# Presentation of Project Content

FAA Project on Process Monitoring

November 3rd 2009, Boston FAA


Dipl.-Ing. Dražen Veselovac

Department of Process and Product Monitoring
Chair of Manufacturing Technology
WZL - RWTH Aachen


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# Outline



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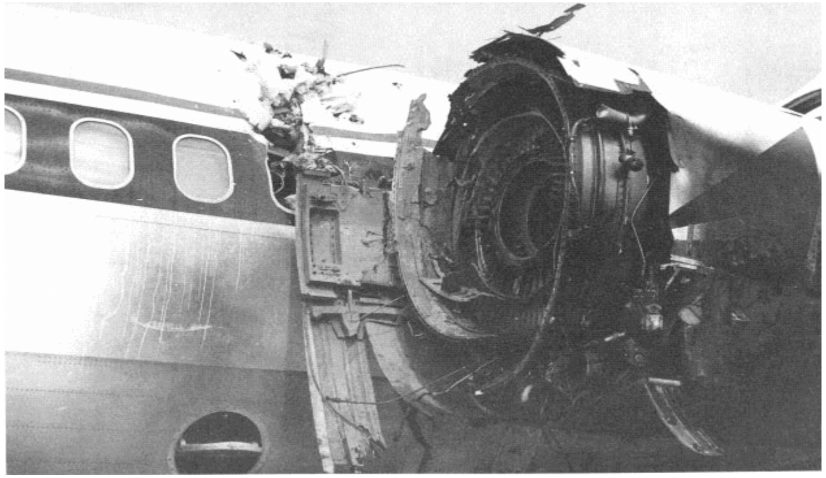
# Introduction

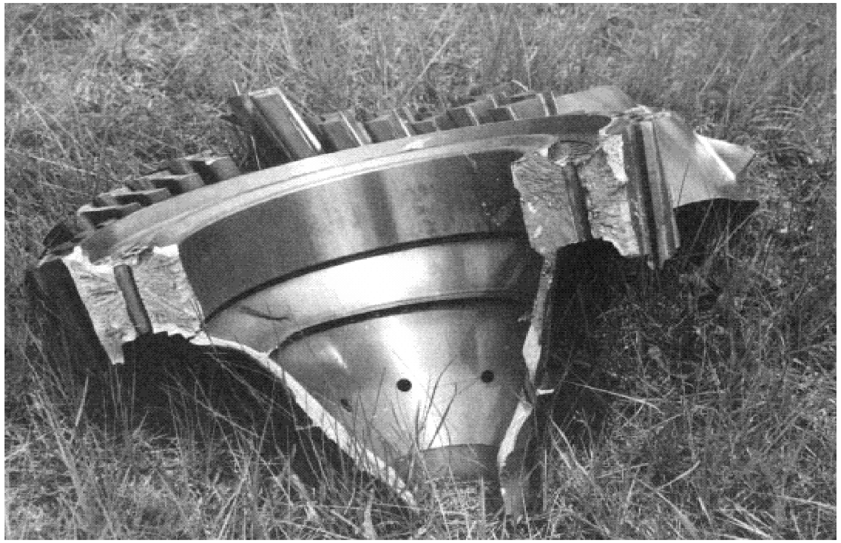
# Needs for workpiece-oriented process monitoring

**ACCIDENT**

***DL 1288, July 6, 1996 - Pensacola, Florida***

- **Broaching and drilling are machining operations carried out to finalise discs' geometry**
- **Drilling is most critical and sensitive process due to difficult cutting tip engagement, complicated chip flow and unfavourable heat dissemination**
- **Broaching is difficult because of one-stroke nature**
- **Need for investigation and monitoring of these operations was expressed several times from ROMAN group based on their Lessons-Learned data base**

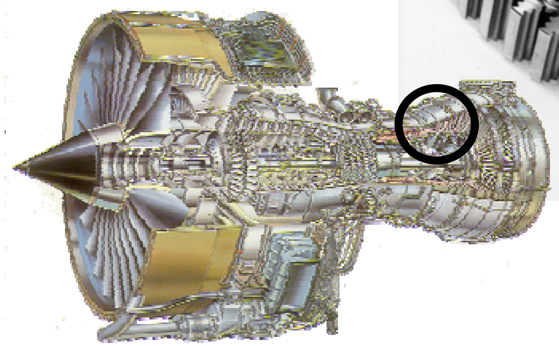


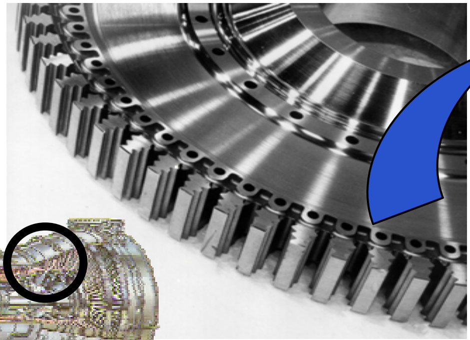


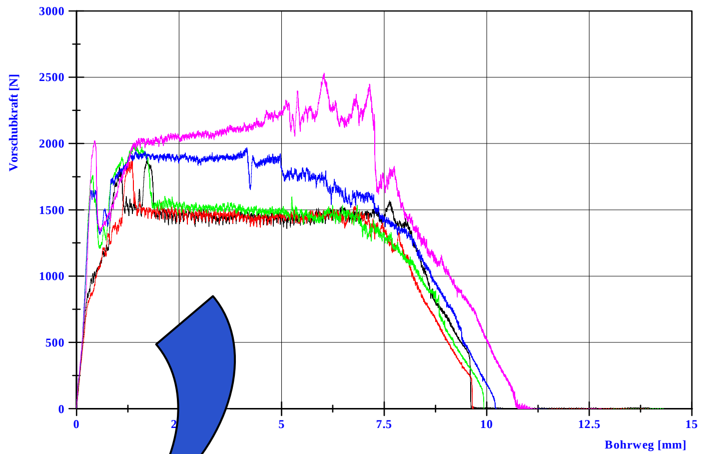
# Workpiece-oriented process monitoring

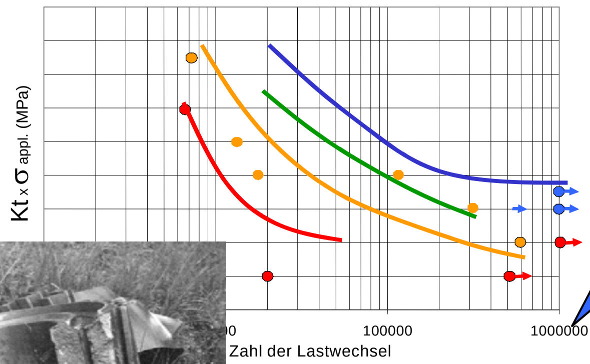
- Stable manufacturing of critical turbine engine discs

- Process monitoring / **temperature control** are required to ensure components without fatal thermal damages







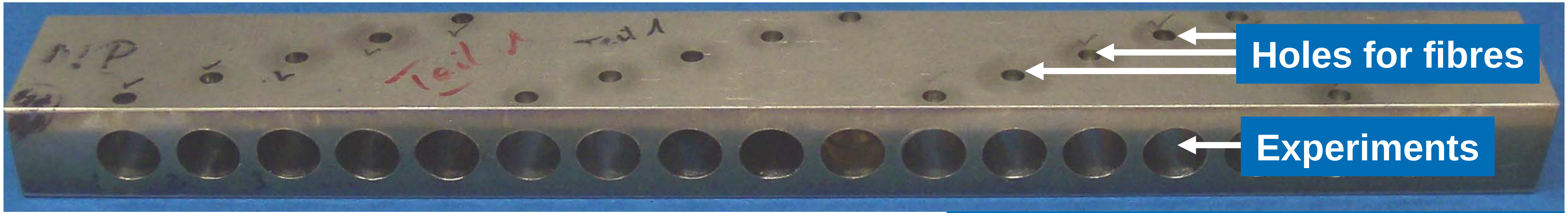




- Correlation of induced thermal impact to LCF-tests of manufactured specimens

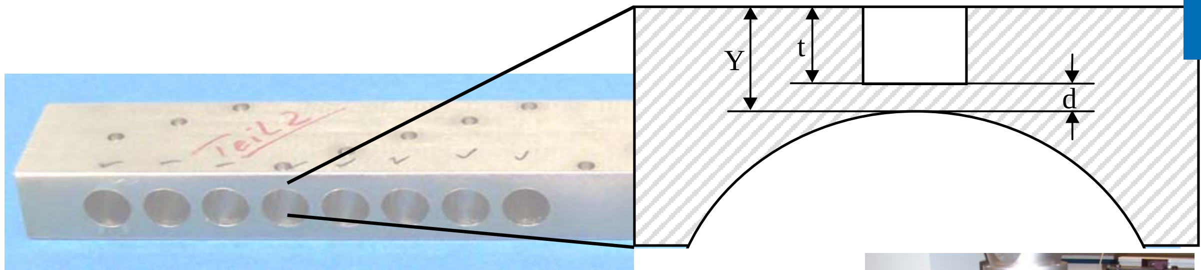
Source: MTU, Rolls-Royce

# Temperature Measurements in Drilling TiAl6V4

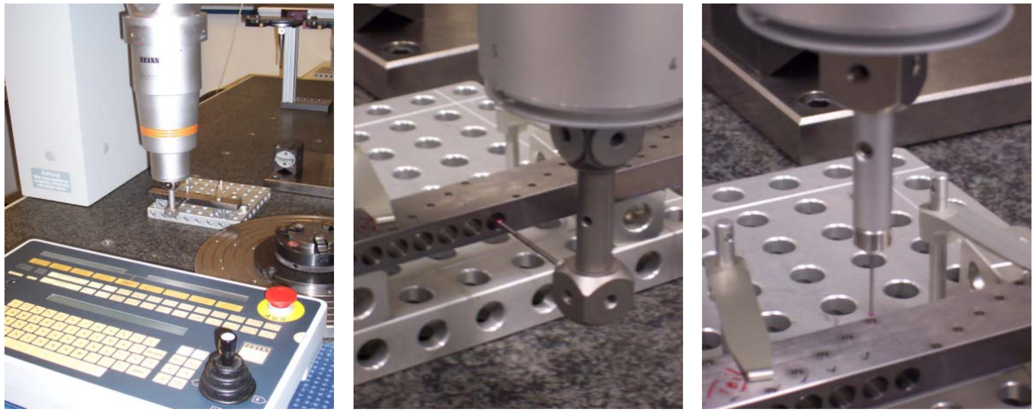
d = 100 µm  d = 200 µm  d = 300 µm



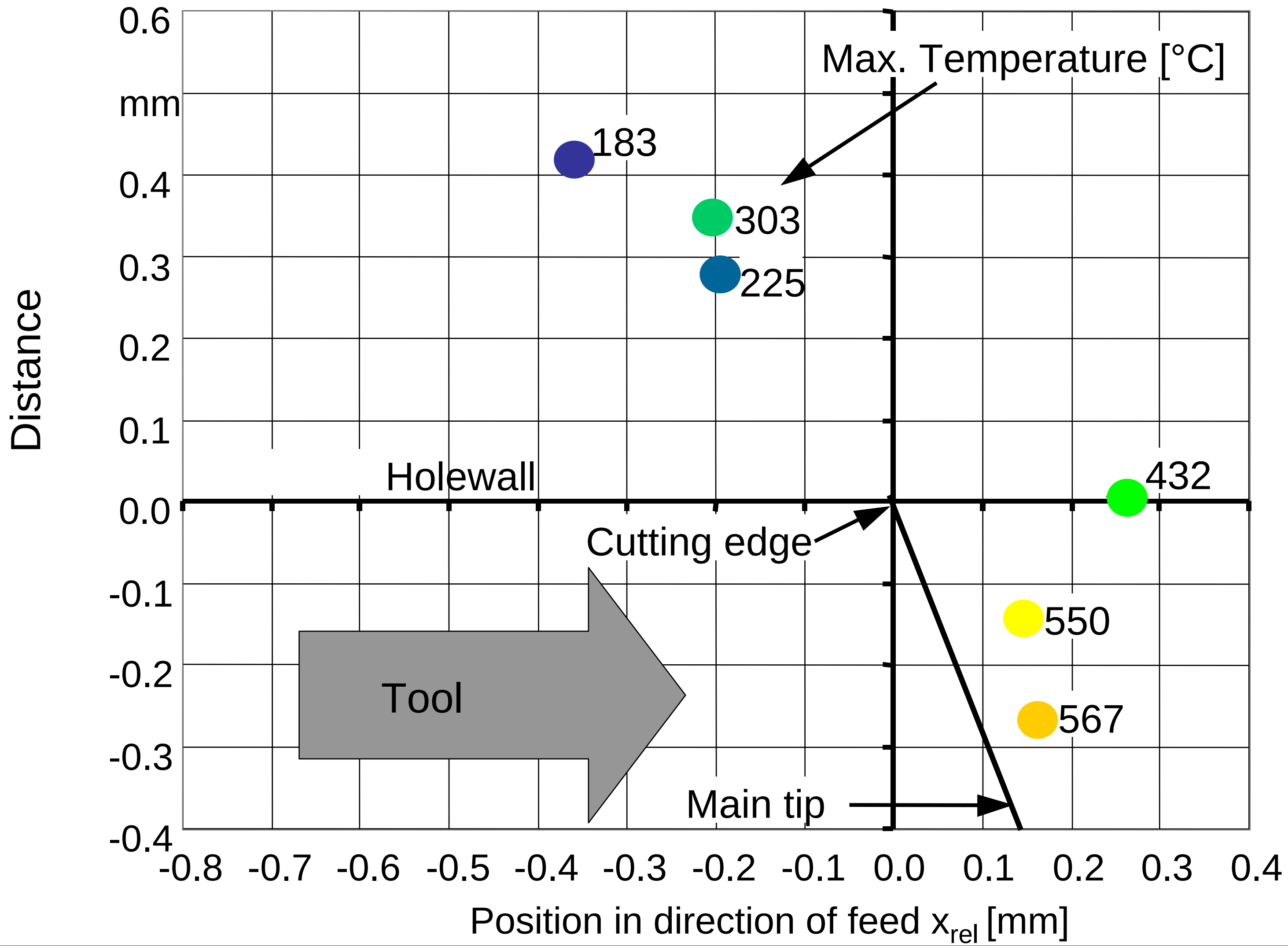

After experimental investigations




3D-Measurment device



# Temperature Distribution around the Cutting Edge

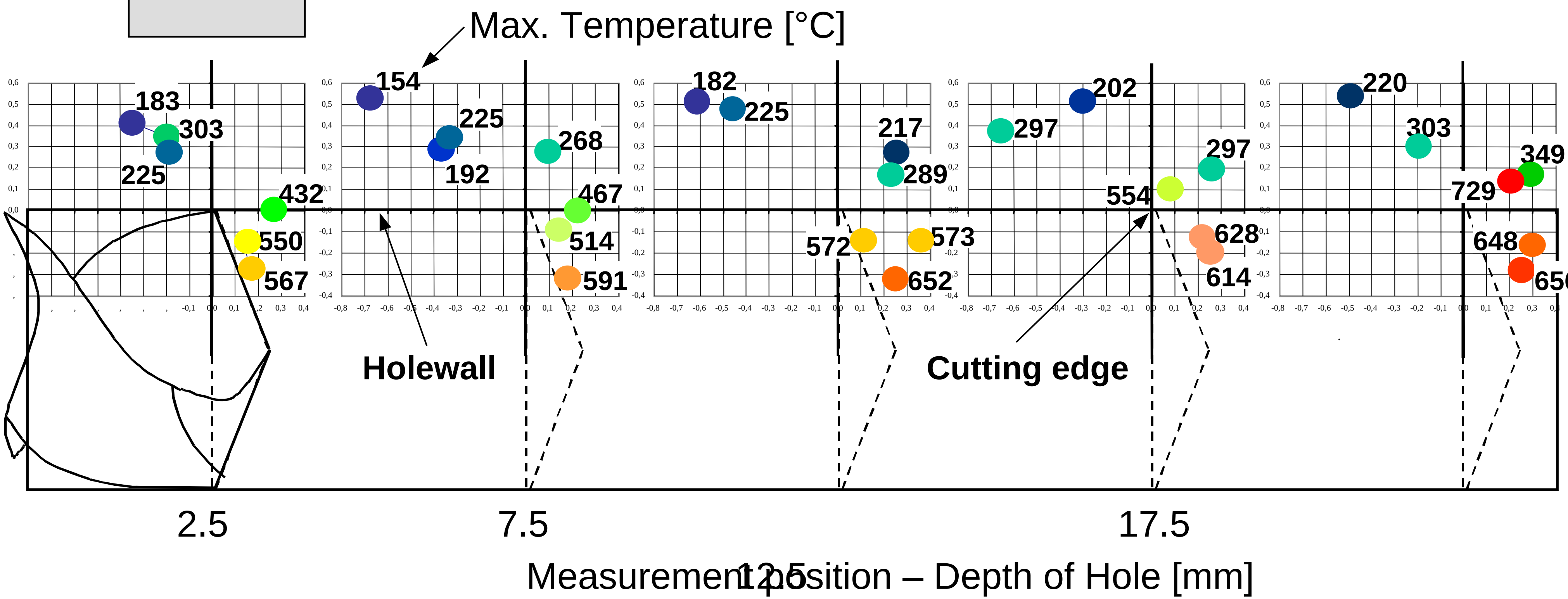


# Temperature Distribution along the whole Drilling Operation

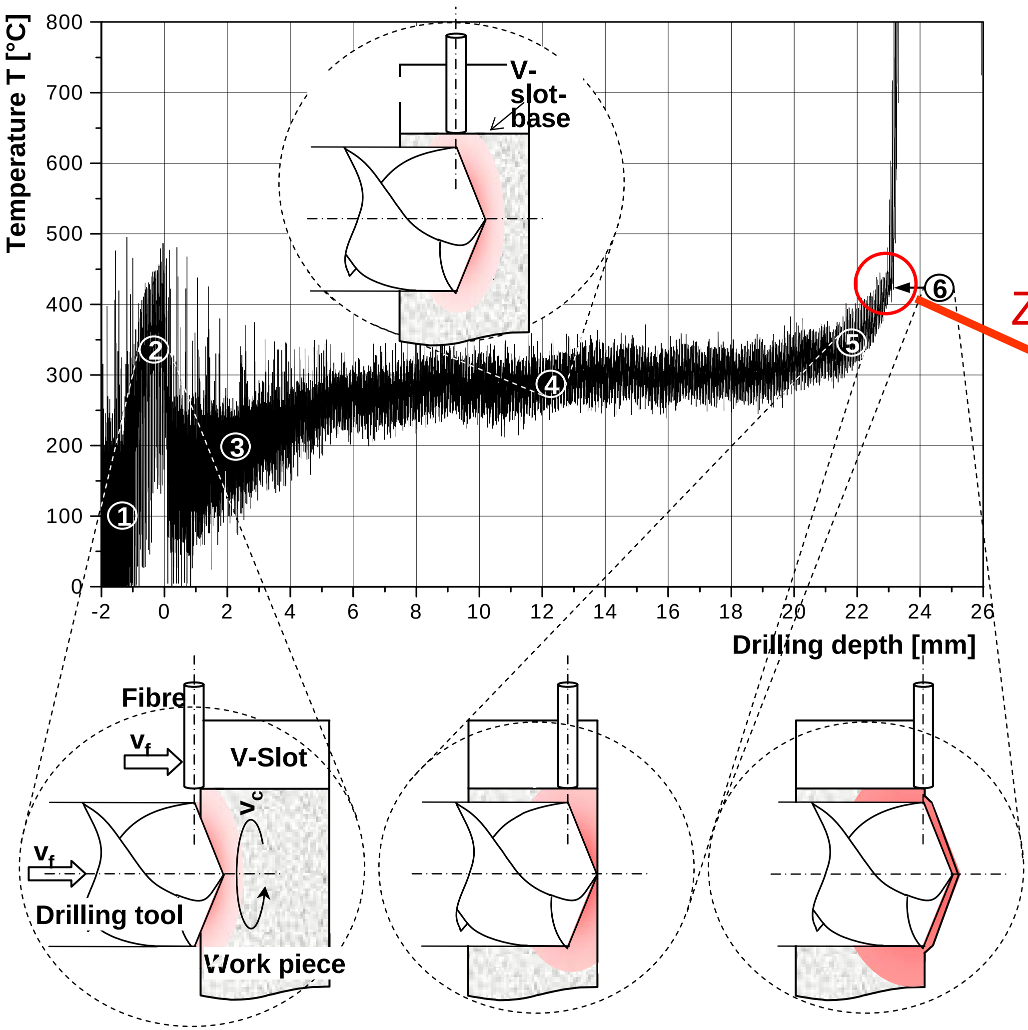
**Cutting parameter:**

**$v_c$ =**
**f =**
**l/D =**

**D =**
**l =**



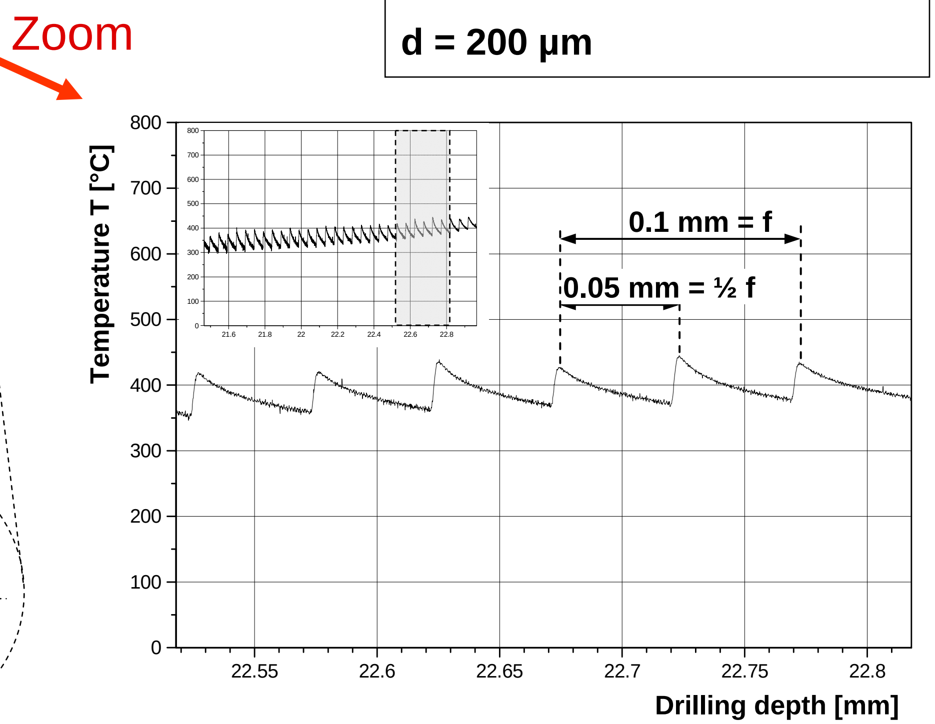
# Temperature distribution in continuous measurements




**Process Parameter:**

**Measurement distance**

**d = 200 µm**

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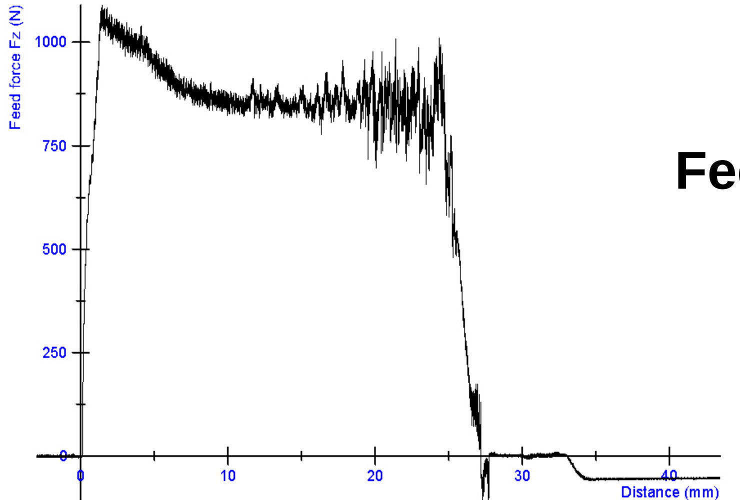
# Analysis of Drilling Process

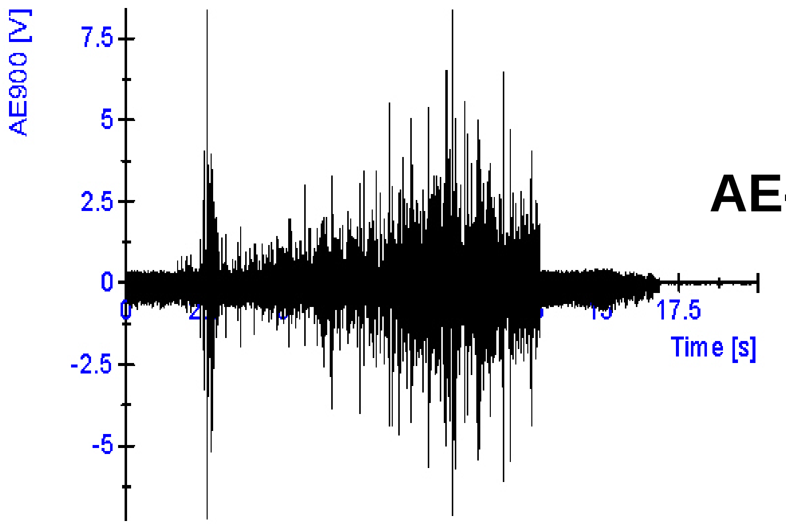
- - Reground tool
  - Already used for 8 holes
  - Dry cut
  - TiN coated

- Process parameter:

$v_c$ =
f =
l/D =

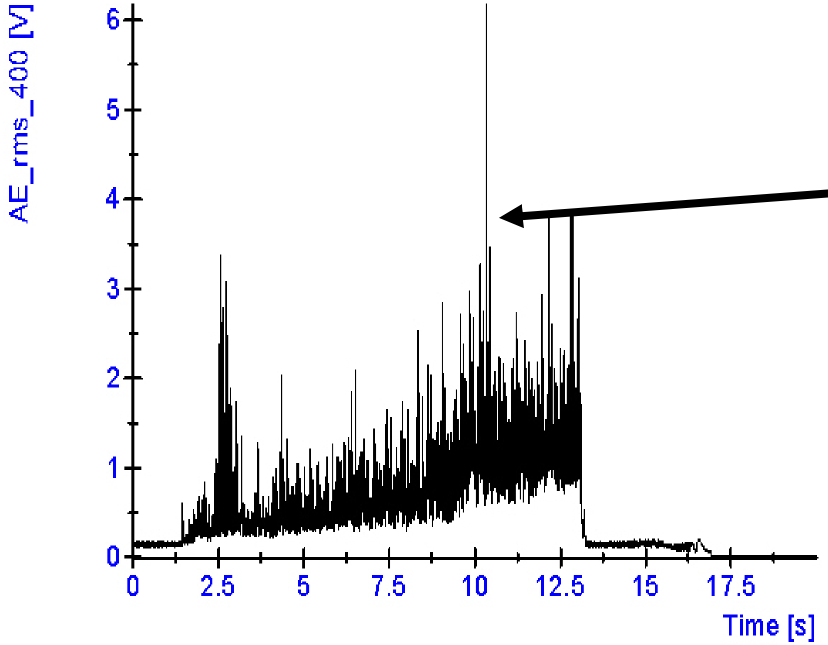



Feedforce

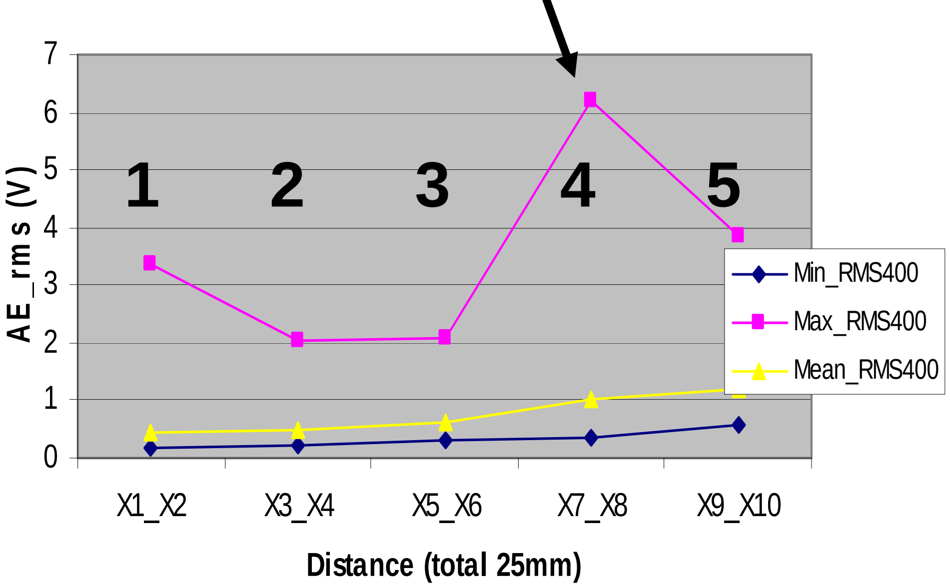



AE-raw Signal

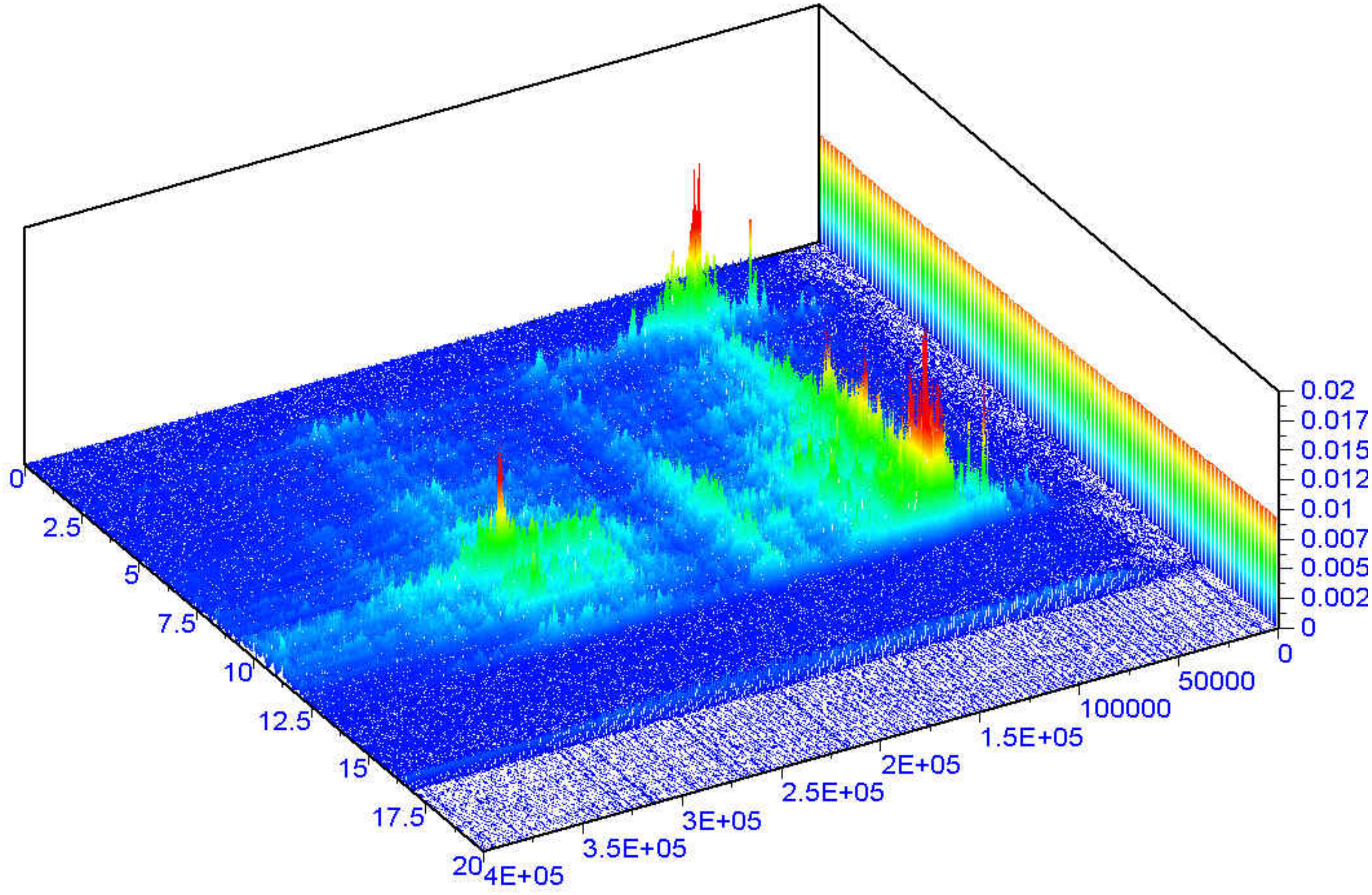
# AE RMS Monitoring for Drilling TiAl6V4




- **Very clear indication of anomaly during the time and drilling depth, where LCF specimen 4 is located**



# Joint Time Frequency AE Raw Analysis

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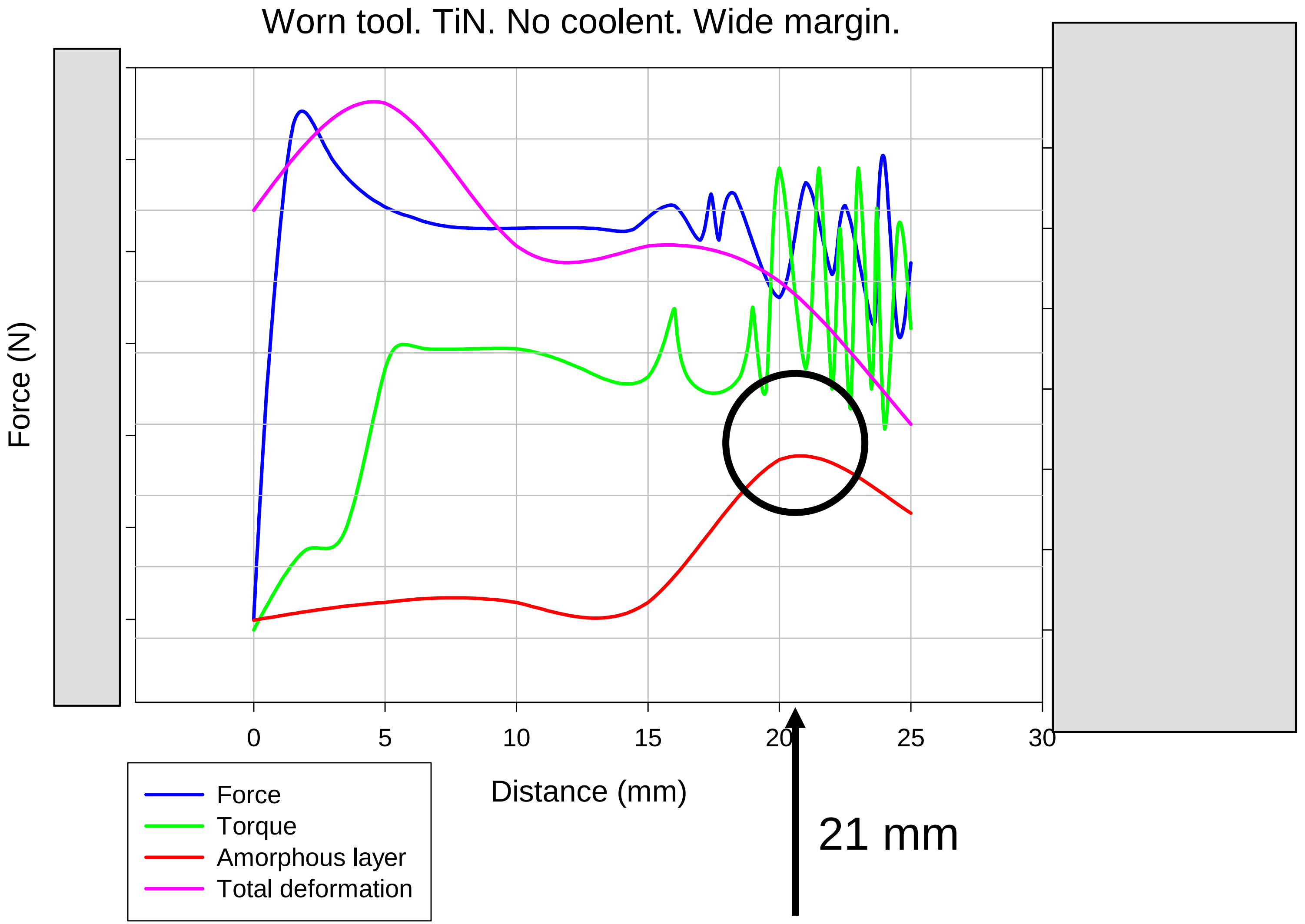
# PM-Anomaly-LCF Correlation

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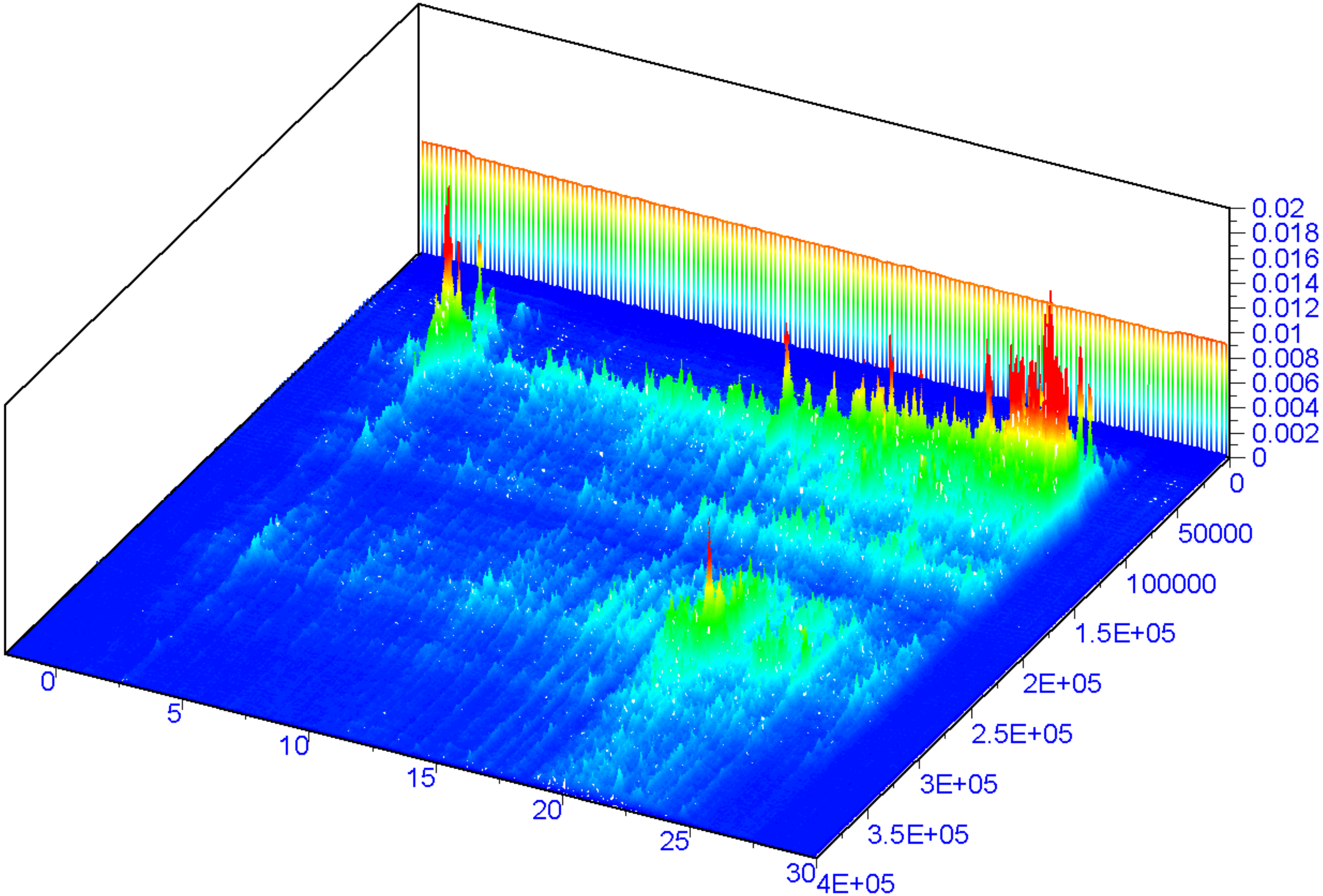
# Joint Drilling Depth-Frequency AE Raw Analysis

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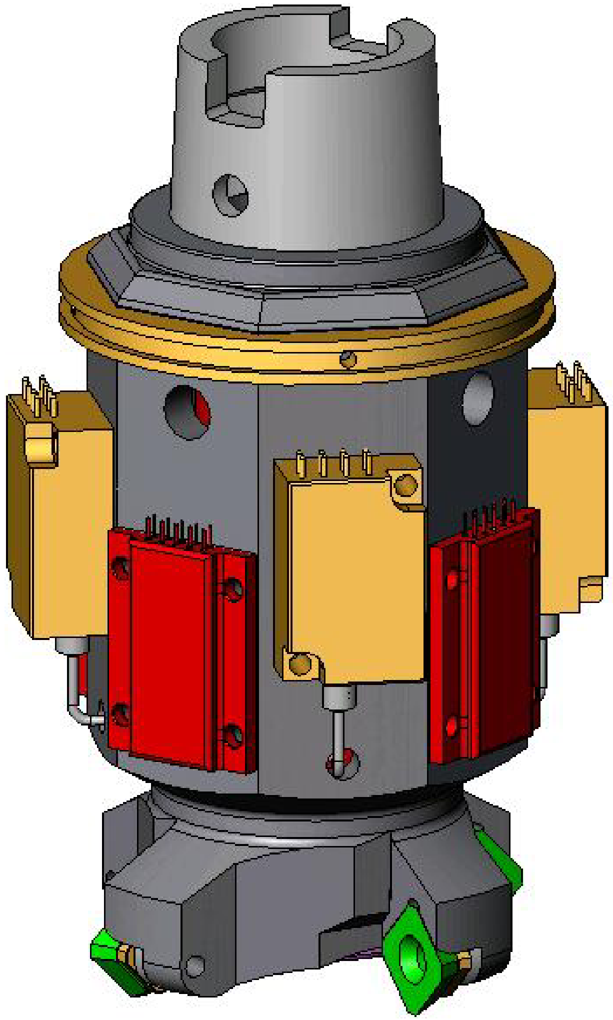
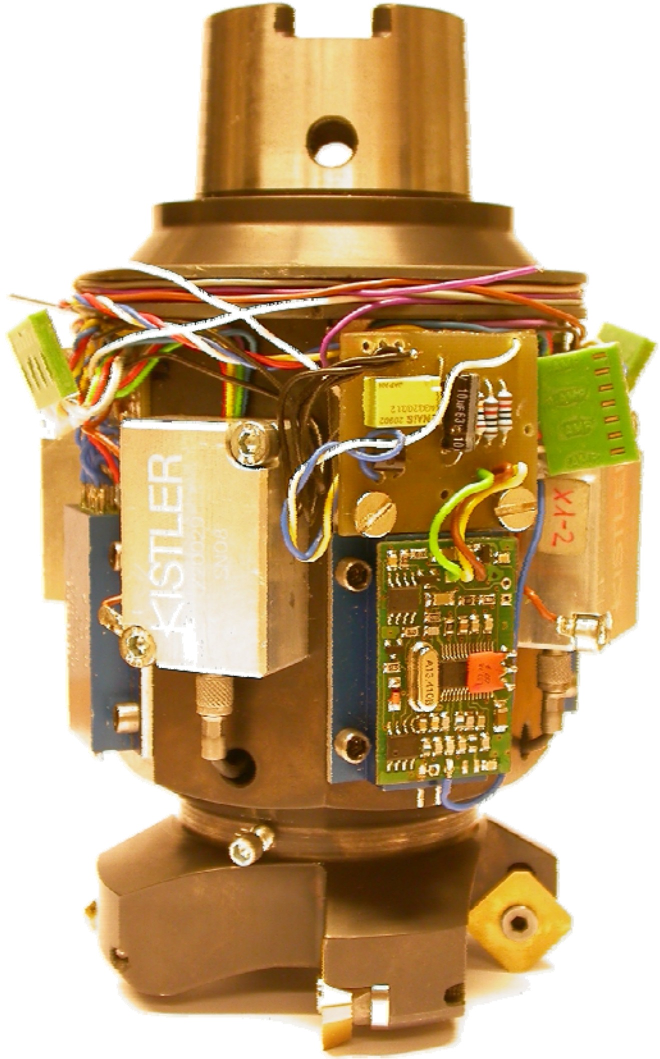
# Design of a Slim-Line integrated face milling tool



**Design and first prototype**

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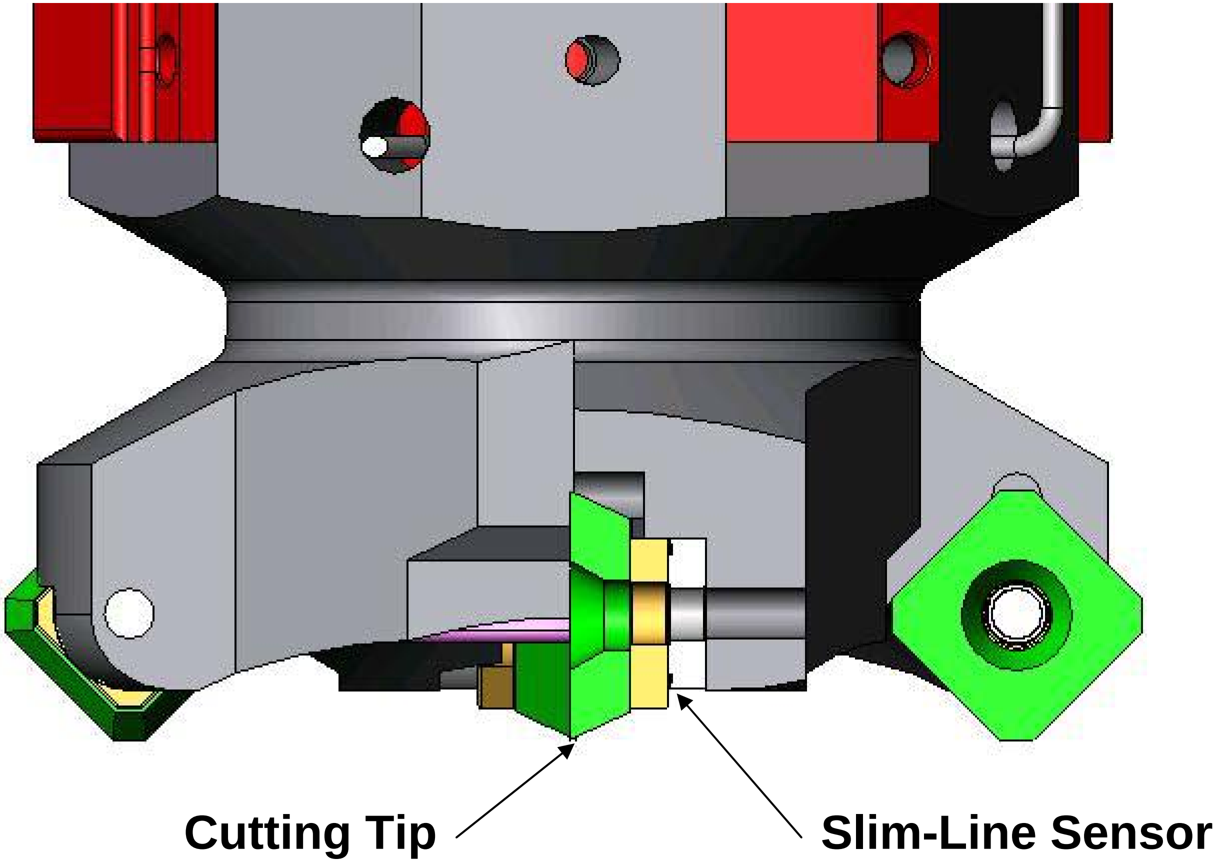
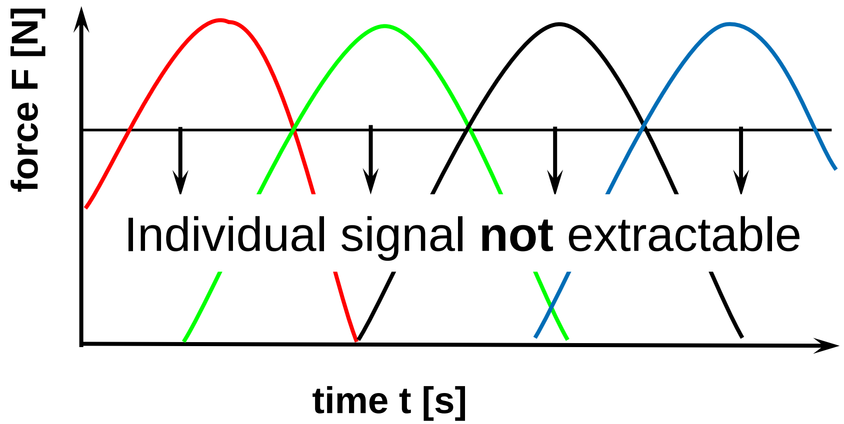
# Design of a Slim-Line integrated face milling tool

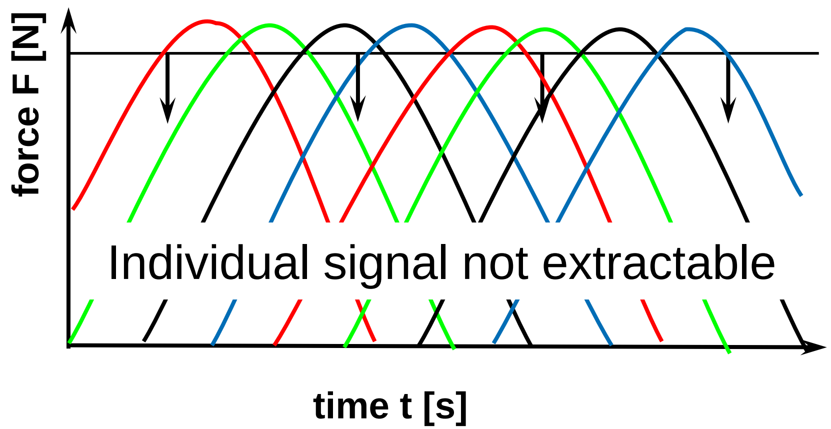


# Design of a Slim-Line integrated face milling tool

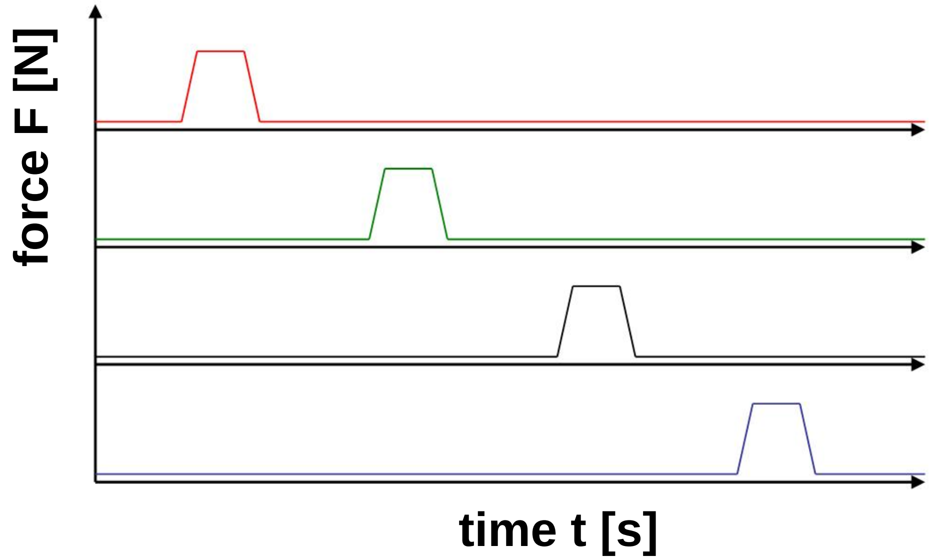
## Force signal of  dynanometer




## Force Signals in HS-Cutting




## New design
## Individual slim line signals




**Ability to monitor individual cutting edge signal**

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# Accelerometric compensation with Slim-Line sensors

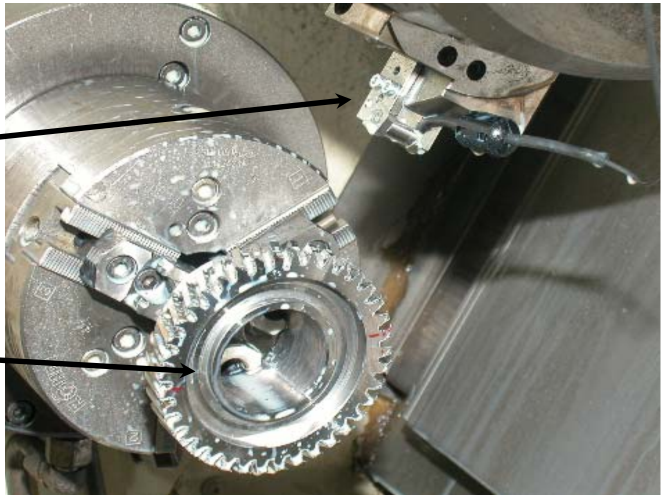
**Slim-Line Sensors**


**Tool holder**

**Cutting tip**

**Tip-mounting and preload transfer device**

**Slim-Line Sensor**



**Tool-holder set-up with Slim-Line force sensor**

**Workpiece for high frequency force interaction**

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# Slim-Line vs. Dynamomter force meausurements

**Process Parameter:**

$v_c$ = 532 m/min

$a_p$ = 0.1 mm

f = 0.05 mm/rev

Coolant = no

$Cal._{slim}$ = 2.4 pC/N

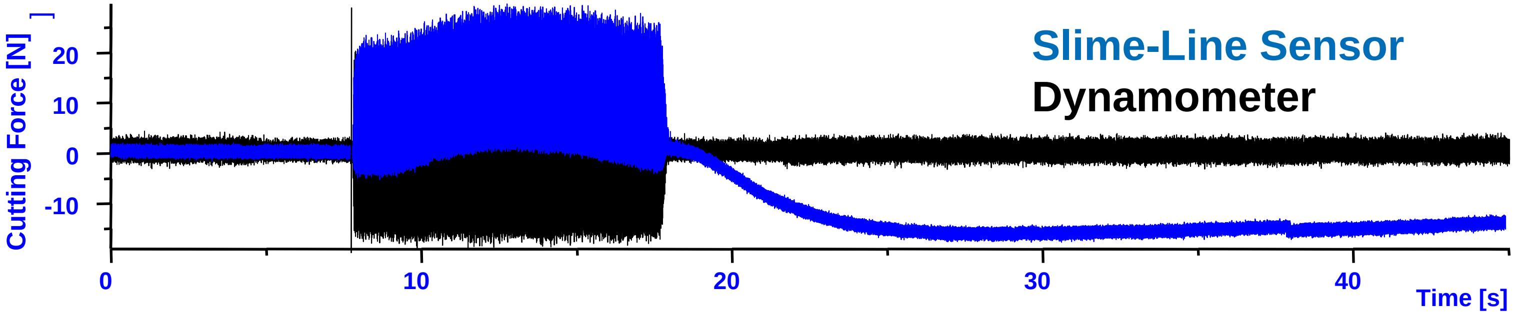
V = 100 N/V

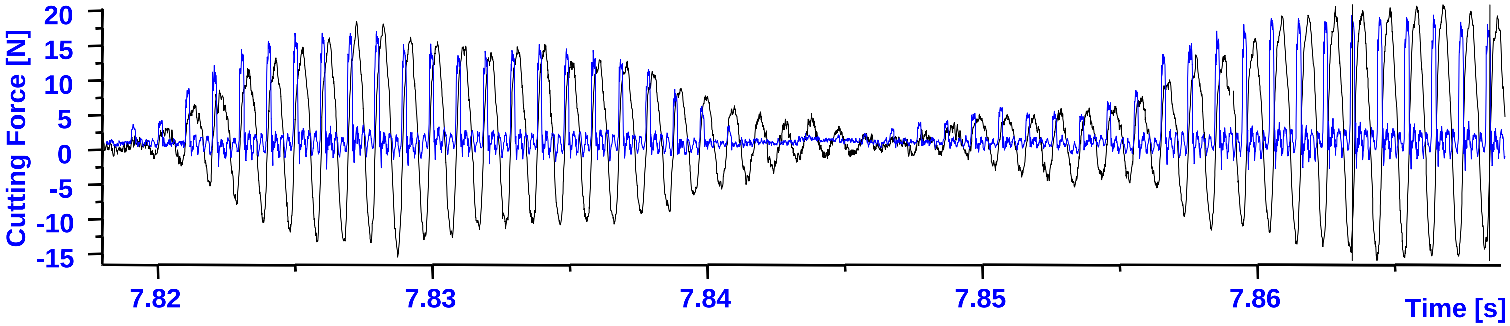
$f_{Eingr.}$ = 1000 Hz

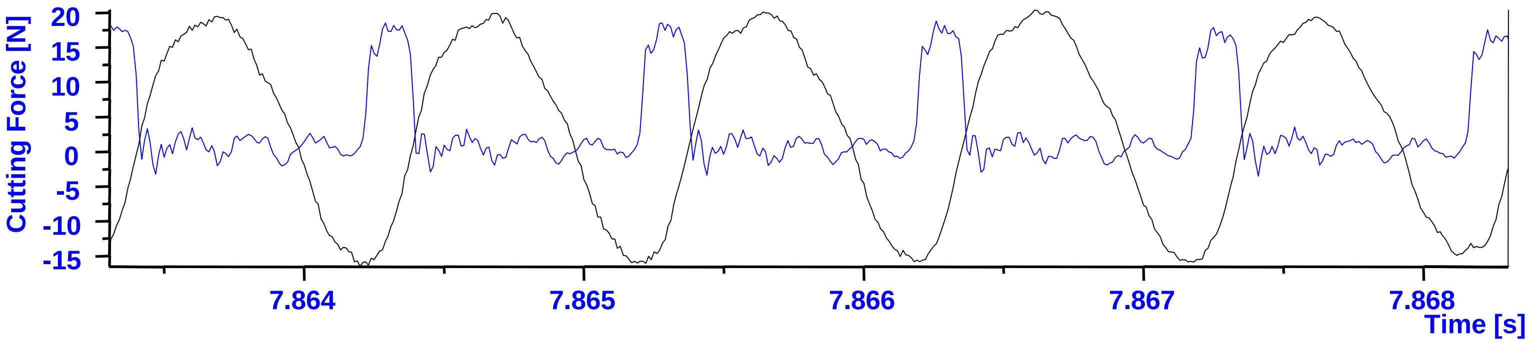
$f_{grenz}$ = no Filter SL

$f_{Abtast}$ = 100 kS/s

Time-const. = Long



# Interest of industrial partners



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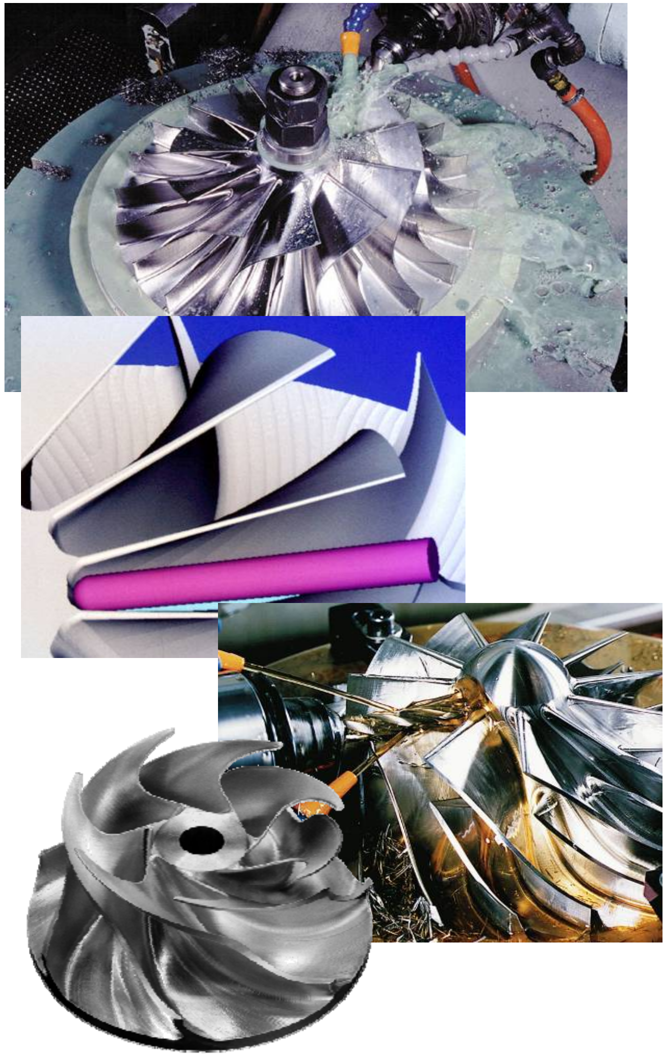
# Industrial partners from WZL



- WZL has become a
  Center of Competence for MTU AERO Engines
  in Compressor Technologies

- WZL is official Partner of Rolls-Royce plc. in
  Production Technology development for Integrative
  Aero Engine components

  - Main development axes are going to focus on 3 – 5 axis machining operations with machining centres

  - Blisk technology is going to be the main focus of technology development for military and commercial aeronautics

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# Support of industrial partners during the project

**Support actions**

- Opportunity to use broaching machine tools for testing

**Support actions**

- Conduction of trials on broaching machine tools

**Support actions**

- Supply work piece material for testing series

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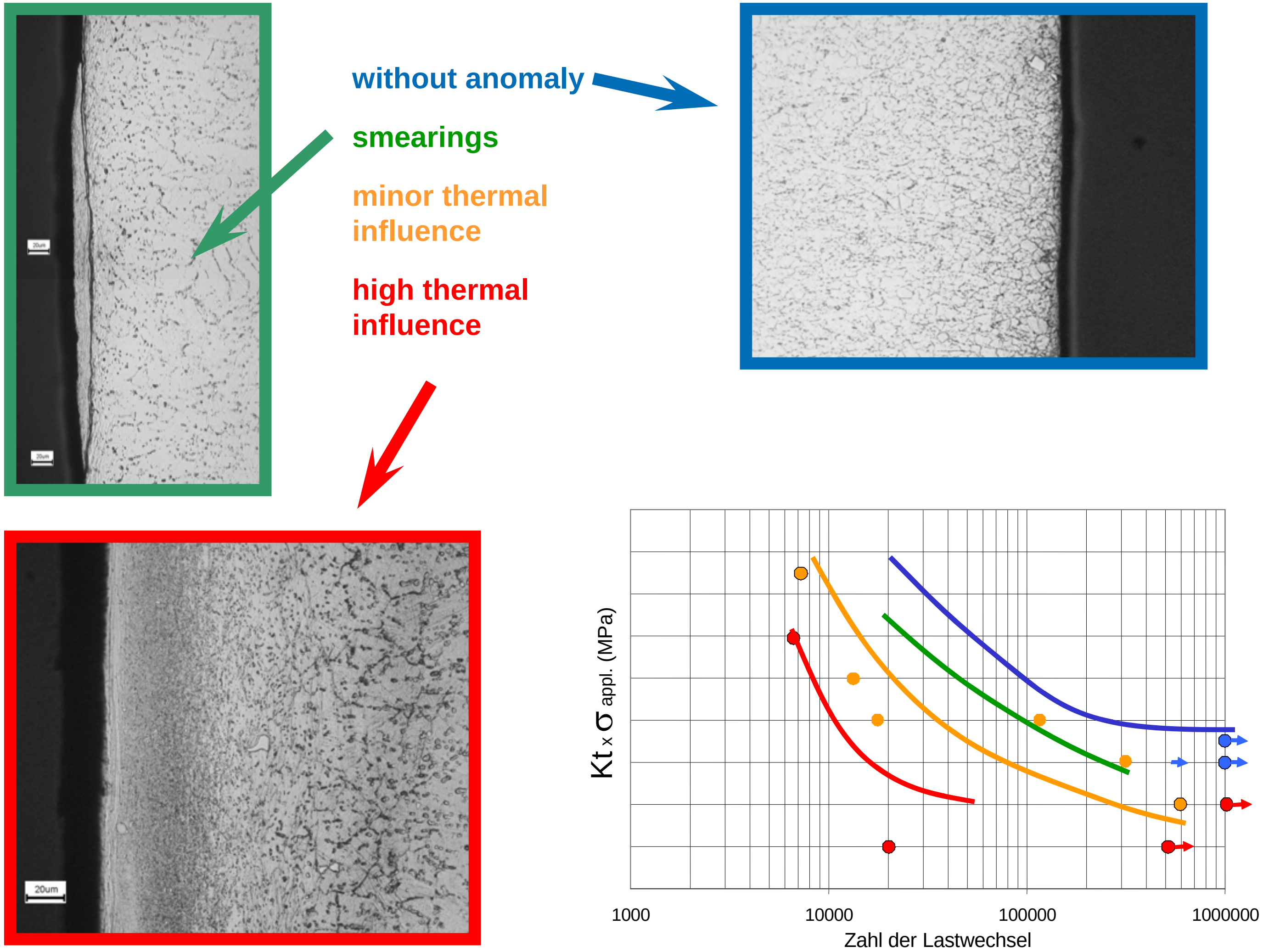
# State of the Art

# Application of Process Monitoring in Manufacturing

- Process Monitoring is seen as effective control for production with little or no part variation (automotive, food processing)
- In manufacture for critical aero engines PM is often seen as a burden rather than a benefit
- Systems in use apply simple techniques e.g. simple gated process monitoring
- These simple techniques fail to detect manufacturing induced anomalies in production, identified during MANHIRP Project




Source: ARMINES, SNECMA MOTEURS

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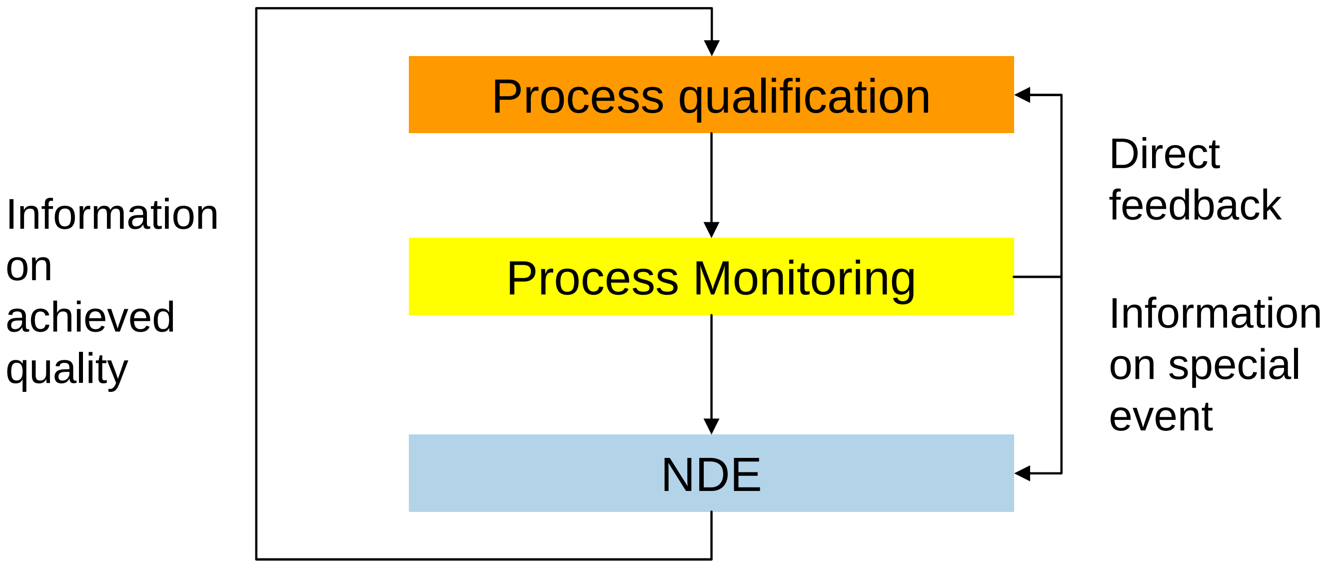
# Adressing state of the art in previous projects

- Initiated by the Pensacola event in 1996, FAA sponsored the Roman Project, which introduced appropriate manufacturing controls
- European aero engine makers formed project MANHIRP, which investigated use of PM for detection of anomalies, NDE, fatigue and probabilistic lifing models
- MANHIRP delivered an anomaly definition and categorization and identification of characteristic process monitoring signals




Source: FAA

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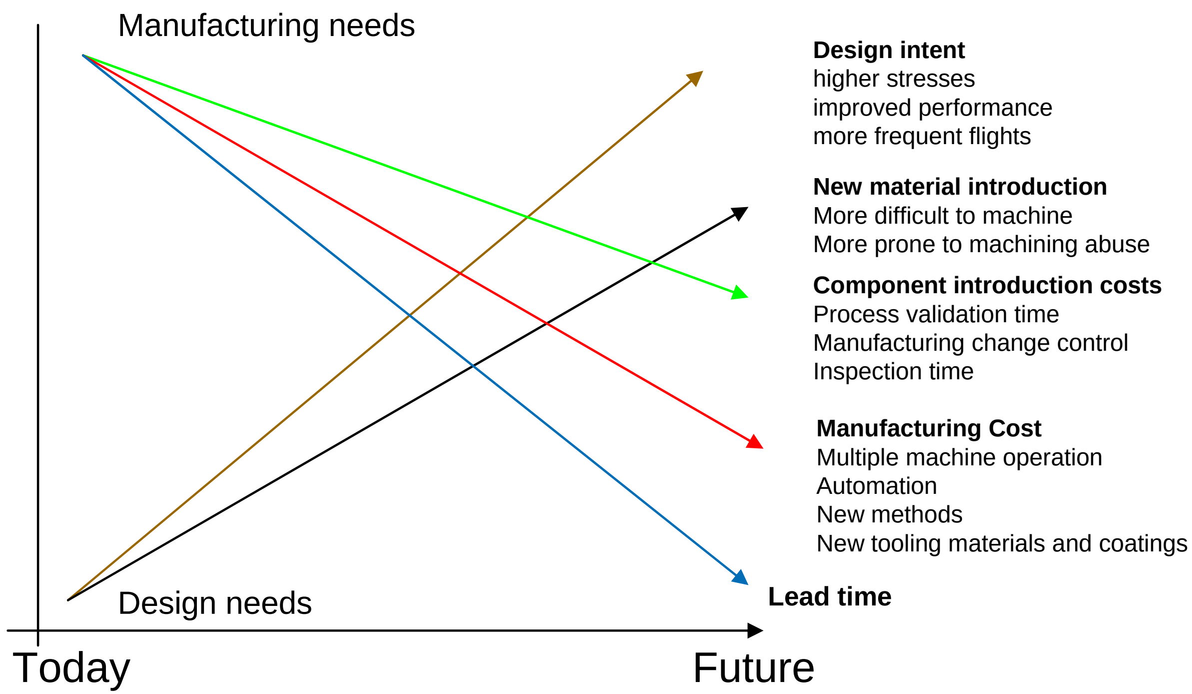
# Addressing state of the art in this proposal

- ability to manufacture critical rotating components whilst offering better quality control will lead to **increased levels of air safety**
- ability to demonstrate a **higher level of quality manufacture** in this most demanding and competitive global market
- development of a product monitoring system will allow **reduction of time required to approval**

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# Objectives and Main Goals

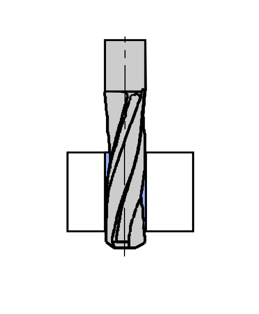
# Process-Material Combinations

- Work of this project will refer to

  Drilling Processes
  Broaching Processes

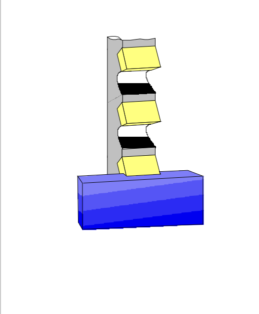
- FAA will choose either one Titanium or Nickel Alloy to conduct trials with
- Trials will be performed with same tools, materials and parameters as they are used in production of critical aero engine components
- Analysis of the trials and evaluation of machined parts will lead to suitable sensor solutions for monitoring material defects
- With regard to known specifications and FAA standards, borders and limits with regard to recorded signals will be defined

Drilling processes



source: Lycoming

Broaching processes



source: MTU

Titanium or Nickelbased Alloy

# Sensor and Mounting Location Selection

**physical process and disturbance quantities** → **sensing principles** → **sensor specifications** → **sensor mounting restrictions** → **possible sensors**

**input:**

*OEM description of process conditions*

ex.: - tool
- cutting steps
- disturbance def.
- disturbance char.
- process features
- :

*Sensing principles*

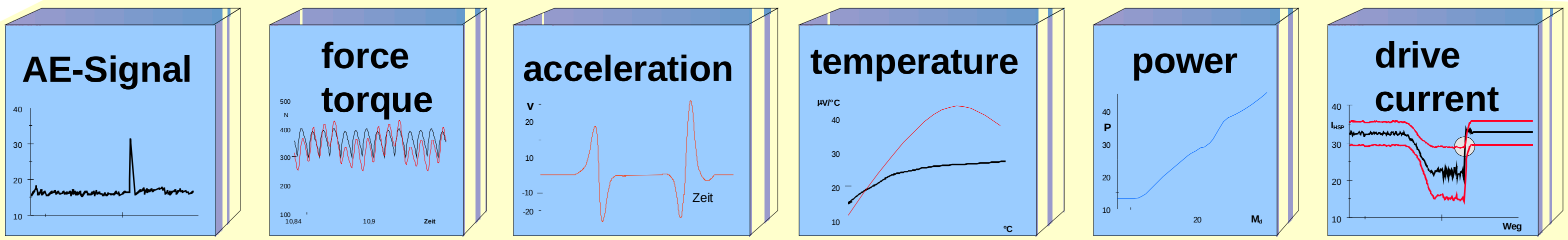
ex.: - piezoelectric
- strain gauge
- hall effect
- structure-borne sound
- :

*Sensor specifications*

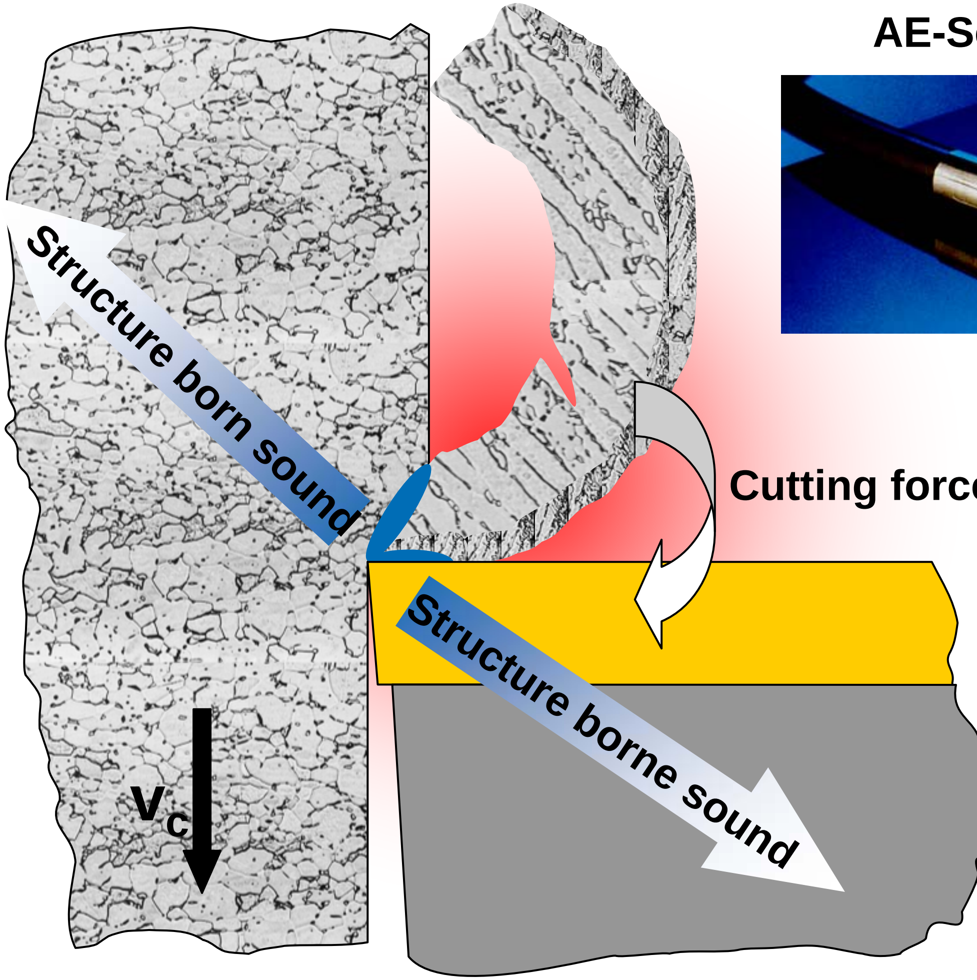
ex.: - frequency band
- frequency response
- range
- sensitivity
- mounting space
- :

*Machine test bed*

ex.: - workpiece handling
- machine 3, 5 axis
- interfaces (mechanical, data)
- process boundary conditions (lubricant, electro magnetic fields, etc.)
- :



# Suited Sensors for Cutting Operations

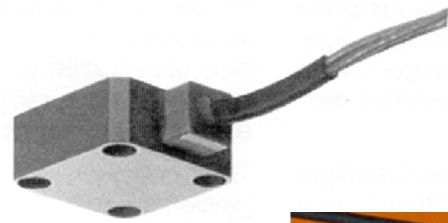




AE-Sensor

Rotating Cutting force Dynamometer (RCD)

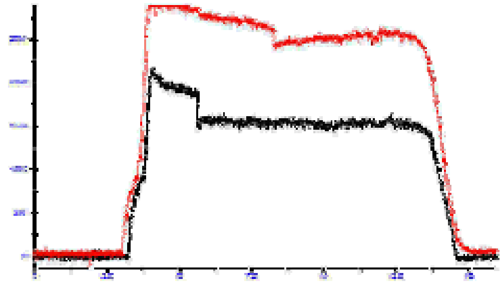
Accerelation Sensor



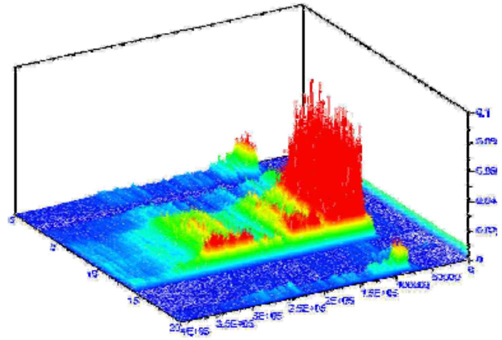
Hall-Sensor

# Signal Analysis

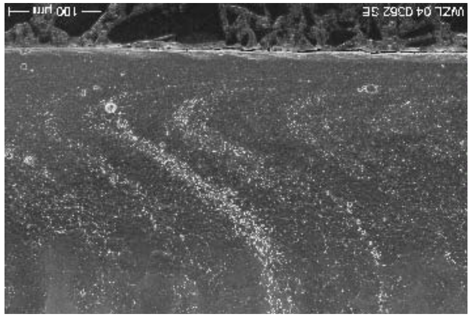
- **Low frequency signals (20 kHz):**
  **- Force, torque and power analysis in time-domain**
  **- Combination of $AE_{RMS}$ and feed-force**
  **- Analysis of acceleration in frequency domain**



- **High frequency signals (500 - 2000 kHz):**
  **- Analysis of $AE_{raw}$-signal in frequency domain**
  **- Time-Frequency analysis of $AE_{raw}$-signal**

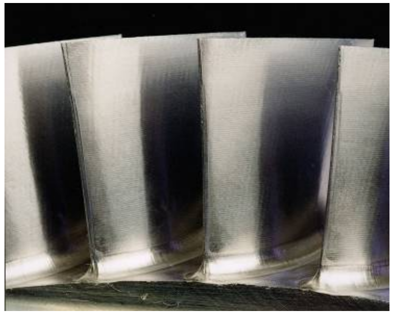


- **Additional analysis of work pieces and tools:**
  **- SEM (WP and tools)**
  **- Surface roughness measurements**
  **- Micro hardness measurements**



- **At WZL's lab:**
  **- Work piece oriented temperature measurements**

# Main Goals of the Project



**- PM-Strategy:**
Development of a position oriented process monitoring strategy for the selected material and process combinations

**- Data Basis:**
Creation of data basis of available monitoring systems on the free market and actual scientific work done in the area of process monitoring

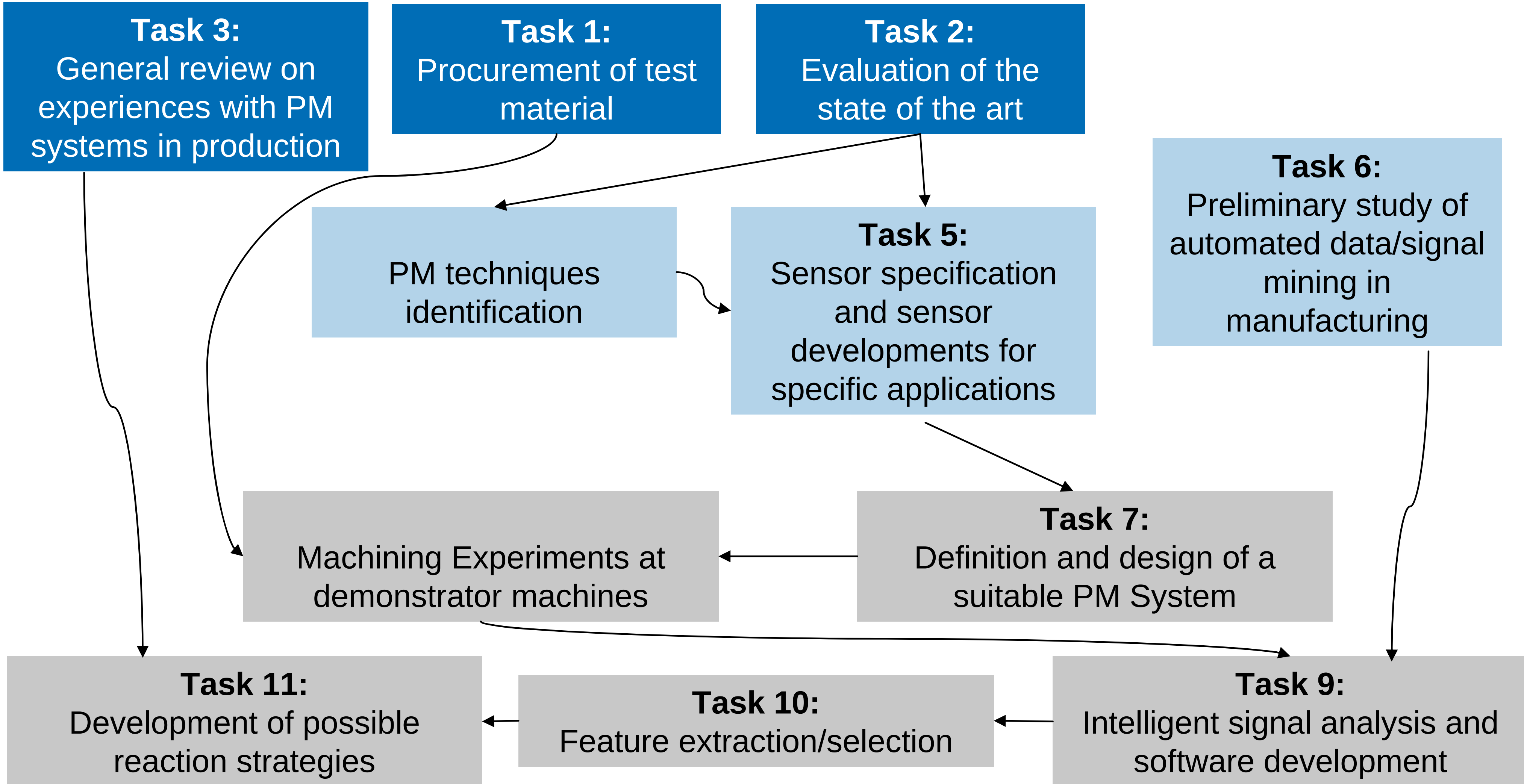
**- Software Tool:**
Development of a software tool for data aquisition of monitoring signals and feature extraction routines

**- Correlation** of identified anomalies to the determined signal pattern

**- Reaction strategies:**
development of possible reaction strategies and measures to be taken for saving time and waste during manufacture

# Scope of the Project

# Task Content and Interaction

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# Task Description

progress

**Task 1: Procurement of test material**

- Material will be used for machining tests/production of test pieces for hole making and broaching trials

**Task 2: Evaluation of state of the art**

- Review of PM techniques studied in MANHIRP project

**Task 3: General review on experiences with PM Systems in production**

- Survey of current knowledge about PM in OEM's shop floors
- Analysis of assessment and benefit in terms of quality, production, safety and human factors

# Task Description

progress

**Task 4: PM techniques identification**

- Definition of useful combination of sensor signals in order to detect anomalies and disturbances

**Task 5: Sensor specification and sensor development for specific applications**

- Specification and development of special sensors to enable surface monitoring system

**Task 6: Preliminary study of automated data/signal mining in manufacturing**

- Literature Study of data/signal mining for PM applications
- Literature Study on models describing measurements considered in the project

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# Task Description

progress

## Task 7: Definition and design of a suitable PM System

- Development of system with suitable sensors and database
- Qualification of sensor system
- Procurement of sensors and equipment

## Task 8: Machining experiments at the demonstrator machines

- Experiments based on DoE analysis

## Task 9: Intelligent signal analysis and software development

- Data collection from various PM sensors and conditions
- Time frequency and statistical analysis of signals in normal and abnormal mode
- Development of software tools based on LabView environment

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# Task Description

progress

## Task 10: Feature extraction/selection

- Find features of PM signals for reliable detection
- Perform analysis isolating the features that give reliable detection of an abnormal mode
- Optimise computational efficiency for high data rate measurements

## Task 11: Development of possible reaction strategies

- Elaboration of reactions strategies, e.g. immediate stop of machining process, reduction of cutting parameters, warnings

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# Risk Management



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# Identified Risks and Measures

| Risk | Action |
| --- | --- |
| No anomalies could be created during standard machining operations | Development of a anomaly creation procedure (analogy trials) which are inducing anomalies, similar to those which can occur during production |
| Machine tool availability is not big enough at the end-user sites as it was planned | Do fundamental analysis for system verification at the available machine tool at the WZL (hydraulic machine tool) on analogical set-ups |