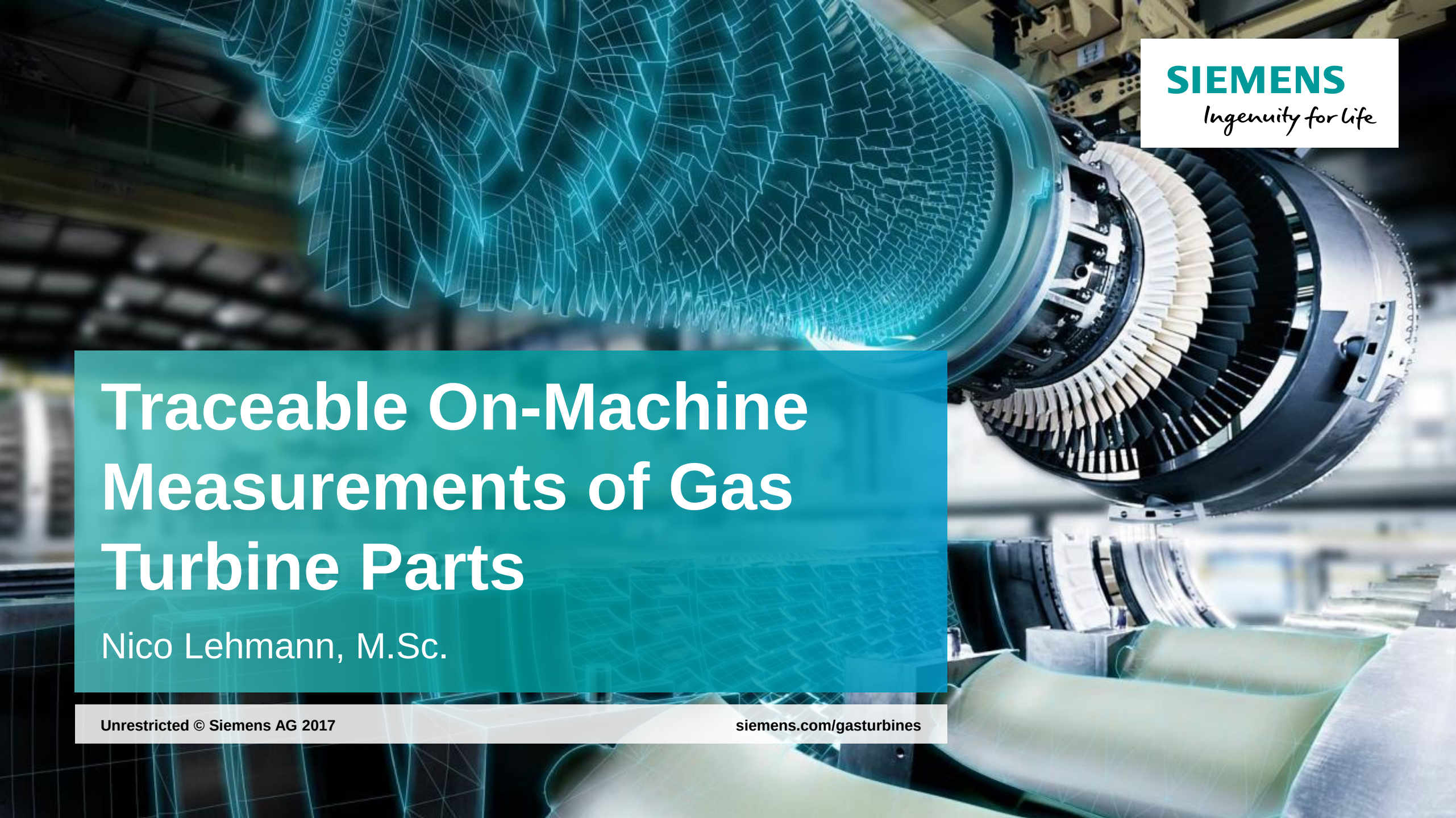

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Traceable On-Machine Measurements of Gas Turbine Parts

Nico Lehmann, M.Sc.

Content

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Power and Gas – a powerful player within Siemens

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Power and Gas

Dresser-Rand Business

Wind Power and Renewables

Power Generation Services

Energy Management

Building Technologies

Mobility

Digital Factory

Process Industries and Drives

Healthineers (separately managed)

Financial Services

O&G → **Power Generation** → **Power Transmission and Distribution** → **Efficient Energy Application**

Imaging and In-vitro Diagnostics

Corporate Core

Corporate Services

30 Lead Countries

Power and Service presence – Close to customers all over the world

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New equipment manufacturing sites complemented by dedicated service sites worldwide

Berlin, Erlangen, Muelheim
- Europe
- Russia / Central Asia
- Africa

Orlando
- Canada
- USA

Bogotá
- Brazil
- Austral-Andina
- Meso-America

Dubai
- Middle East
- Central Africa

Shanghai
- Japan
- Northeast Asia

Singapore
- South Asia
- ASEAN
- Pacific

The heart of a power plant – Siemens heavy-duty gas turbine

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Proven technology

>1,000
gas turbines

delivered in more than
60
countries

- Highest reliability: > 99%
- Power output between 117 and 564 MW
- Highest efficiency: 61%*
- Environmental friendliness with lowest emission values
- Flexibility

In Berlin, we generate customer benefit

*Combined cycle efficiency SGT-8000H series

Siemens has more than 65 years experience in gas turbine technology

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1904
Foundation of
turbine factory Berlin Moabit

1948
Muelheim
Start of gas turbines R&D activities

1961
Commercial operations of VM 80: World's largest single-shaft gas turbine (23.4 MW)

1969
Foundation of
Kraftwerk Union AG

1972
Berlin
1st gas turbine for power plant 62.5 MW (V93.0)

1978
World's most powerful gas turbine 116 MW (V94.1)

1980
Delivery of V94.2 gas turbine (148 MW) – today known as **SGT5-2000E**

1996
1st **SGT5-4000F**

1998
Merger with Westinghouse

2011
World's largest GT, efficiency record
SGT5-8000H

2015
Opening
Clean Energy Center
Test center for components

2016
Berlin
Shipment of the
1,000th gas turbine

and

World's **most efficient combined cycle power plant**

AEG | Kraftwerk Union AG | Siemens AG

Technology that matters – proven, reliable, innovative

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1991	1999	2008	2011	2016
50%	56%	58.5%	60%	61.5%

SGT5-2000E
CCPP Killingholme
2x1 / 2 x 450 MW

SGT5-4000F (intro)
CCPP Cottam
1S / 390 MW

SGT5-4000F (latest upgrade)
CCPP Mainz-Wiesbaden
1x1 / 405 MW

SGT5-8000H (intro)
CCPP Irsching 4
1S / 578 MW

SGT5-8000H
CCPP Lausward Fortuna
1S / 603.8 MW

25 years of world-class combined cycle performance

Reference examples | All performance data based on ISO conditions on site

The new HL-class:
An evolutionary development step from proven H-class design

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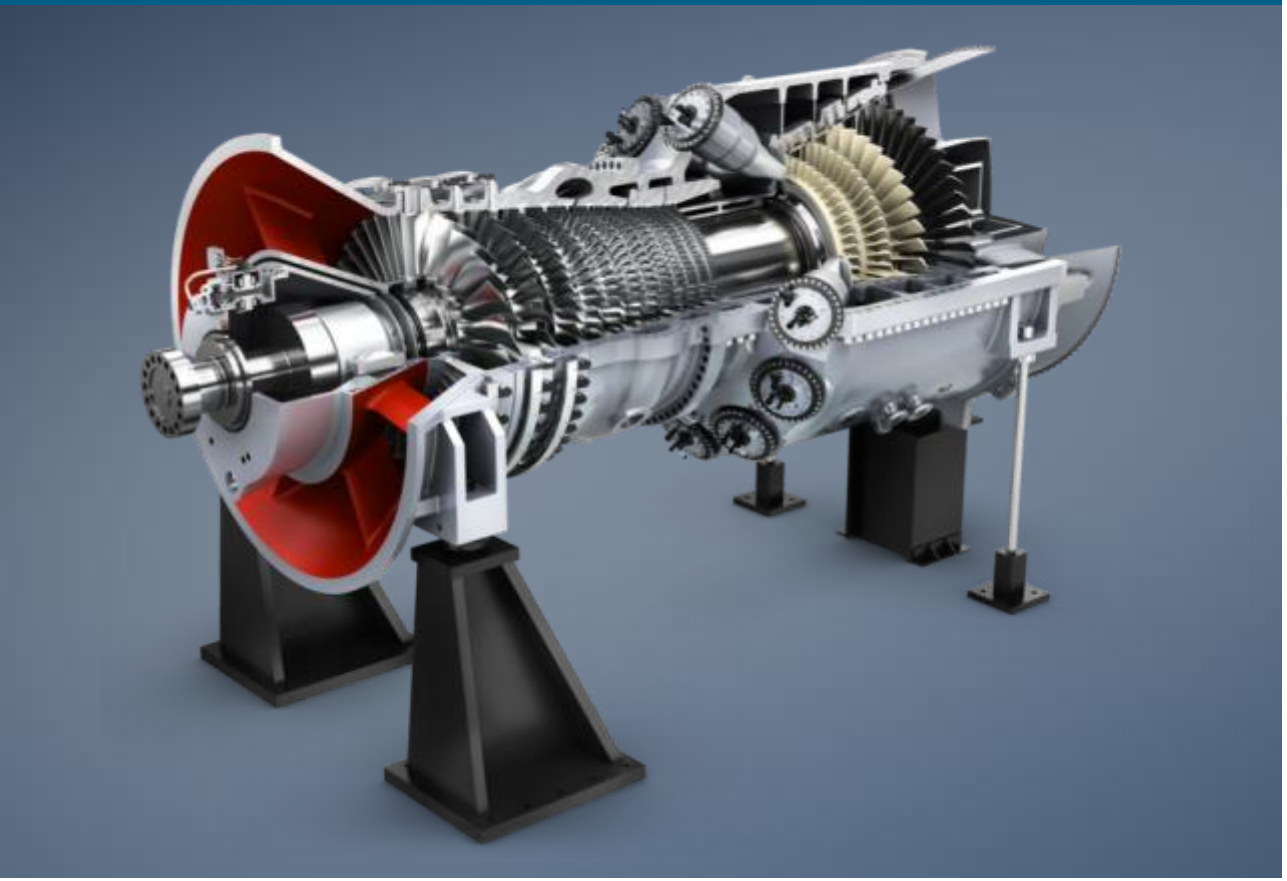
SGT5-9000HL / SGT6-9000HL / SGT5-8000HL



HL-class: Technology carrier to 65 %

- Continuing the leadership trend in proven, high-efficiency, air-cooled large gas turbines
- Pushing efficiency and performance to the next level
- Optimized for lowest lifecycle costs and operational flexibility

Joined DNA based on proven H-class design

- Air-cooled
- Hirth serration and single tie-bolt rotor
- 3D 4-stage turbine
- Hydraulic Clearance Optimization (HCO)
- Steel rotor
- Can annular combustion system

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Current Process

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Procedure is applied for each measurement step

Preparation

- Wait for lubricant disappearance
- Put on and secure climbing harness
- Install ladder and climb into machine

Measurement

- Diameter: inside micrometer screws
- Length and groove width: sensor and plunger equipment
- Groove depth: caliper gauge

Clean Up

- Remove ladder and put measurement devices in boxes
- Climb out of machine and harness

Data Transfer

- Calculate measured values and type into tool wear
- Store measuring data on paper sheets

Motivation

- Machining interruption for each measurement step
- Machine operator has to measure manually
- Workplace safety is worthy of improvement due to certain circumstances within measurement operation in large casing part
- Several measurements tools have to be used inside the part

→ Measurement process plays a large part in the total processing time

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Future Vision

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- **Traceable on-machine measurements of gas turbine parts**
  - Use tactile measurement probe for automated on-machine measurement process
  - Establish appropriate monitoring system in order to ensure required measurement process quality & stability

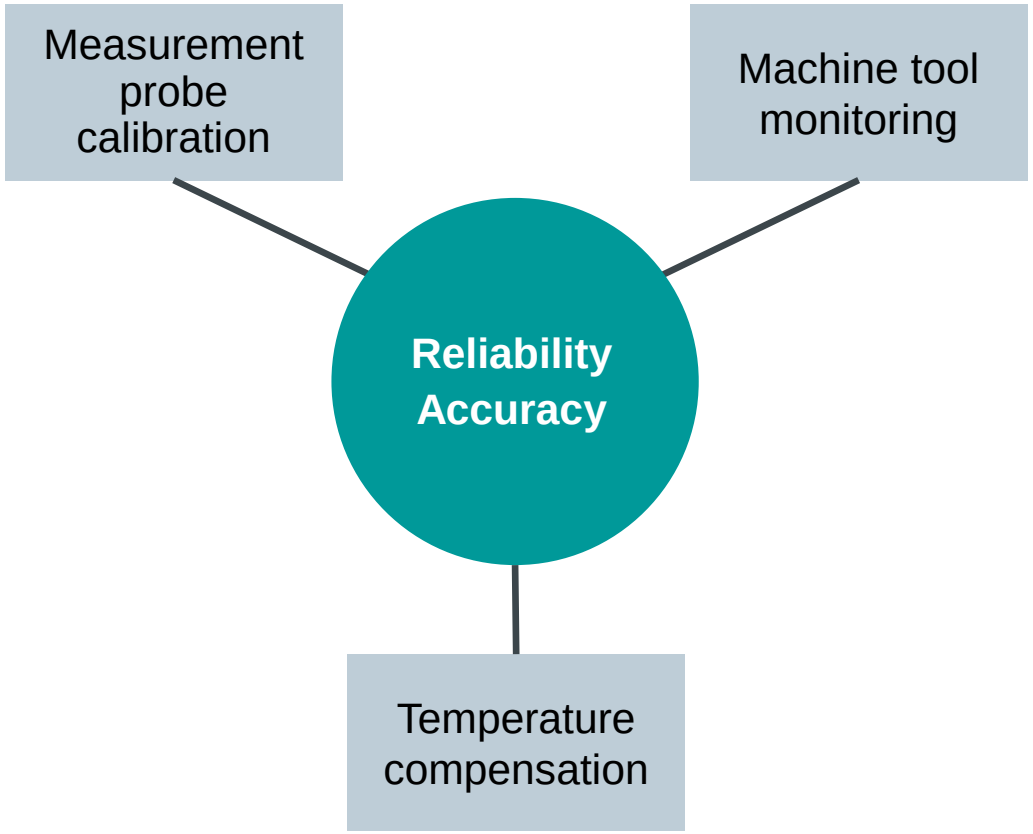
Idea

- Calibration routine for measurement probe
- Calibration routine for machine tool
- Temperature compensation for continuous stability of measurement process

Challenge

- Knowledge about systematic and random errors in order to determine process capability of machine tool for on-machine measurements
- Compensation of influential factors
- Ensure measurement process stability

3 Factors to obtain reliability and accuracy



Machine tool monitoring

- Ensure no changing in position accuracy
- Perform appropriate machine tool calibration routine

Measurement probe calibration

- Determines diameter and length of measurement probe in fact of wear or damage

Temperature compensation

- Mandatory to ensure measurement capability in the entire temperature range
- Selects compensation tables based on present temperature of axes

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Theoretical determination of machine tool capability

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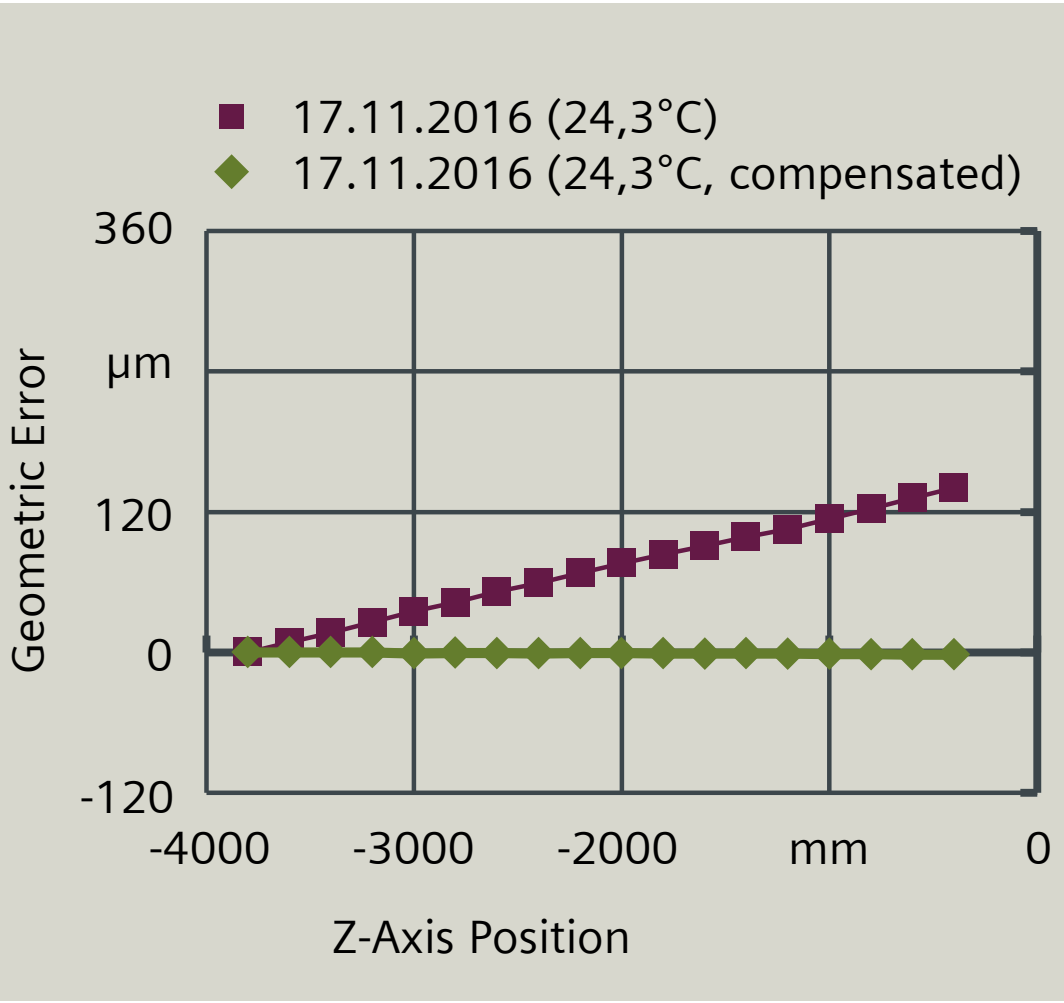
Z-Axis positioning error (EZZ – ISO 230-1)

Determine theoretical capability for on-machine measurements by calibrating machine tool:

- Z-Axis positioning error (EZZ) is the major influencing factor for positioning errors in Z-direction
- Z-Axis positioning error (EZZ) in November is about 40µm/m

→ Z-Axis positioning error in November is compensated significantly



Calibration of machine tool:
Large vertical turning center, Waldrich Coburg
Geometric Error (ISO 230-1):
EZZ (Positioning error of Z-Axis)
Measurement device:
API XD-Laser

Practical verification of process capability

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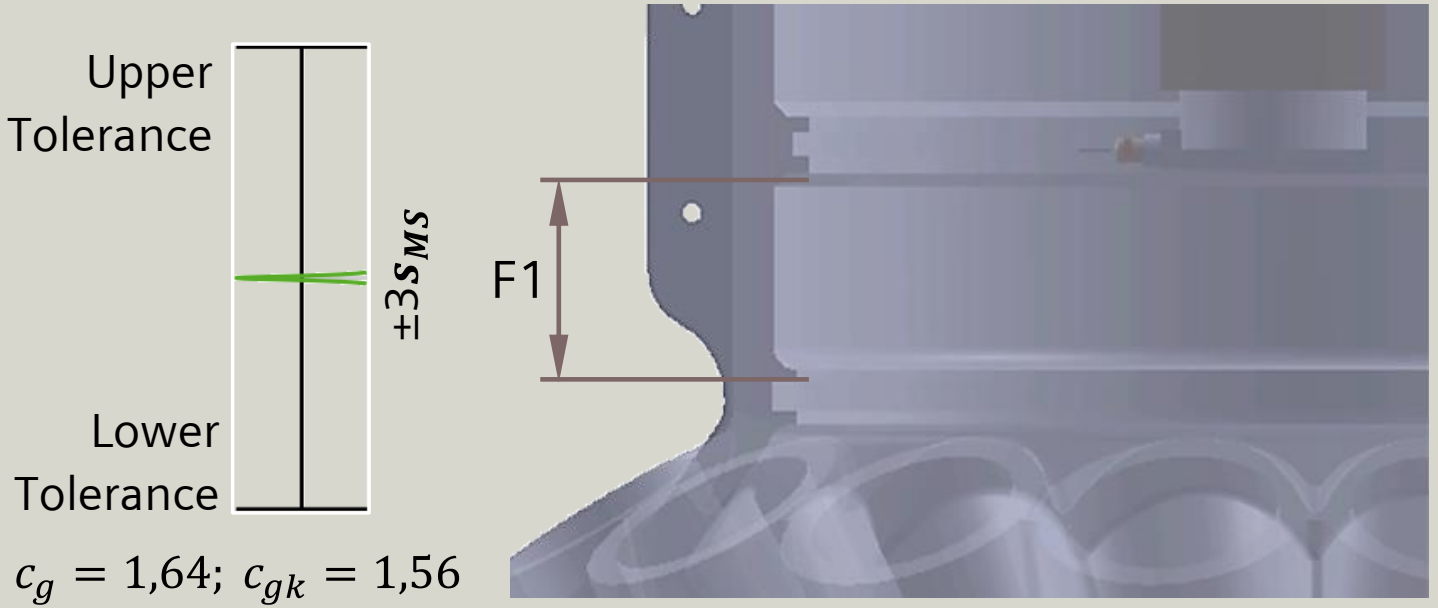
Process capability (ISO 22514-7) for challenging measurement feature

Practical verification of process capability for on-machine measurements by measuring repeatedly with touch trigger probe:

- As a characteristic the measurement probe and the tool holder were changed after each measurement
- Feature is closely tolerated (<0,1mm)
- Process capability is about 1,64
  → Process is capable (c_g>1,33)

Feature 1 (F1): Length measurement



$c_g = 1{,}64;\ c_{gk} = 1{,}56$

Remark: The illustrated feature is not showing actually measured feature.

Practical verification of minimum process capability

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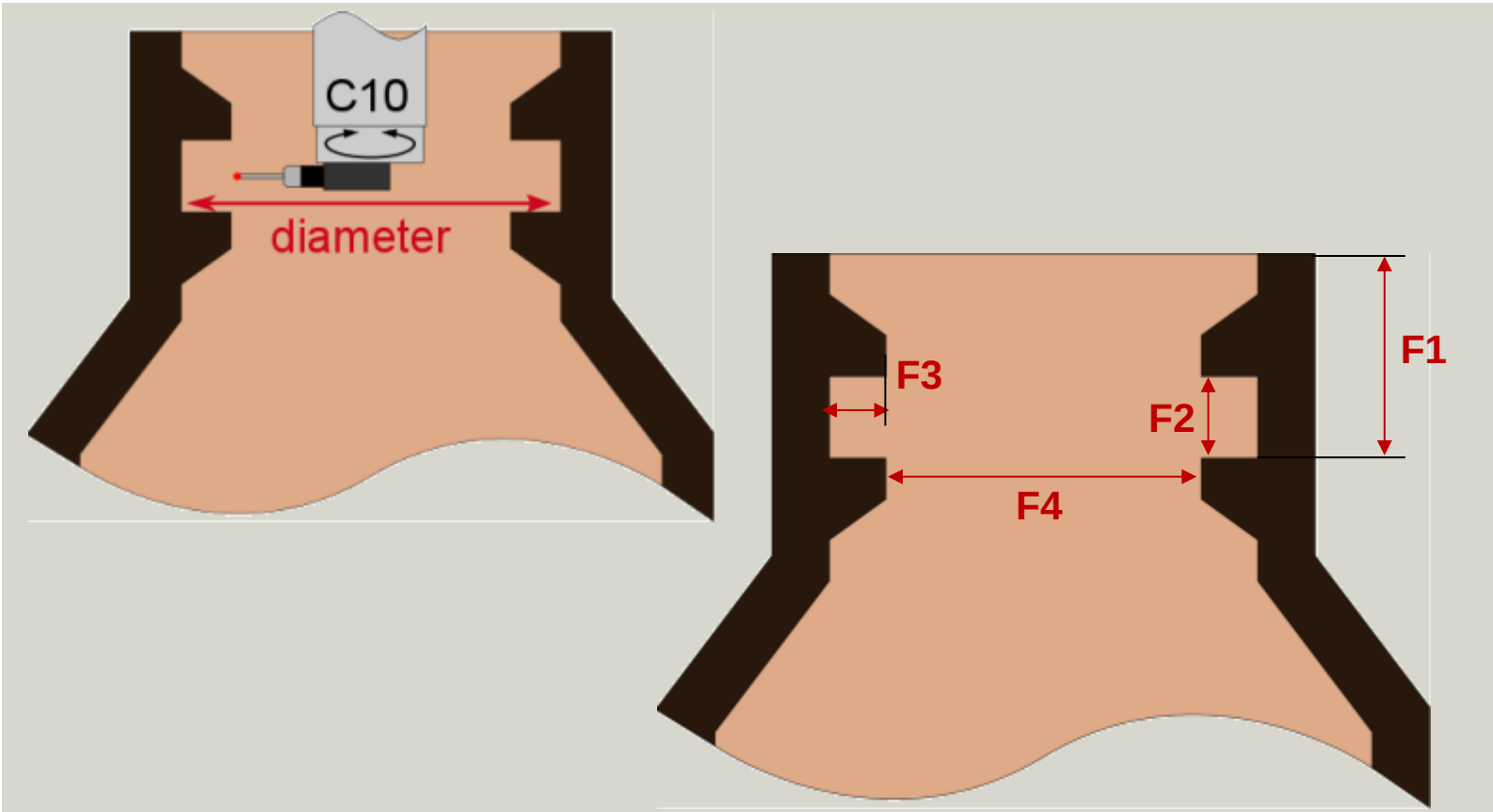
Minimum process capability (ISO 22514-7) typical measurement features

Comparative measurements with laser tracker and conventional measurement method are performed as reference for minimum process capability:

- Laser tracker is not suitable for measurement task

  → Compared with conventional measurement method the process is capable (c_{gk}>1,33) for almost all measured features



<u>Remark</u>: F1-F4 are typical measurement features

Determination of temperature stability

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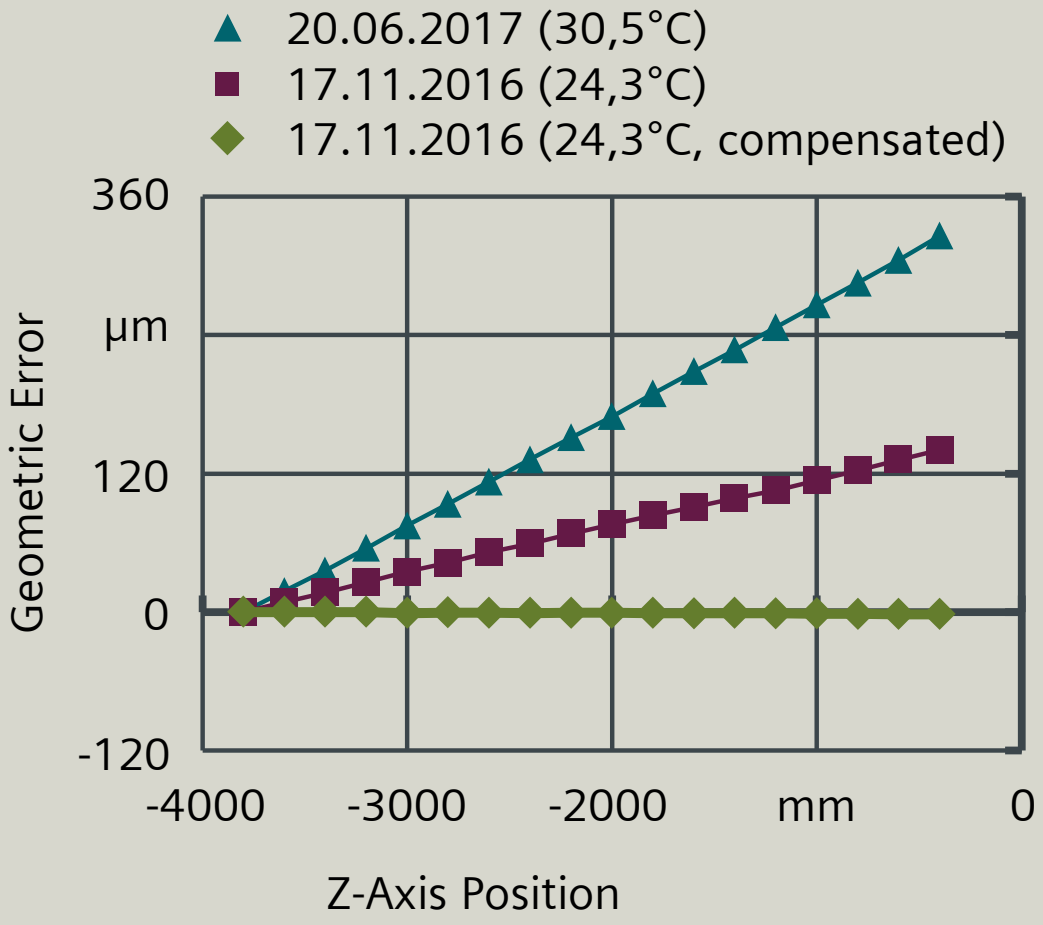
Z-Axis positioning error (EZZ – ISO 230-1)

Determine temperature stability for on-machine measurements by calibrating machine tool on different dates:

- Z-Axis positioning error in November is about 40µm/m
- Z-Axis positioning error in June is about 80µm/m

→ Changes in temperature have a major influence on positioning errors of machine tool axes

→ Temperature range for capable measurement of closely tolerated feature F1 is about ±1,5°C



Calibration of machine tool:
Large vertical turning center, Waldrich Coburg
Geometric Error (ISO 230-1):
EZZ (Positioning error of Z-Axis)
Measurement device:
API XD-Laser

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Outlook

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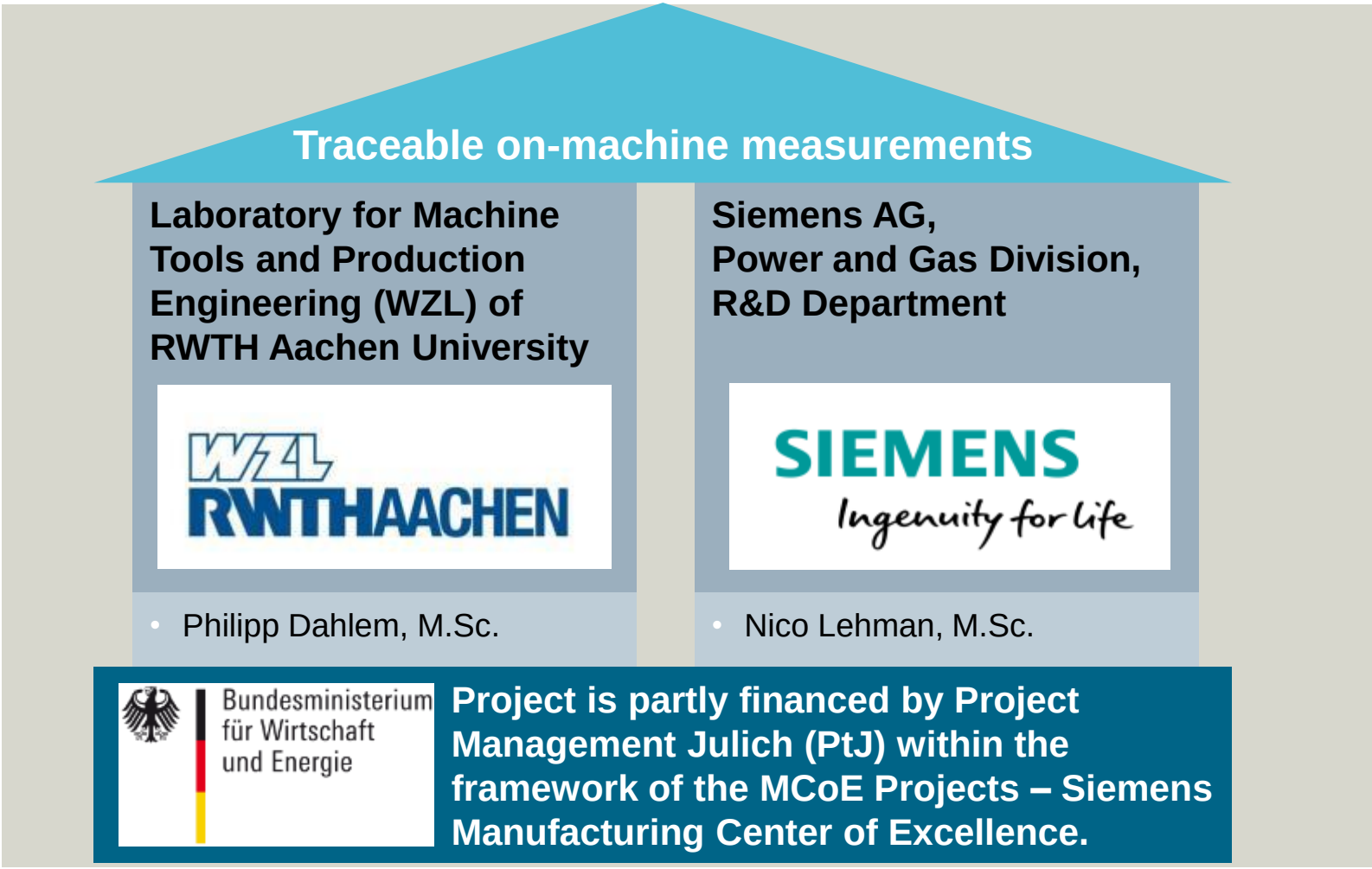
Implement the 3 factors to obtain reliability and accuracy for on-machine measurements.

Next Steps:

- Collect more measuring data for qualify automated measurement process
- Implement developed solution for temperature compensation
- Establish calibration routine with laser tracker as monitoring concept for machine tool

Project Setup

- This project is carried out in cooperation with the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University
- MCoE is a funded project with the title: Development of manufacturing technologies for future and competitive gas turbines



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