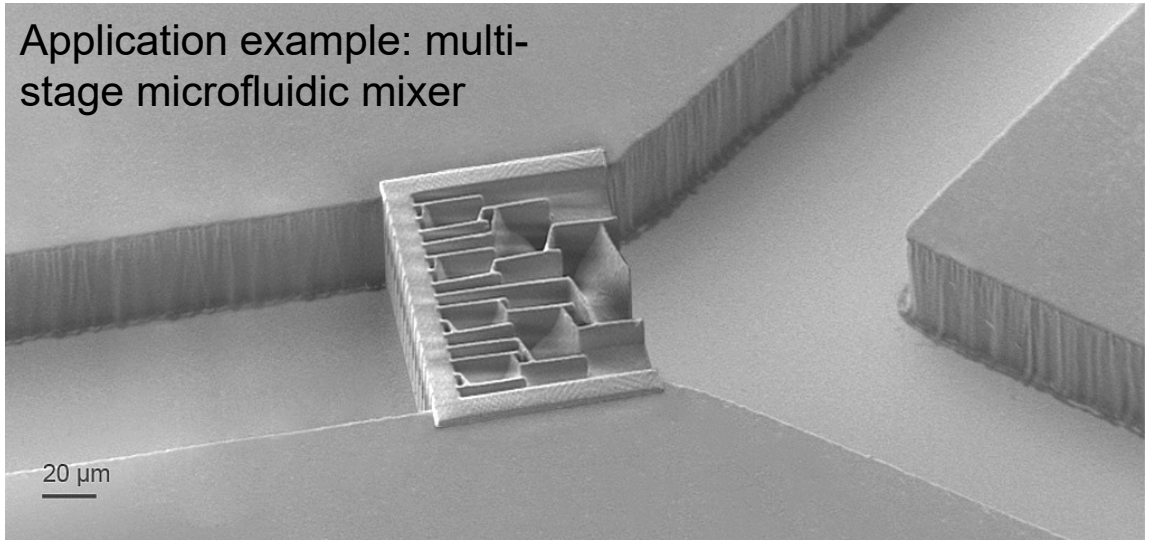
Trend: Capable
Better accuracy (lower uncertainty) for additive manufactured nano structures and …



https://www.nanoscribe.com/

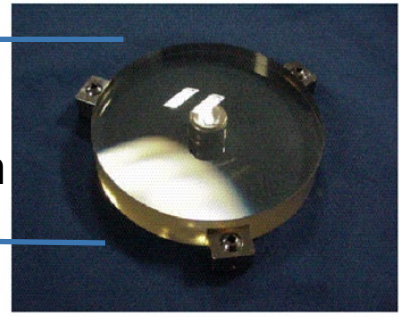
https://www.nanoscribe.com/

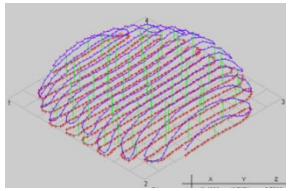




https://www.nanoscribe.com/en/news-insights/news/3d-printed-multi-stage-microfluidic-mixer-with-swap-structures

Trend: Capable
Better accuracy (lower uncertainty) for mirrors and …



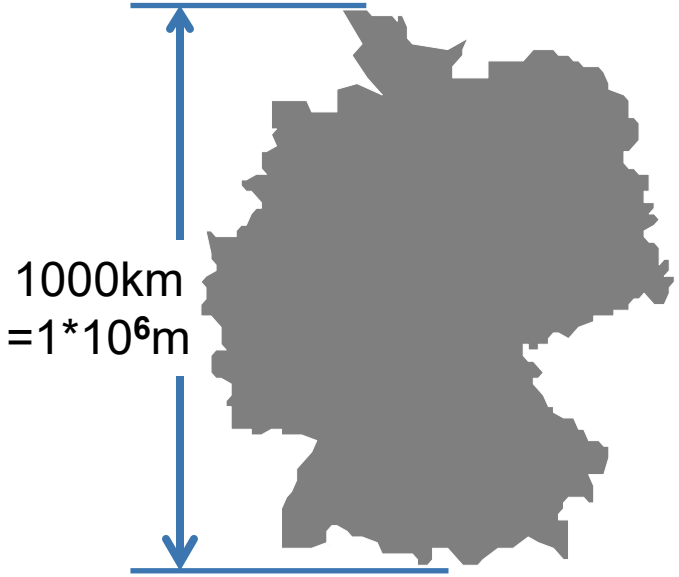


surface roughness
approx.150pm = $1,5*10^{-10}$m

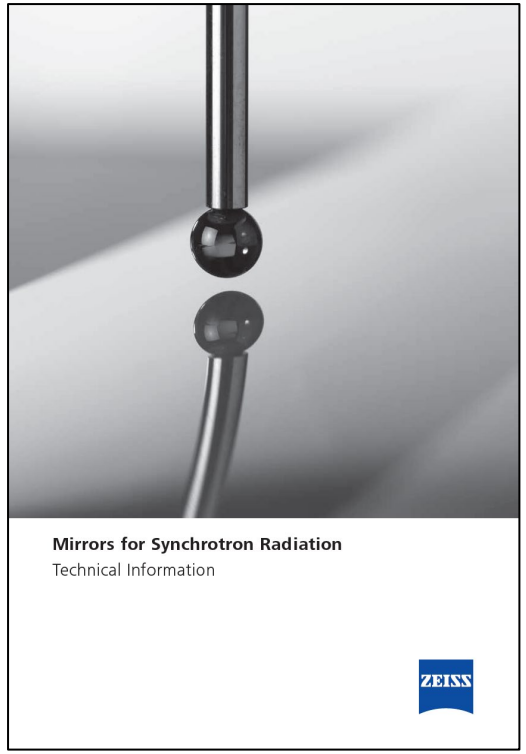
comparable roughness for 1000km=$1*10^{6}$m => $1,5*10^{-3}$m=1,5mm

The achieved results are ultimately limited by the accuracy of the measurement technique.

(Source: Carl Zeiss SMT GmbH: Mirrors for Synchrotron Radiation, Technical Information, Oberkochen, Germany 2016, https://www.zeiss.com/content/dam/smt/downloads/products_and_solutions/optic_systems/ENsynchrotron.pdf)



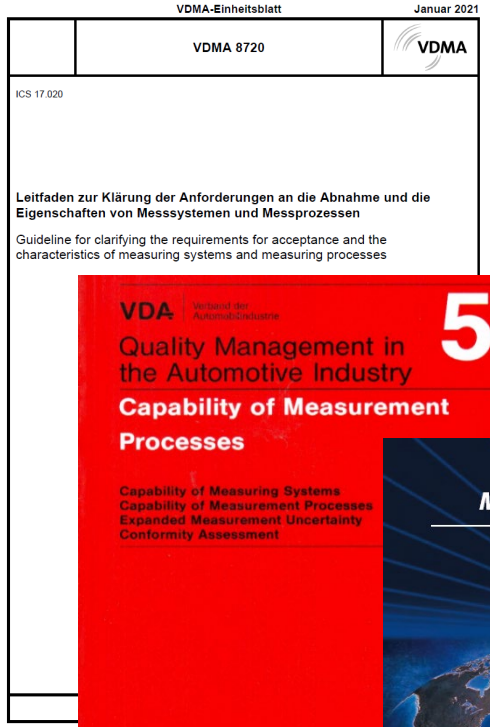
Zugspitze: 2962m (highest German mountain)



Source: Heil, T., Lowisch, M.: EUV lithography – the future of chip manufacturing, Photonik international, AT-Fachverlag GmbH, 70734 Fellbach, Germany 2008.

Trend: Capable
Better accuracy (lower uncertainty) and approved uncertainty

https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6


VDMA-Einheitsblatt Januar 2021

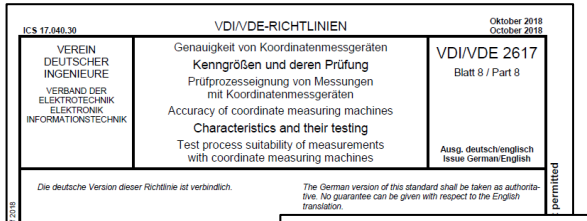
VDMA 8720

ICS 17.020

Leitfaden zur Klärung der Anforderungen an die Abnahme und die Eigenschaften von Messsystemen und Messprozessen

Guideline for clarifying the requirements for acceptance and the characteristics of measuring systems and measuring processes

Which one to chose?


ICS 17.040.30 VDI/VDE-RICHTLINIEN Oktober 2018 October 2018

VEREIN DEUTSCHER INGENIEURE
VERBAND DER ELEKTROTECHNIK ELEKTRONIK INFORMATIONSTECHNIK

Genauigkeit von Koordinatenmessgeräten
Kenngrößen und deren Prüfung
Prüfprozesseignung von Messungen mit Koordinatenmessgeräten
Accuracy of coordinate measuring machines
Characteristics and their testing
Test process suitability of measurements with coordinate measuring machines

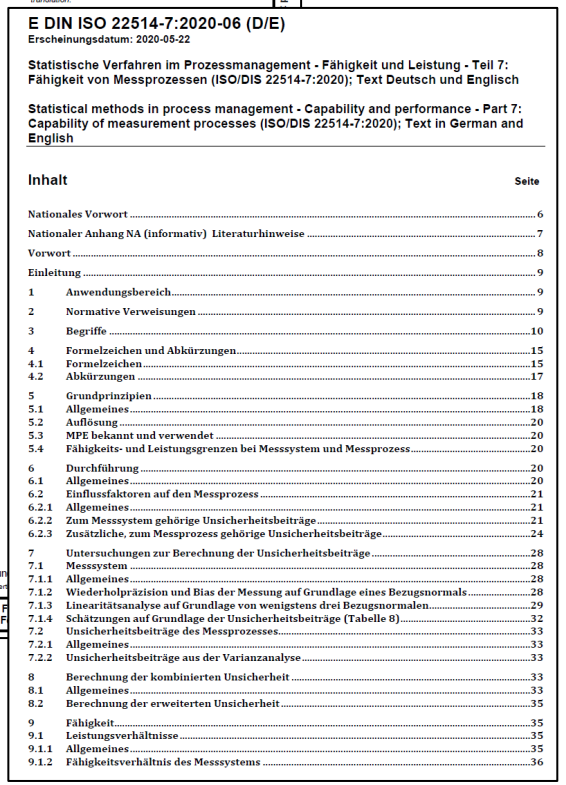
VDI/VDE 2617
Blatt 8 / Part 8

Ausg. deutsch/englisch
Issue German/English

Die deutsche Version dieser Richtlinie ist verbindlich.

The German version of this standard shall be taken as authoritative. No guarantee can be given with respect to the English translation.

Inhalt Seite


E DIN ISO 22514-7:2020-06 (D/E)

Erscheinungsdatum: 2020-05-22

Statistische Verfahren im Prozessmanagement - Fähigkeit und Leistung - Teil 7: Fähigkeit von Messprozessen (ISO/DIS 22514-7:2020); Text Deutsch und Englisch

Statistical methods in process management - Capability and performance - Part 7: Capability of measurement processes (ISO/DIS 22514-7:2020); Text in German and English

Inhalt Seite

Trend: Flexibility
Selection of the appropriated sensor becomes more difficult (Sensor portfolio of ZEISS industrial metrology)

2021

https://www.zeiss.com/metrology/products/sensors.html


RDS


CSC


RST-P


XDT


ViScan


LineScan


DotScan


VAST XXT


VAST XTR und XT gold


VAST gold


ROTOS


EagleEye


FalconEye


COMET


T-SCAN

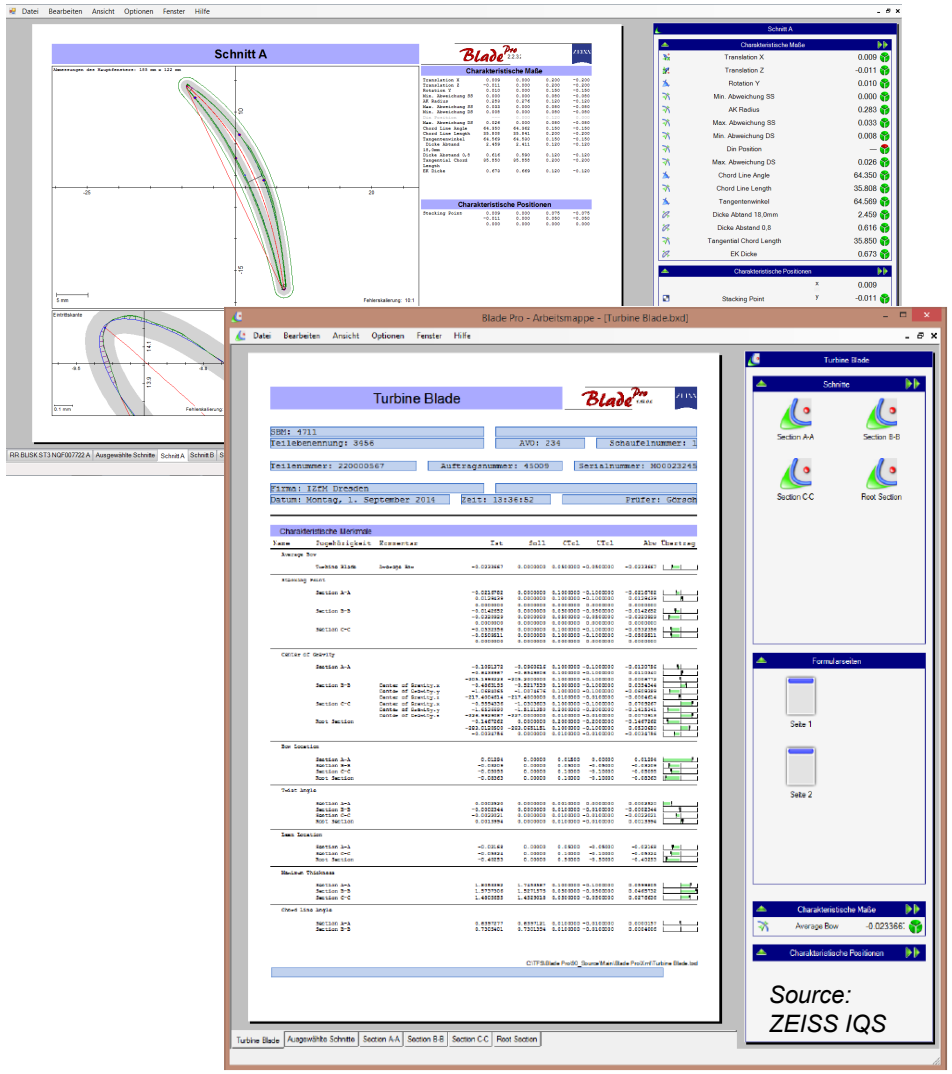
2000

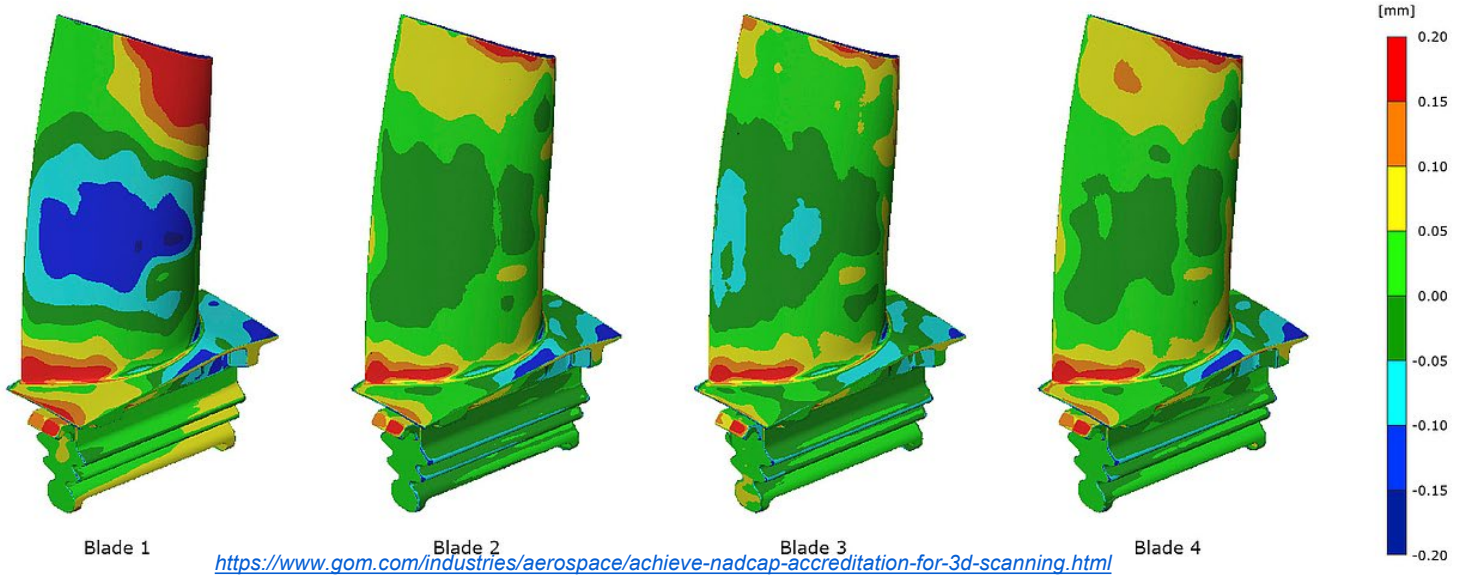




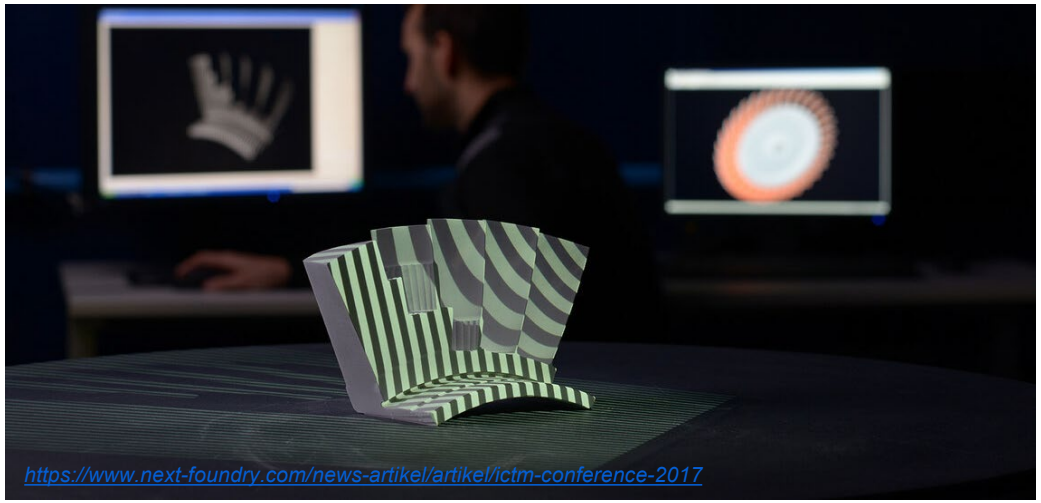


Trend: Holistic
Colored images are better to understand, than lists of numbers or profiles





https://www.gom.com/industries/aerospace/achieve-nadcap-accreditation-for-3d-scanning.html



https://www.next-foundry.com/news-artikel/artikel/ictm-conference-2017

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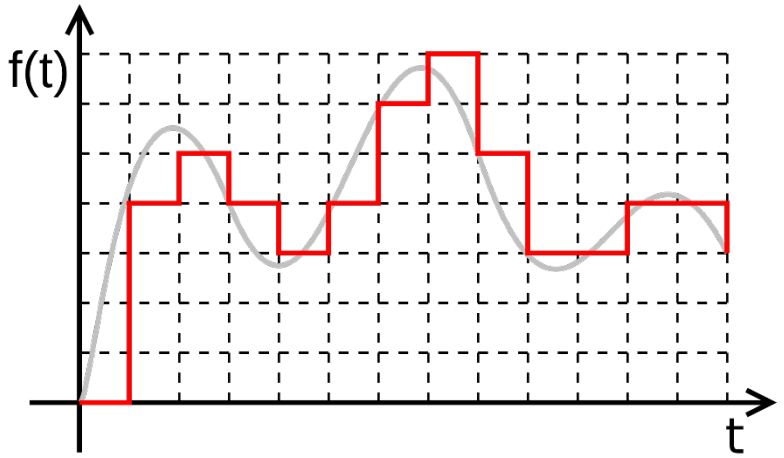
From Digitalization to the Digital Transformation



https://de.wikipedia.org/wiki/Digitalsignal#/media/Datei:Digital.signal.svg

Digitalization (Digitization) means originally the **conversion of analogue values into digital formats** and their processing or storage in a digital systems. In signal processing, **digitalization** refers to the **conversion from an analog signal into a digital signals** by means of sampling (Analog-to-digital conversion).

(Source: Beucher, O.: Signale und Systeme: Theorie, Simulation, Anwendung, Springer Vieweg; Auflage: 2., 2015 and https://en.wikipedia.org/wiki/Analog-to-digital_converter)

The term digitalization is nowadays used less and less in its original meaning (see above), but **more and more in the sense of the comprehensive trend of changes in industrial production through the use of digital technology**. It finds very diverse and sometimes contradicting applications (e.g. automation, changing business models).

(Source: Imkamp, D., Schönberg, B.: Digitalisierung und Geometriemessung in der Produktion im Wandel der Zeit, Sächsisches Geometriesymposium, Chemnitz, 17. & 18. März 2020, https://www.gartner.com/en/information-technology/glossary/digitalization)

Increasing Computer Performance

Gordon Moore, co-founder of Intel:
"If the **automobile industry had set a pace similar to that of the semiconductor industry,** a **Rolls Royce would drive 200,000 kilometers per liter of fuel** today and it would be **cheaper to throw it away than to park it.**"

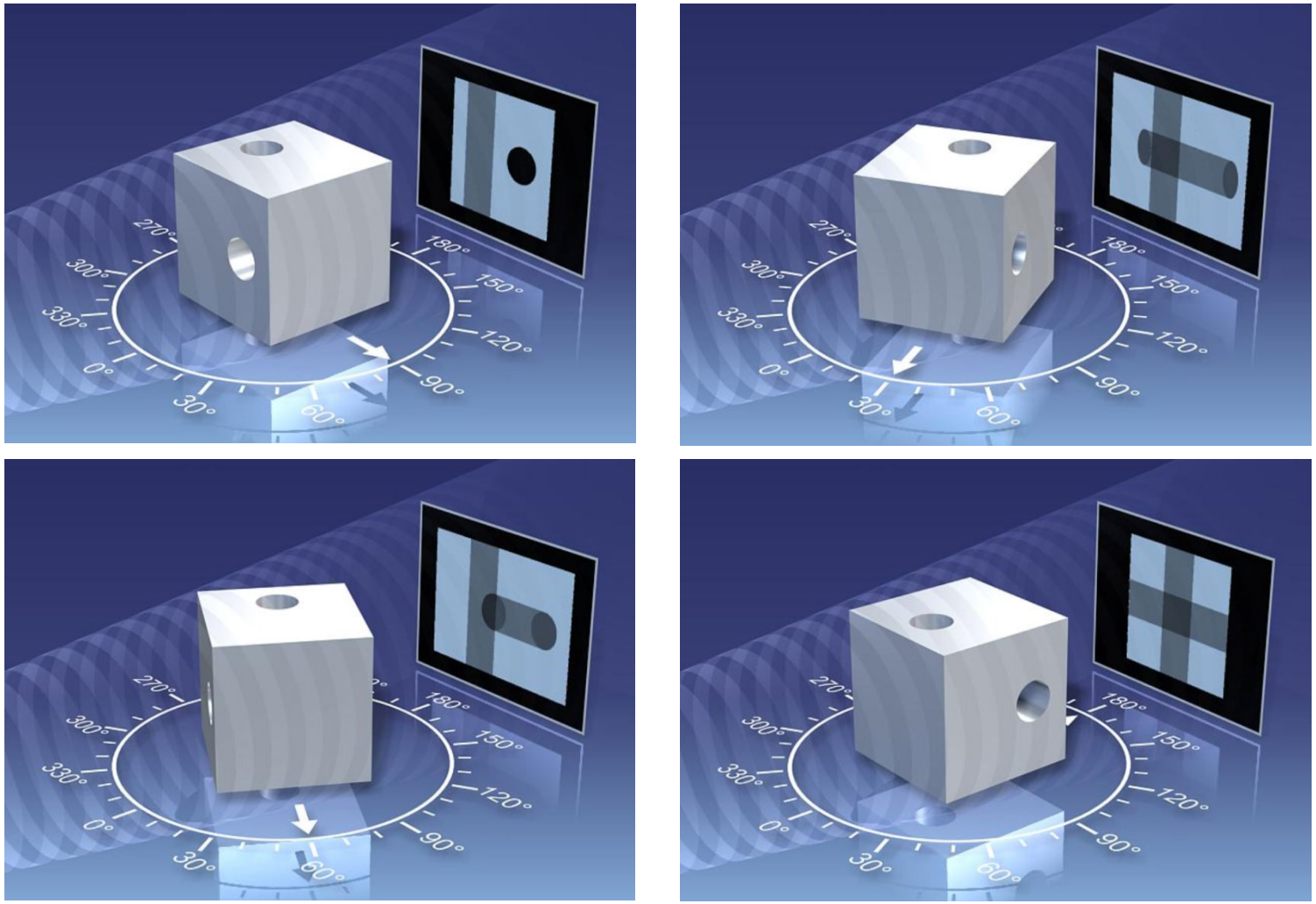
https://www.zeiss.com/semiconductor-manufacturing-technology/products-solutions/semiconductor-manufacturing-optics/about-optical-lithography/moore_s-law.html

Networking between all Computer-controlled Devices

ZEISS's press release for the Control Show 2017
- The Smart Measuring Lab:
"Networked intelligent **systems** that enable the results to be correlated in real time, calculated and visualized: **these will become even more important in the Smart Factory."**
says Andrzej Grzesiak, Senior Director of Metrology Systems at ZEISS.

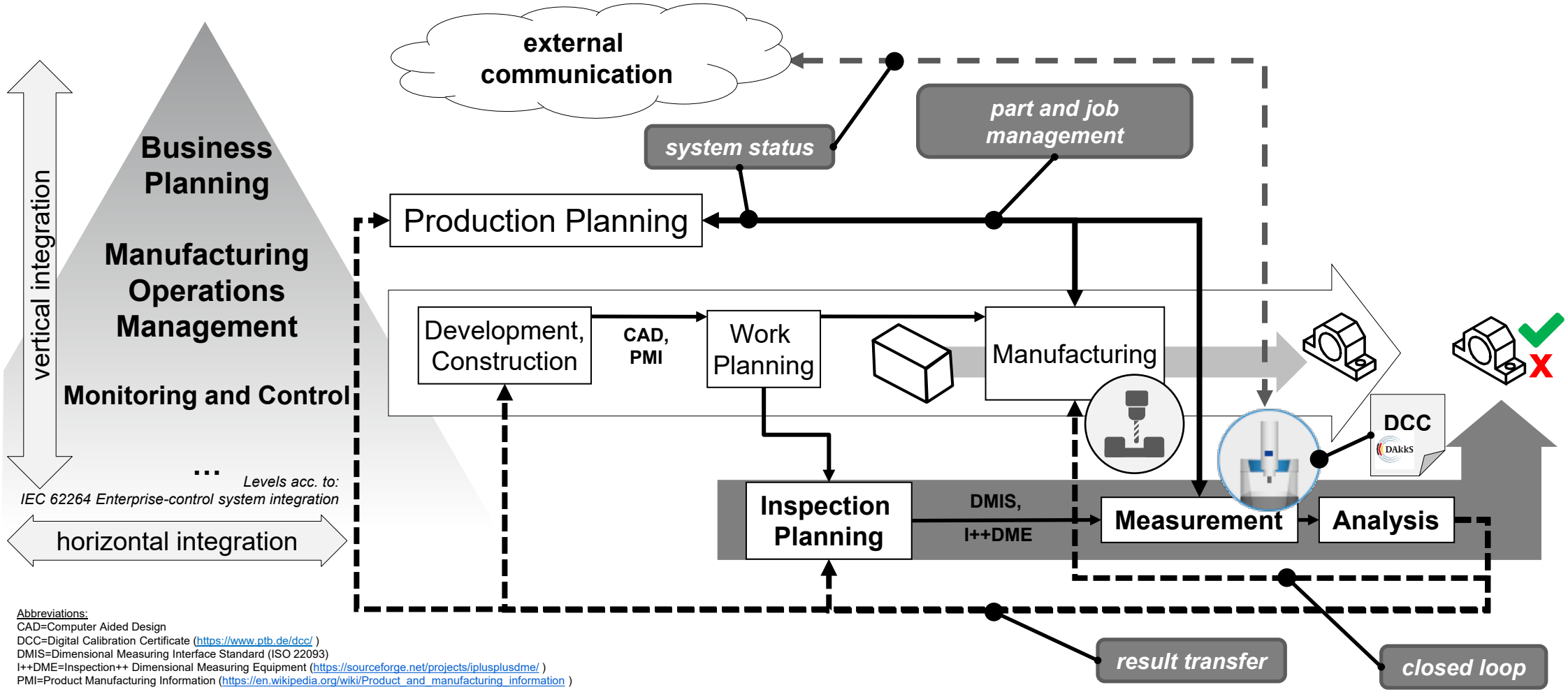
https://metrology.news/smart-measuring-lab-demonstrated-at-control-expo/

Increasing computer performance – Prerequisite to use computed tomography for dimensional measurements: “a lot helps a lot”



Source: ZEISS IQS

Looking beyond metrology itself – integration into digital production through networks (OPC UA use case with italic/white letters)

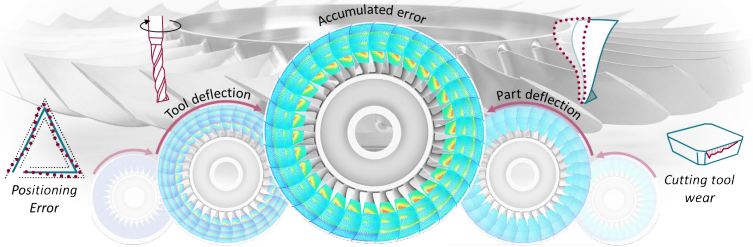


Abbreviations:
CAD=Computer Aided Design
DCC=Digital Calibration Certificate (https://www.ptb.de/dcc/)
DMIS=Dimensional Measuring Interface Standard (ISO 22093)
I++DME=Inspection++ Dimensional Measuring Equipment (https://sourceforge.net/projects/iplusplusdme/)
PMI=Product Manufacturing Information (https://en.wikipedia.org/wiki/Product_and_manufacturing_information)

Source (Translated from): Imkamp, D., Heil, H. G.: Messtechnik goes Digital – Schnittstellen und Modelle für die digitale Produktion, QZ Qualität und Zuverlässigkeit, Carl Hanser Verlag, München Jg. 66 (2021), Nr. 5, S. 40-43.

Replacing Metrology by Manufacturing Process Simulation (Digital Twin) Validation and Uncertainty

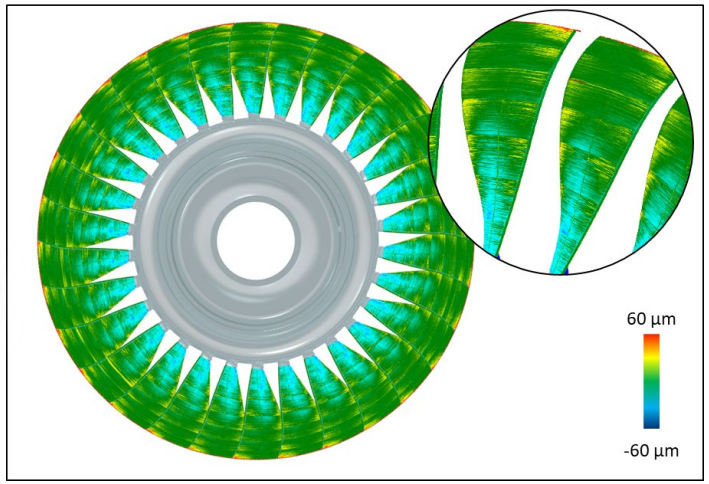
Digital Twin



Source: Venek, T.: Uncertainty Quantification for the Quality Inspection Driven by Manufacturing Data, Collaborative R&D 2021 –ICTM (International Center for Turbomachinery Manufacturing) Annual R&D Meeting, Aachen, Germany January 21st, 2021 (not published)

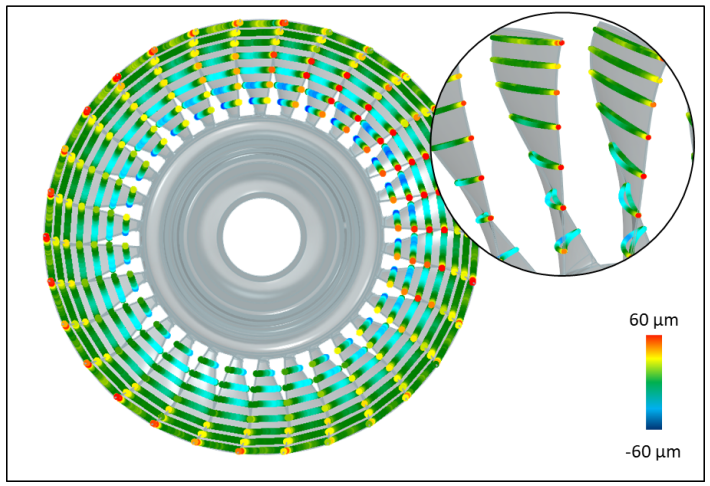
Predicted profile deviations

Measured profile deviations on the part related to positioning



Measurement results

Measured profile deviations on the part related to positioning



E_n acc. to ISO 13528, ISO/TS 15530-4

(or coverage of uncertainty ranges acc. to VDI/VDE 2617-7, with linear addition of uncertainties)

Predicted Result: R_{pred}

with its Uncertainty: U_{pred}

$$E_n = \mathbf{0,46} = \frac{100{,}021\ mm - 100{,}019\ mm}{\sqrt{4{,}2^2\ \mu m + 1{,}05^2\ \mu m}} \leq \mathbf{1}$$

Measurement Result: R_{meas}

with its Uncertainty: U_{meas}

(Artificial values, only for demonstration)

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1. Metrology for (Advanced) Manufacturing
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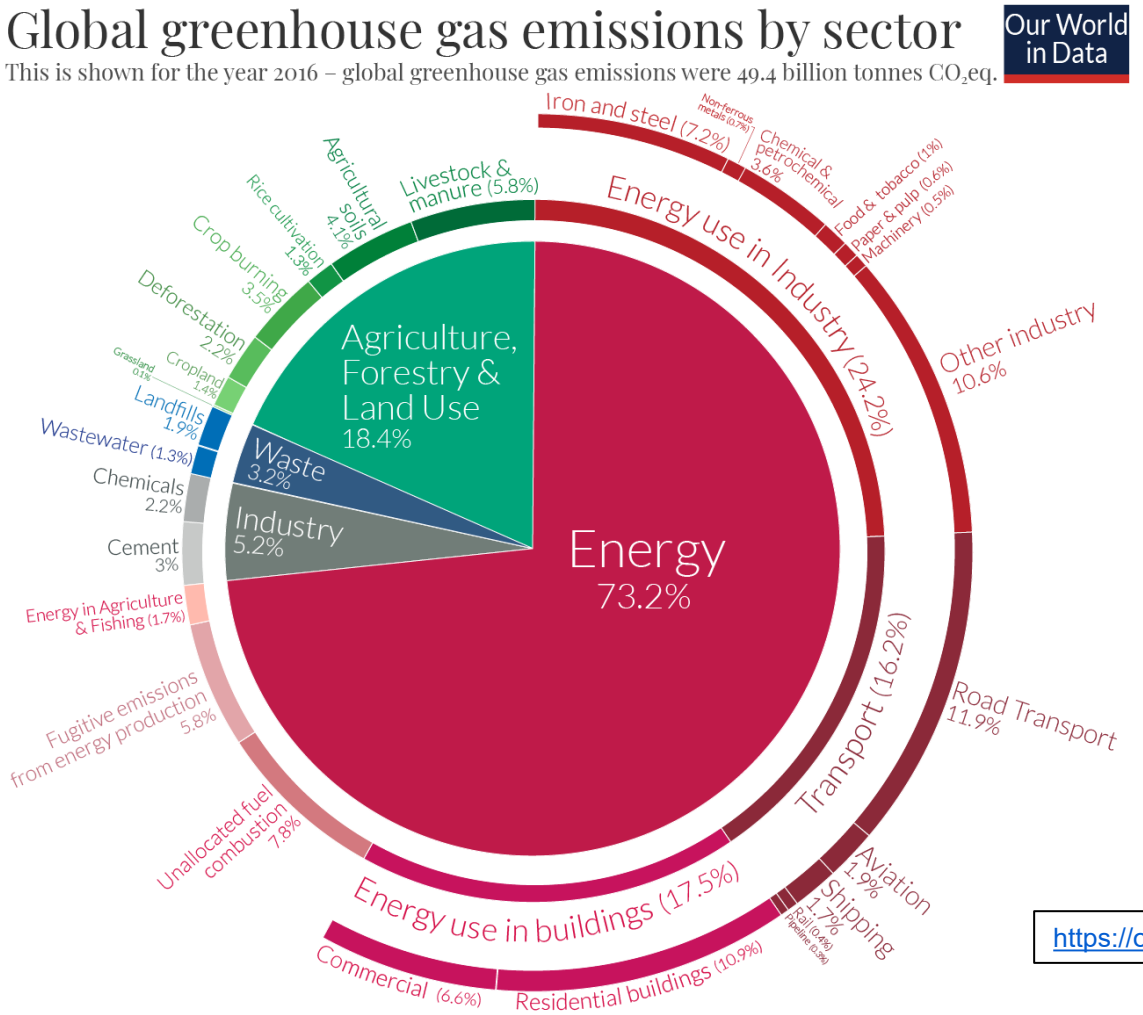
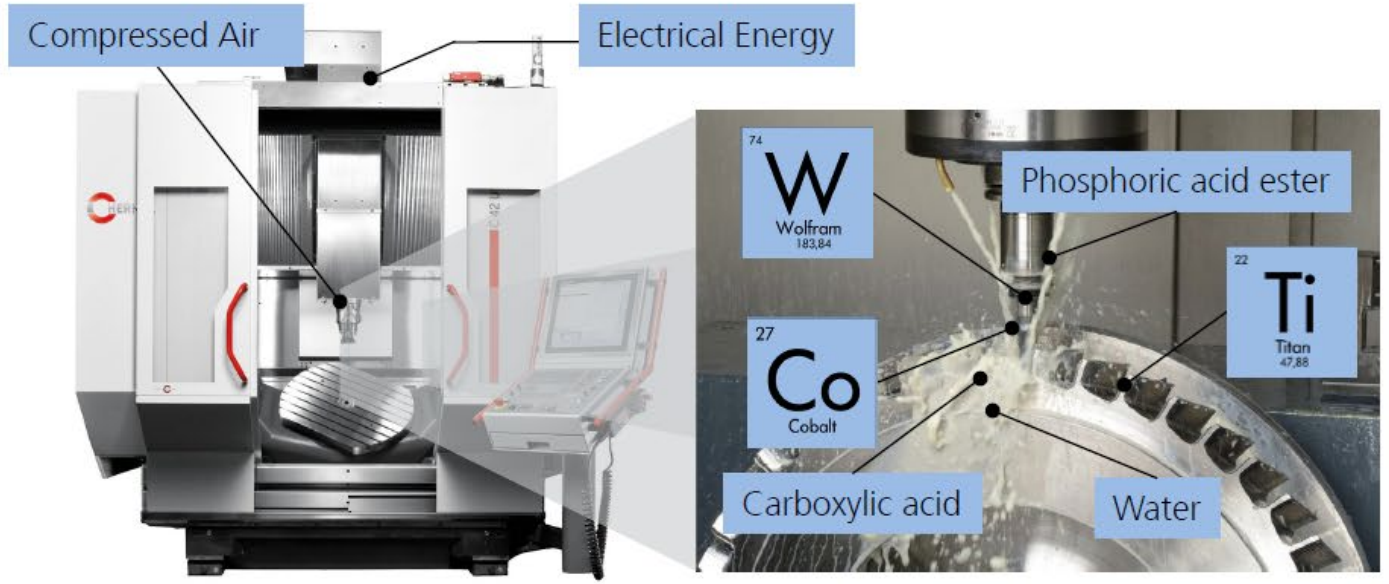
6. Summary

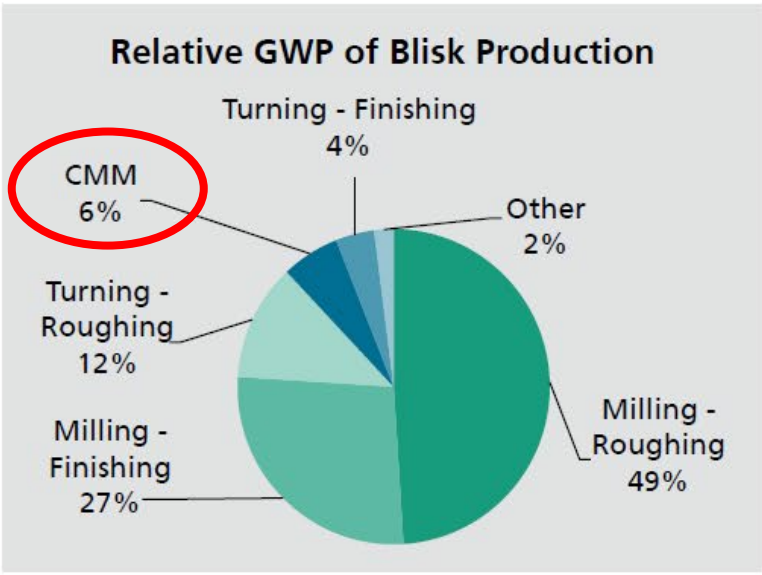
Global Warming and Energy Use in Industry



https://ourworldindata.org/emissions-by-sector

The contribution of metrology in manufacturing to GWP (Global Warming Potential): Example Blisk (Blade on Disk) Production for Aero Engines





CMM=Coordinate Measuring Machine

Calculation using Software OpenLCA
based on LCIA Method "CML"

Source: Fricke, K.: Life-Cycle-Assessment for Turbomachinery Manufacturing R&D 2021 –ICTM (International Center for Turbomachinery Manufacturing) Annual R&D Meeting, Aachen, Germany June 15th, 2021 (not published)

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Metrology and Trust
Does the Topic return in the Digital Transformation?

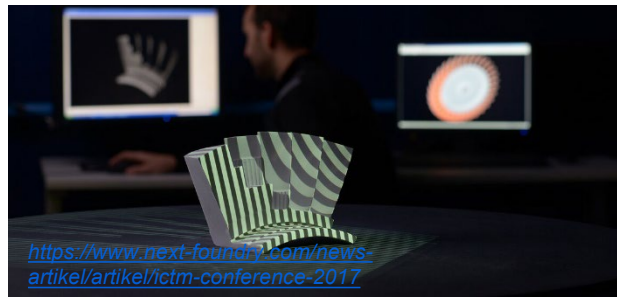
Source: Innovation SPECIAL Metrology 9, 2007, Carl Zeiss IMT, Germany

Metrology and Trust
Digital Data replace the Paper Protocol…

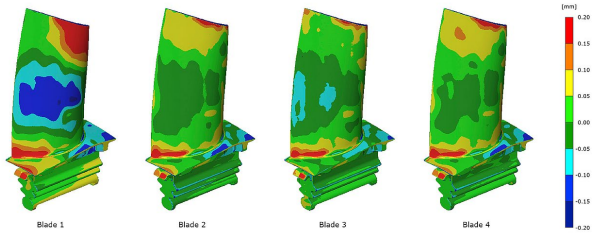
Source: Innovation SPECIAL Metrology 9, 2007, Carl Zeiss IMT, Germany

Why does trust in measurement becomes an issue?

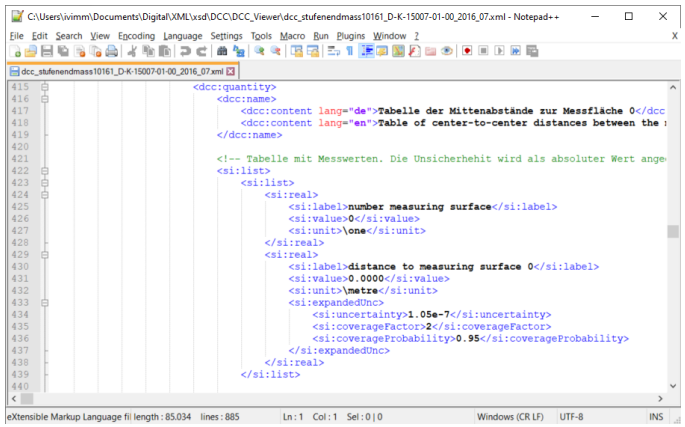
- measurement systems becomes more complex,
- software is an inherent component of many modern systems,
- digital protocols and calibration certificates replace paper.
- …



https://www.next-foundry.com/news-artikel/artikel/ictm-conference-2017



https://www.gom.com/industries/aerospace/achieve-nadcap-accreditation-for-3d-scanning.html



The request to the NMIs and the EMN AdvanceManu

What does this mean for manufacturing?

Measurement will **provide trusted information and confidence** in its source

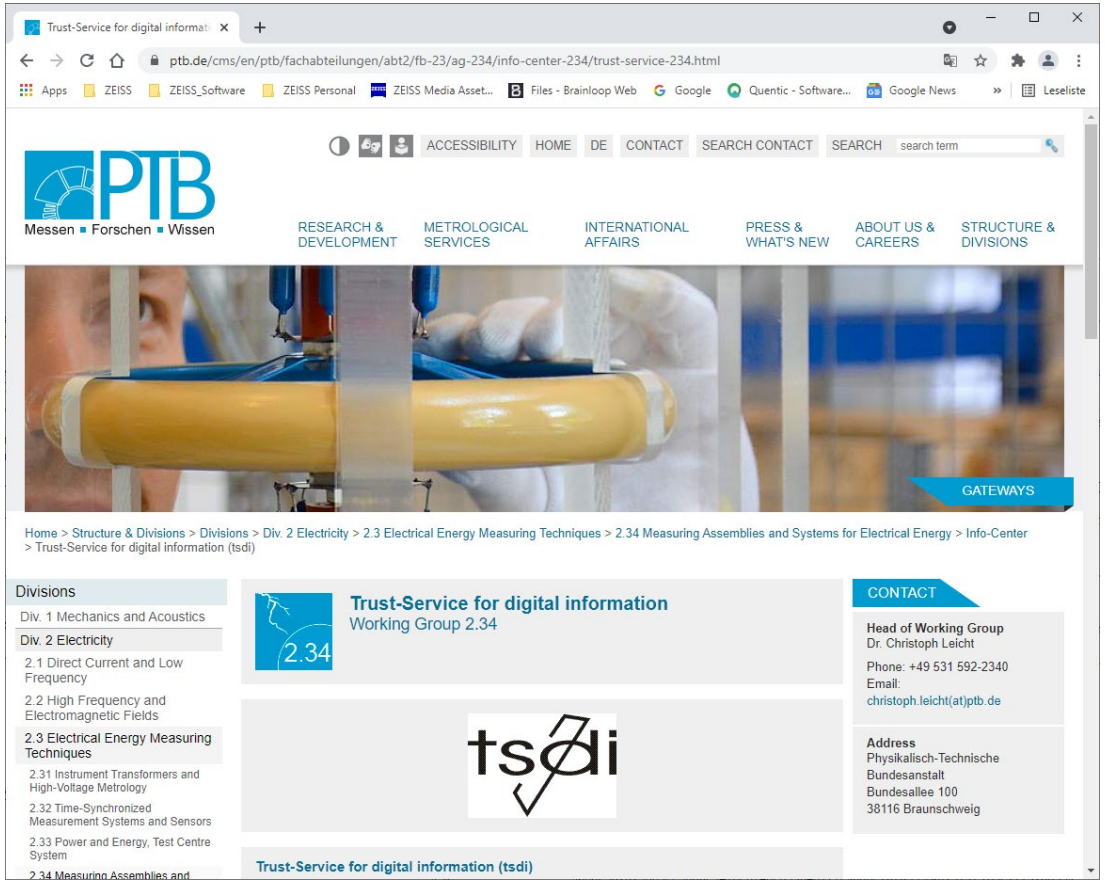
…and provide **trusted** data through **digital** certification

Source: National Physical Laboratory (NPL): Technology and Measurement Foresighting, A vision of the 2030s shaped by metrology, Teddington, Middle-sex, United Kingdom, November 2020
DOI: https://doi.org/10.47120/npl.8948

Emerging challenges

Advanced Manufacturing: … Here, production decisions are reliant on measurement data that will be required to be traceable and comparable for these decisions **to be fully capable of trust.** Input from the metrology community is necessary to build this confidence.

Source: The European Partnership on Metrology, Draft Proposal - June 2020
https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_rtd_he-partnerships-metrology.pdf



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Summary: Metrology for Advanced Manufacturing of the next Decade

- Metrological Trends in (Advanced Manufacturing): Fast, Capable, Flexible and Holistic
- Digitalization: Increasing Computer Performance and Networking
- Metrology Contribution to achieve Climate Protection Goals

The EMN AdvanceManu strengthens the trust in measurement for advanced manufacturing.

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