FAA-Project on Process Monitoring

Dipl.-Ing. Dražen Veselovac

January 26th (West Palm Beach / FL)

Fraunhofer Institut Produktionstechnologie

WZL RWTHAACHEN

Gliederung

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Processmonitoring – Aims

- Detect failures / disturbances during the process
- Realise decision-making based on recorded process data
- Ensure a stable / acceptable product quality during the production process
- Document a „process image“ as a quality certificate

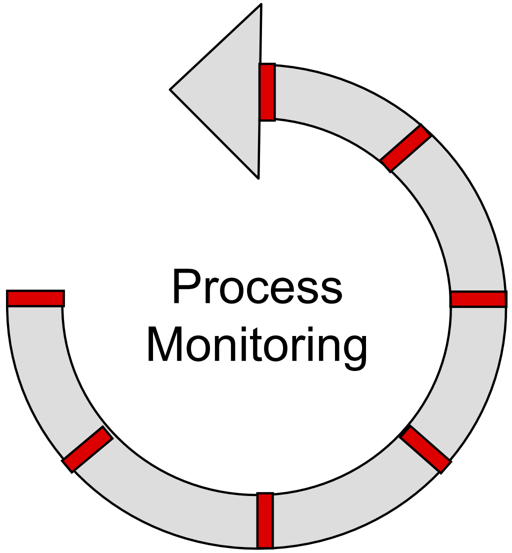
Process Monitoring - Strategy

Decision-making

- React on the process

Analyse and evaluate

- Signal processing
- Evaluate process-specific signal behaviour



Define aims and boundary conditions

- Quantitative and /or qualitative aims

Record status-quo

- Signal conditioning
- Record sensor signals

Describe process

- Define process specific key variables and parameters

Select measurement equipment

- Select and adapt hard-ware and measurement range to the process

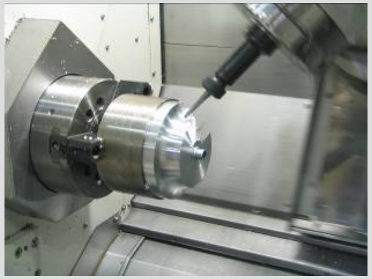
Inetgrate measurement equipment

- Mount sensors and measurement equipment to the machine tool

Description of the process

Manufacturing Process

mechanical, thermal and chemical processes



Process inputs

- Work-piece / material
- Tool / cutting material
- Machine Tool
- Environment

Process outputs

- Quality measures
- Change of the systems machine tool and tool
- Environment

Internal and external disturbances

- Tool wear
- Geometric and kinematic deviations
- NC-chain

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Selection of measurement equipment (sensor solution)

Which measures have to be detected? → *Force, temperature, displacement, …*

In which range does the measure occur? → *Choice of needed measurement range*

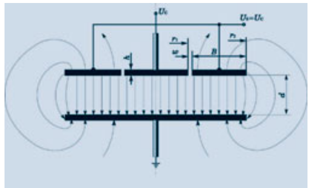
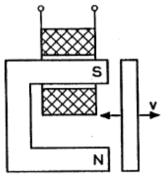
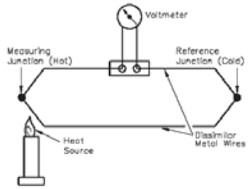
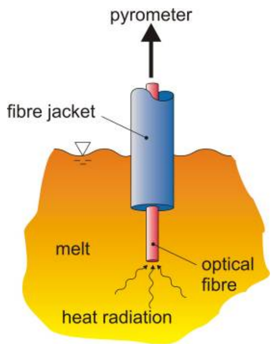
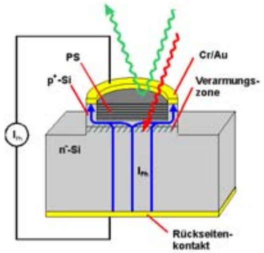
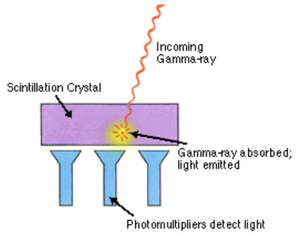
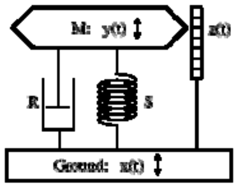
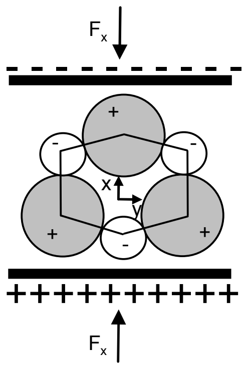
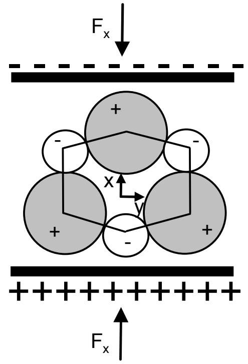
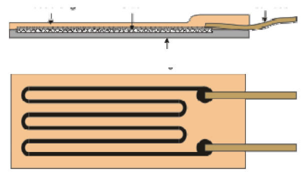
How big is the expected change of the measure due to the process? → *Termination fo needed sensors‘ sensitivity*

Selection of the sensor system → Integration into the process

Physical principles used by sensors

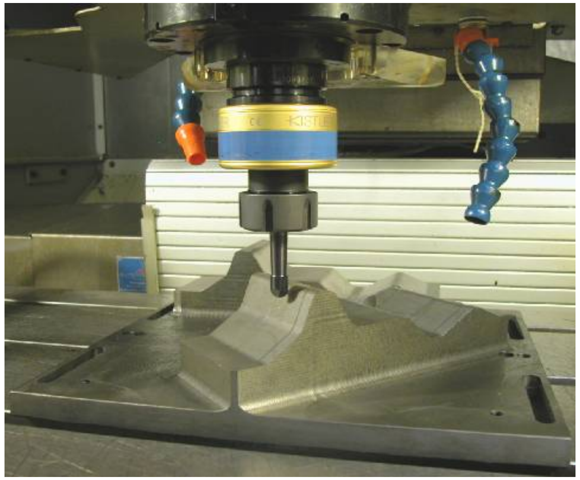
- **Mechanic** *(Movement, displacement, rigidity)*
  - Position
  - Acceleration
  - Velocity
  - Force
  - Torque
  - Stress and strain
  - Pressure, etc.
- **Thermal** *(kinetic energie of atoms and molecules)*
  - Temperature
  - Heat
  - Specific Heat
  - Thermal conductivity, etc.
- **Elektric** *(elektric field)*
  - Voltage
  - Current
  - Charge
  - Conductivity, etc.
- **Magnetic** *(magnetic field)*
  - Permeability
  - Magnetic Flux, etc.
- **Radiation** *(elektromagnetic radiation)*
  - Energy
  - Intensity
  - Emission
  - Reflection
  - Permeability, etc.
- **Chemical** *(Forces between atomic nuclei and elektrons, binding energy of molekules)*
  - Chemical components
  - Concentration, etc.

Typical measures and principles

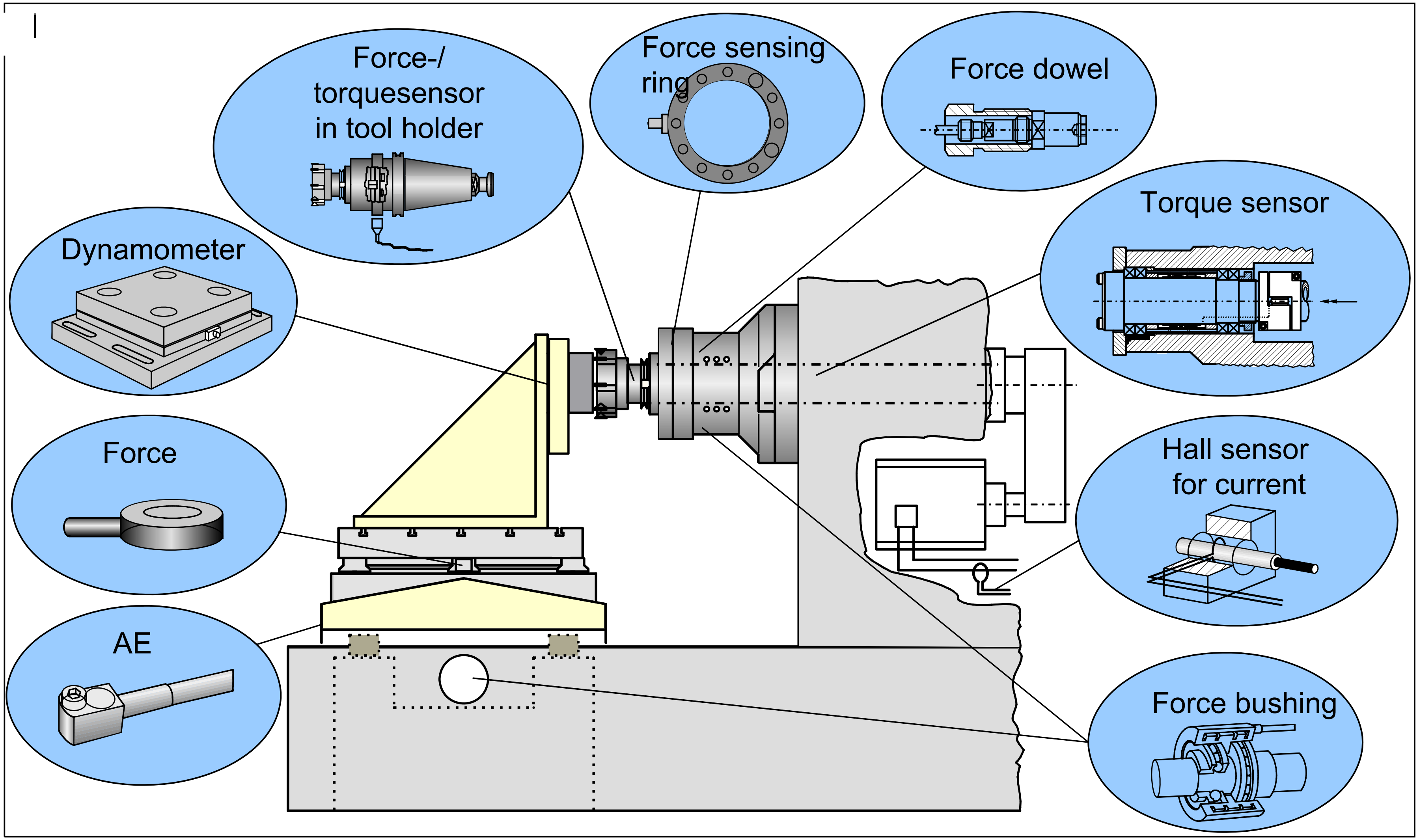
Stroke / distance	Temperature		Acceleration / Acoustic Emiss.	Force
El. resistance Capacity  Induktivity  Optical	Thermo-elektrical effect  Radiation (Pyrometer) 	Radiation (Photodiode/ CCD camera)  Scintillation 	Inertia  Piezoelektric effect 	Piezoelectric effect  El. resistance 

Most common in metal machining processes…

- Force
- Torque
- Effective power
- Temperature
- Acceleartion
- Acoustic Emission (AE)
- …



Examples for sensor application in machining processes



2.2.3: Definition of PM-System for Tool Life Testing and Failure Modes

Physical Process and Disturbance Measures → **Sensing Principles** → **Sensor Specifications** → **Sensor Mounting Restrictions** → **Possible Sensors**

OEM Description of Process Conditions

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

Sensing Principles of the Sensors

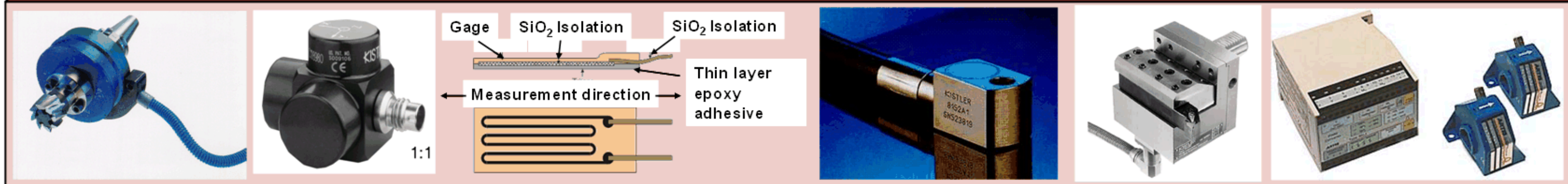
Ex.:
- hall effect
- strain gauge
- piezoelectric
- structure-borne sound
- ...

Specifications of the Sensor

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

Machine Test Rig Dependent

Ex.:
- workpiece handling
- number of axes
- mech. interfaces
- boundary conditions (lubricant, magn. fields, etc.)
- ...



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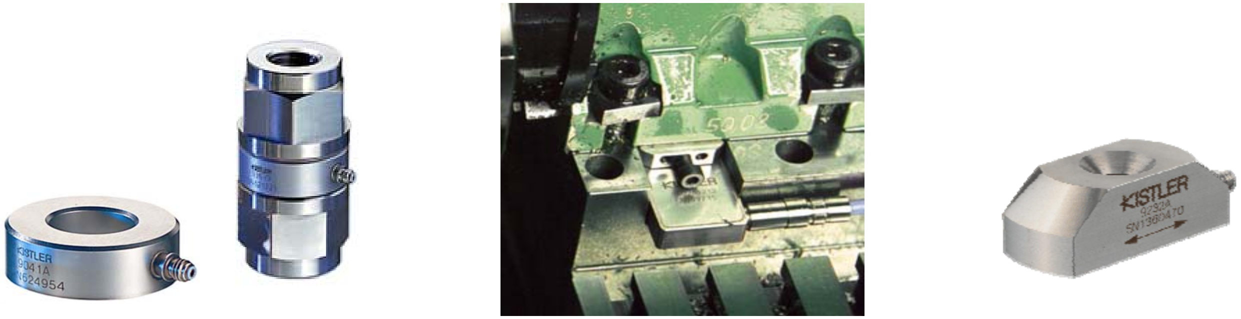
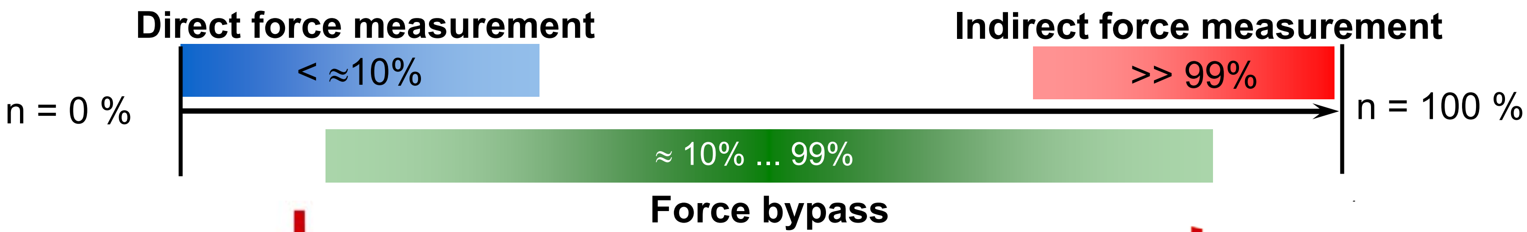
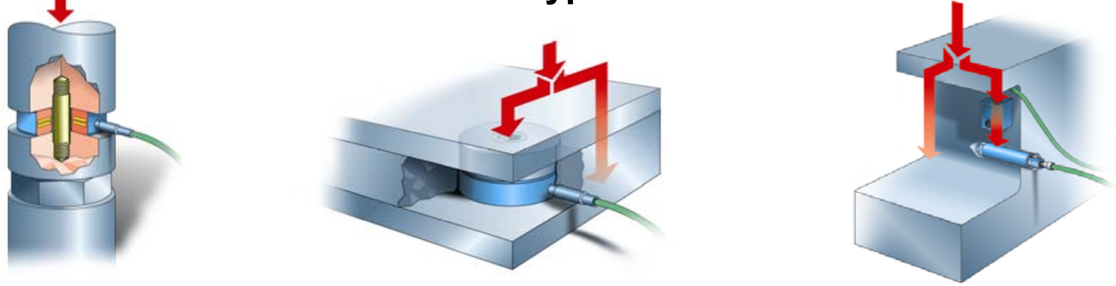
Measuring Process Variables

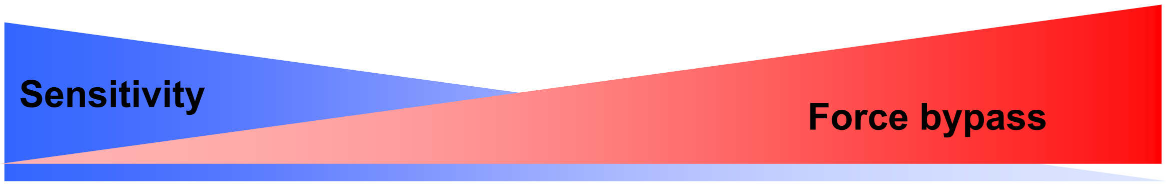
- Force & Torque (direct and indirect)
- Real Power
- Acceleration
- Acoustic Emission

Alternatives in measuring forces



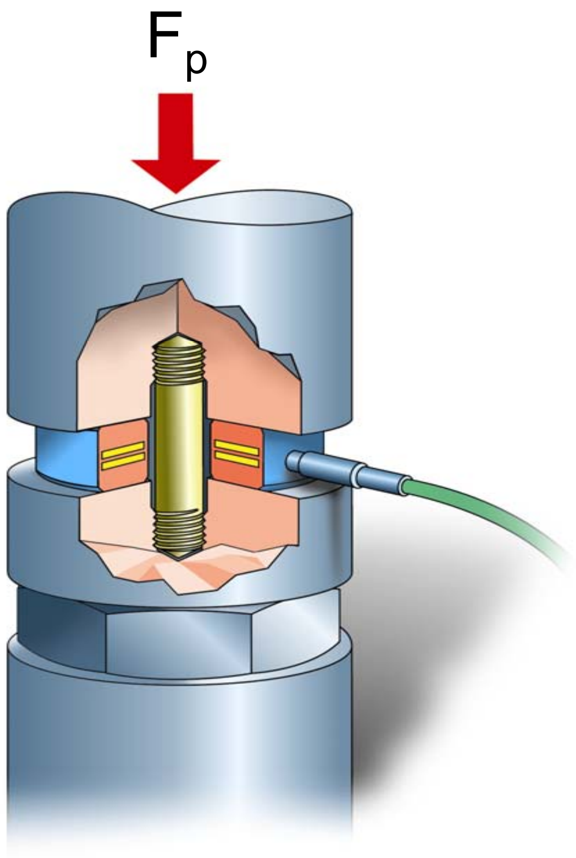






[Source: Kistler Instrumente AG]

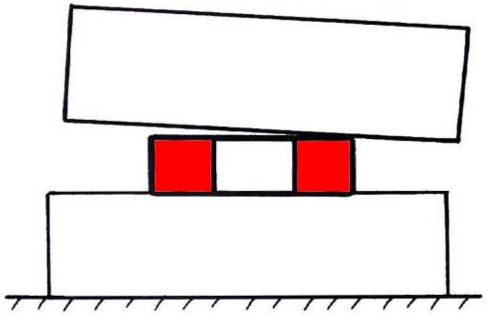
Force main flux



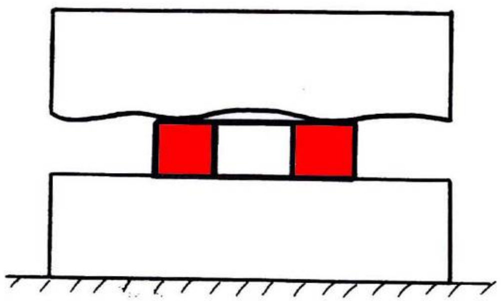
- Almost the entire force from the process goes into the sensor
- Little force-bypass-fraction due to preloaded elements (<10%)
- Sensor's measurement range > process force F_p
  Sensors: in-situ-calibration required
- Preloaded sensors: calibrated sensitivity with defined linearity & hysteresis
- Dynamometer: force signal independent from point of orgin (within spiezific limits)
- Integration in machine tool structure can be sophisticated

[Source: Kistler Instrumente AG]

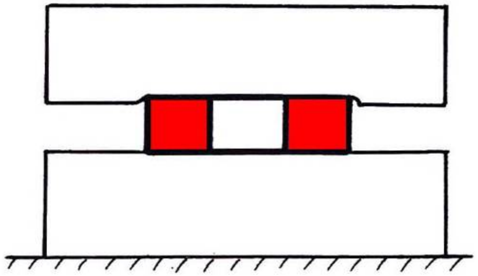
To be considered for integration into machine tool



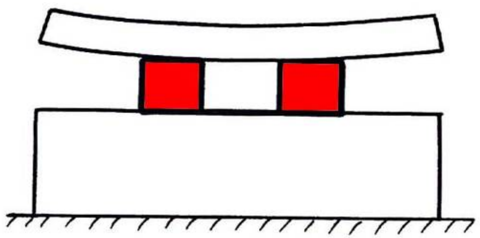
Parallelism



Flatness



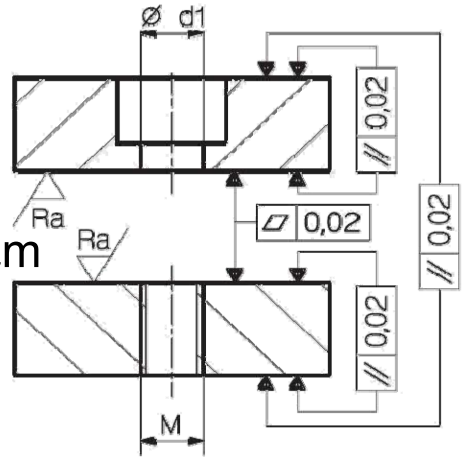
Stability



Deflection

Ground surface recommended

Ra 1,6 µm
(N7)



Max. tensile strength
150 N/mm² (or more)

Thickness of plates
> 2 · hight of sensor

[Source: Kistler Instrumente AG]

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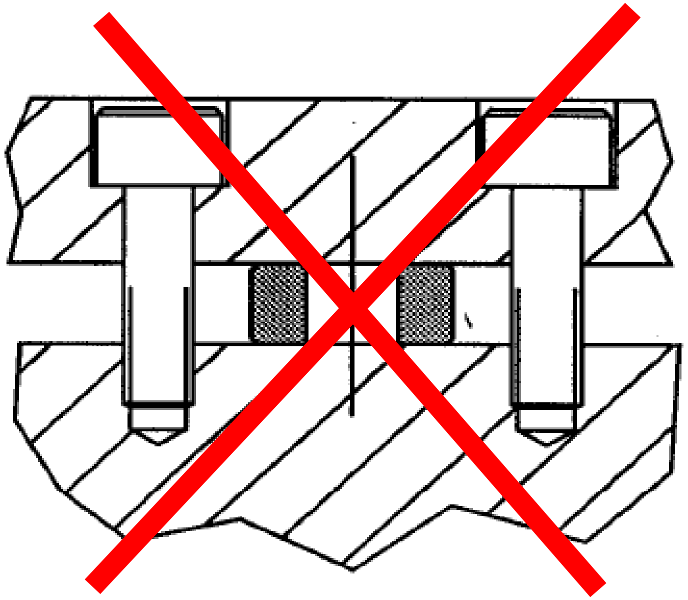
Sensor preload



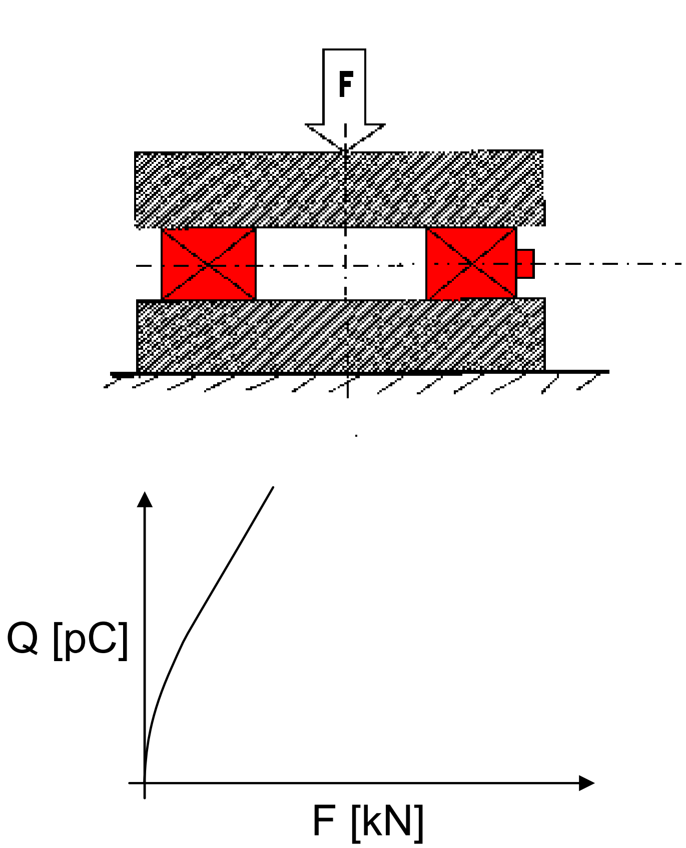
- Difficult to achieve an even distribution of the pre load over all bolts Bending moments
- Poor liniarity
- Risk: damage of Quartz-plates while tightening the bolts
- Lower sensitivity (more than in case of force bypass) than using a single bolt

Note: To be discussed in broaching: machine tool built in force sensor

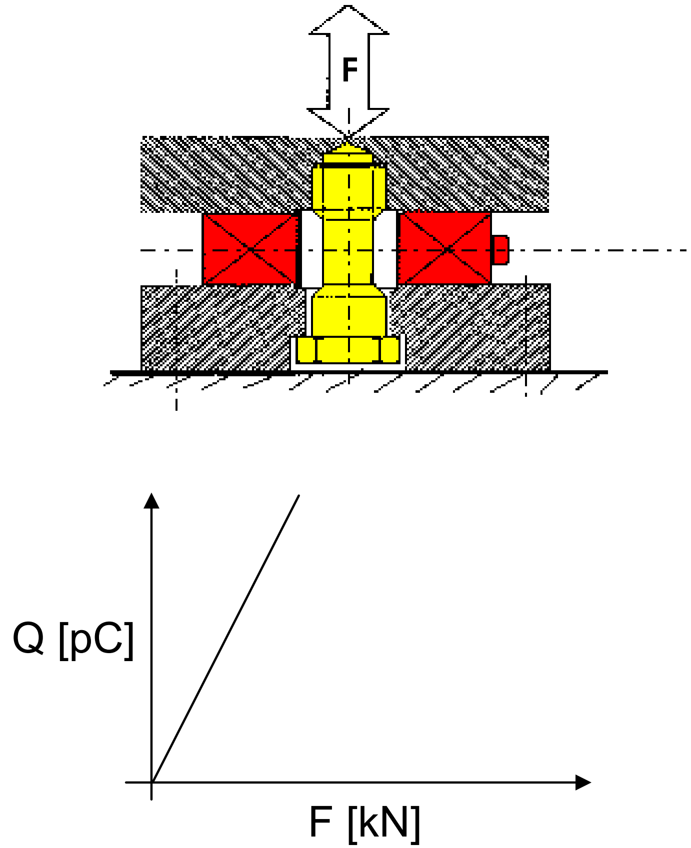
Better: Take pre-loaded calibrated system from a supplier!

[Source: Kistler Instrumente AG]

Pre-load improves measurement range's linearity



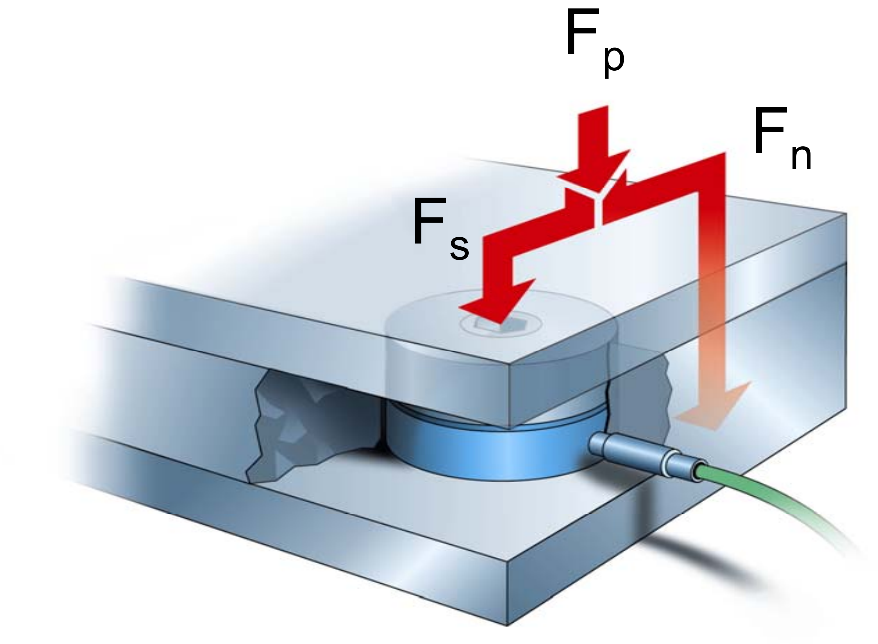
Installation without pre-load



Installation with pre-load

[Source: Kistler Instrumente AG]

Force bypass



F_p = Total processs force

F_n = Force bypass

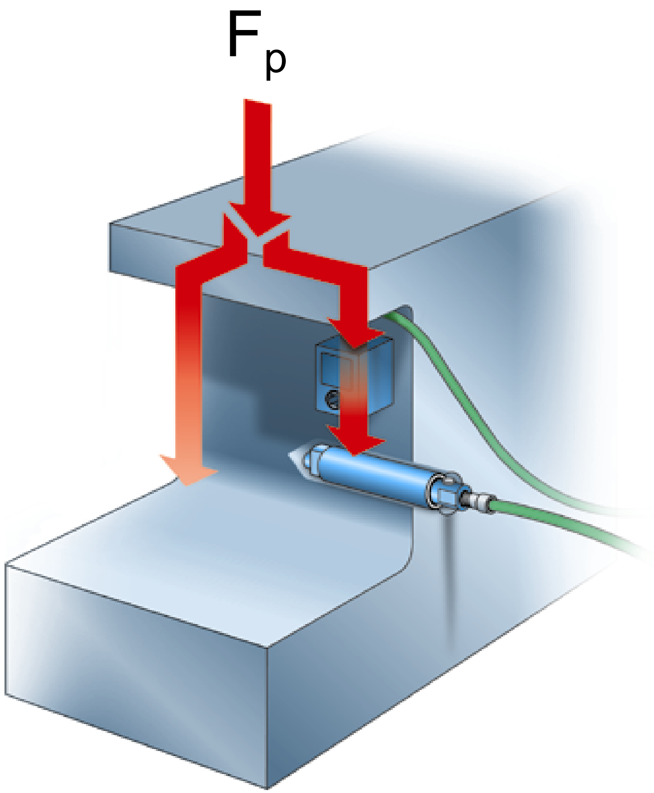
n = Force bypass (fraction of process force which <u>cannot</u> be measured by the sensor

$$n = \frac{F_n}{F_p} \cdot 100$$

- If the force‘s point of origin is not known, the actual force from the process cannot be determined

[Source: Kistler Instrumente AG]

Indirect force measurement



- Indirect force measurement by measuring structure‘s strain
- A negligible fraction of the process force goes through the sensor (n >> 99%)
- Measurement range > max. strain of the structure
- Force signal is dependent on point of origin
- Linearity and hysteresis are dependent from mounting location
- In-situ-calibration required

- <u>But:</u> very easy to mount!

[Source: Kistler Instrumente AG]

Force measurement – strain gages

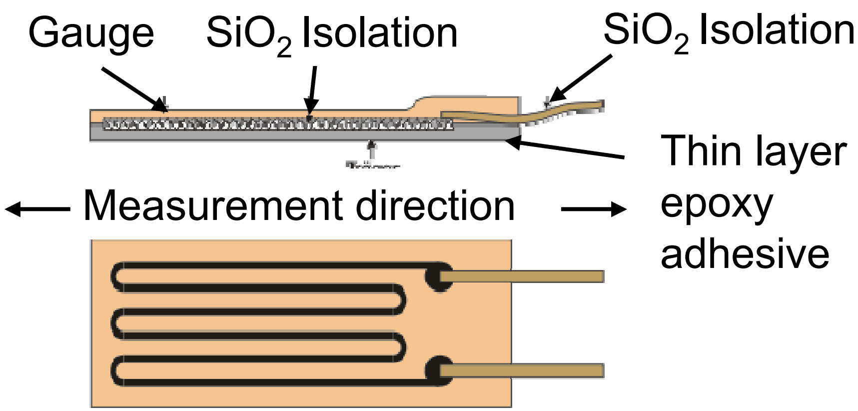
Torque & Force Measurement:

(by means of Strain Gauges)

- Suitable for static forces
- Relatively cheap

Disadvantages:

- Detected resistance is influenced by environmental temperature, material properties, bonding adhesive, etc.
- Dependent on strain and therefore on bending, torsion, POISSON, etc.
- Complex wiring

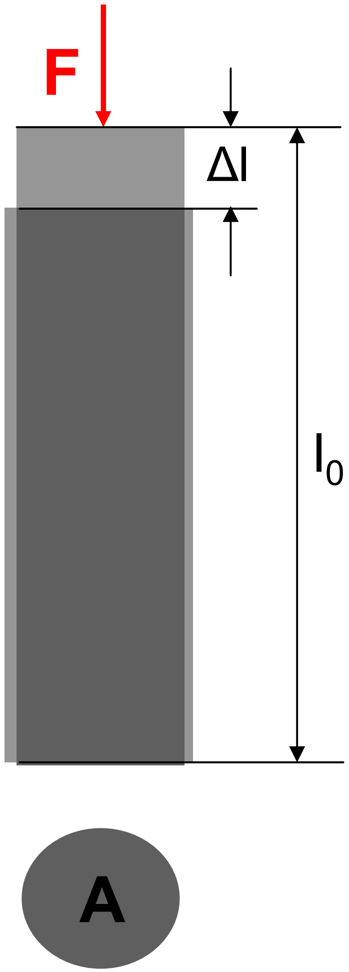


Stress $\sigma = \dfrac{F}{A} = E\varepsilon$

Strain $\varepsilon = \dfrac{\Delta L}{L}$

HOOKE‘s Laws

Length variation, stress and strain…



Stress $\sigma = \frac{F}{A}$ $\varepsilon = \frac{\Delta l}{l_0}$ Strain ε

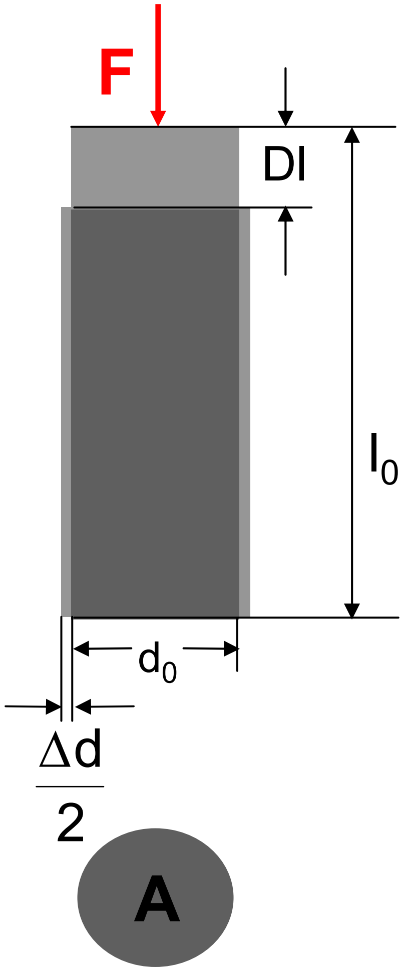
Hooke Law $\sigma = \varepsilon \cdot E$ ➡ $\frac{F}{A} = \frac{\Delta l}{l_0} \cdot E$

Length variation Δl $\Delta l = \frac{F \cdot l_0}{A \cdot E}$

Strain e $\varepsilon = \frac{F}{A \cdot E}$

Rigidity $c = \frac{F}{\Delta l} = \frac{A}{l_0} \cdot E$

Strain sensor



Longitudinal strain e

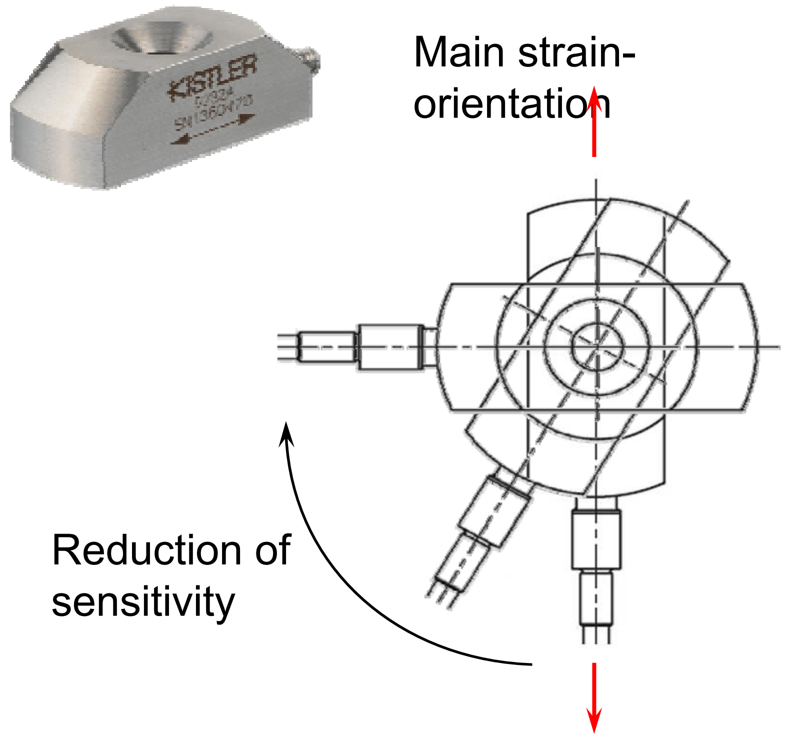
$$\varepsilon = \frac{\Delta l}{l_0} = \frac{F}{A \cdot E}$$

Transversal strain e_q

$$\varepsilon_q = \frac{\Delta d}{d_0}$$

Poisson ratio μ

$$\mu = \frac{\varepsilon_q}{\varepsilon}$$

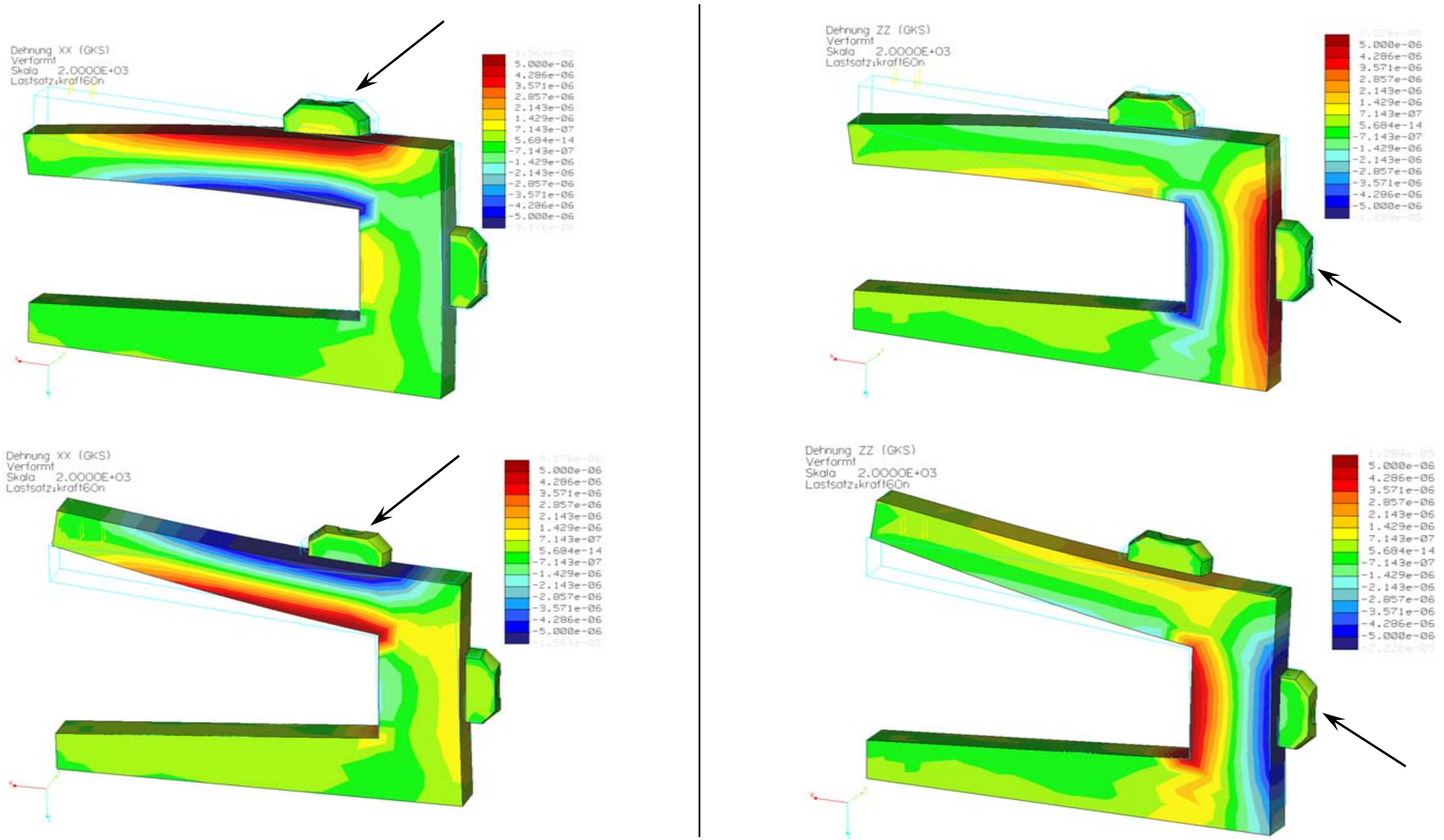


Typical values:

$1/\mu \approx 3 \ldots 4$ for steel

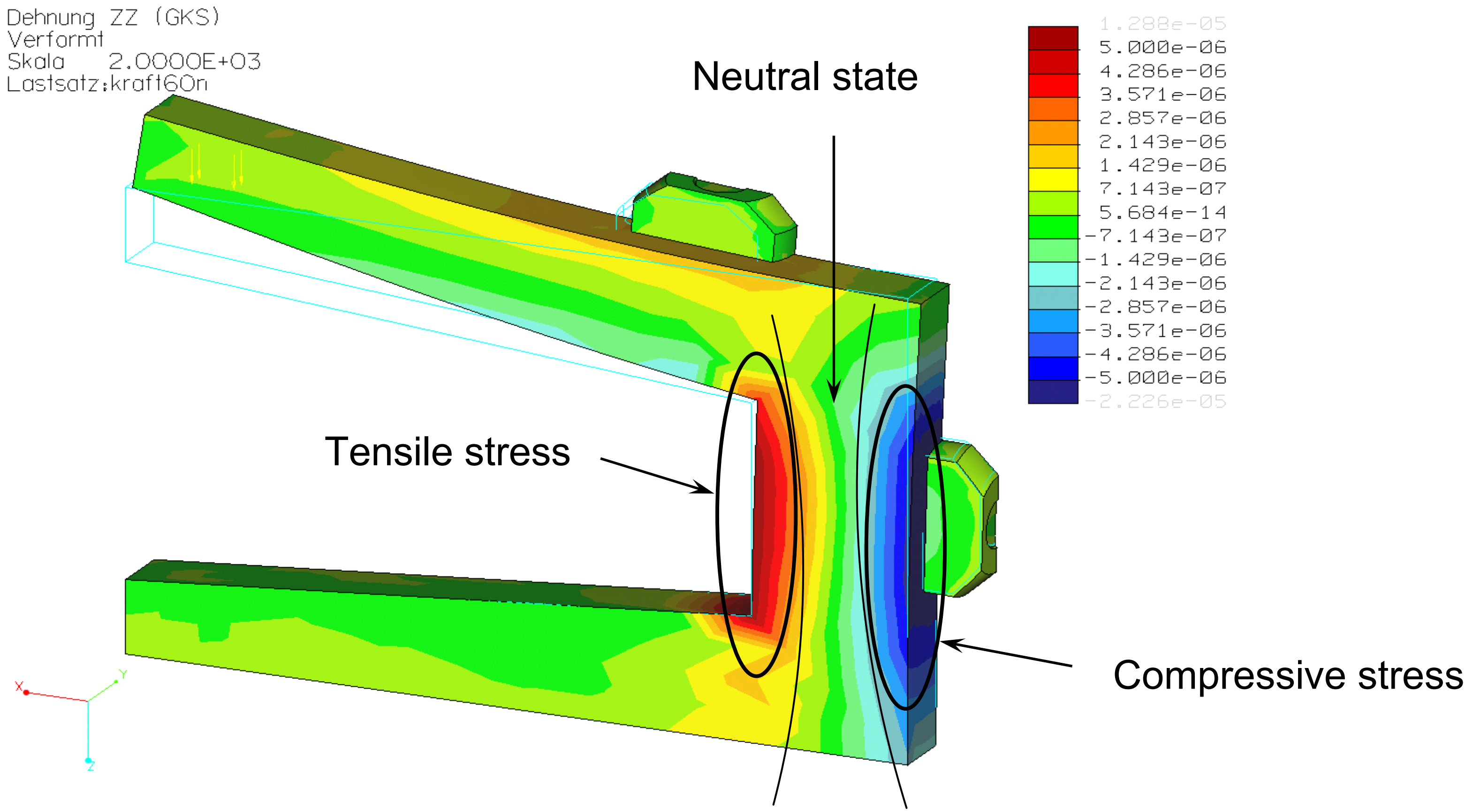
$1/\mu \approx 5 \ldots 9$ for cast iron

Assembly of a strain sensor



[Source: Kistler Instrumente AG]

Assembly of a strain sensor



[Source: Kistler Instrumente AG]

Pre-loaded piezoelectric systems

Torque & Force Measurement:

(by means of Piezoelectric Sensors)

- Suitable for quasi-static and dynamic forces up to high frequencies
- High resolution (e.g. >10mN in a range of 5 kN)
- High linearity, no measureable hysteresis
- High stiffness, only a few micrometer deflection under full load
- High natural frequency, very small intrinsic damping
- High CURIE-temperature (use up to 400 °C)
- Precise Information about the process (single cutting-edge entrances, …)

Disadvantages:

- No measurement of static forces
- Requirement for charge amplifier

3 Component Dynamometer

Rotating Multi-Component Dynamometer

Source: KISTLER

Measuring Process Variables

- Force & Torque (direct and indirect)
- True Power
- Acceleration
- Acoustic Emission

Effective power / true power

Power consumption of driving motor

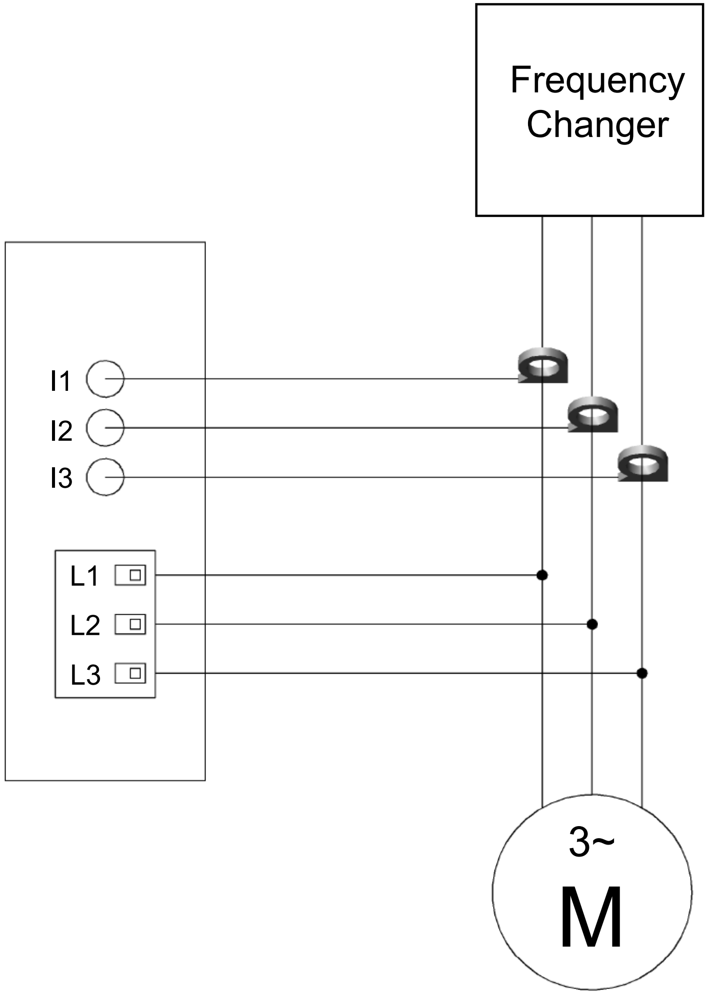
True power ~ Torque

Reactive power

$$P_w = \sqrt{3} \cdot U \cdot I \cdot \cos\phi$$

System properties:

- No change of process boundary conditions
- In most machine controls available as an internal signal
- Externally available as one-, two- and three phase system
- Limited dynamic behaviour
- Limited resolution

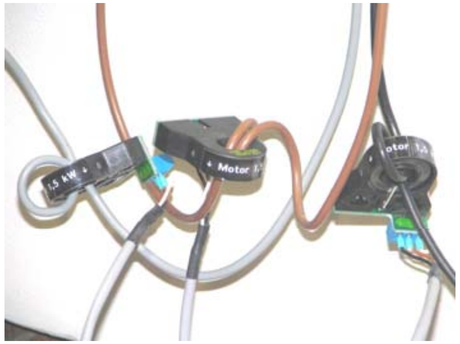


Example for implementation into machine tool

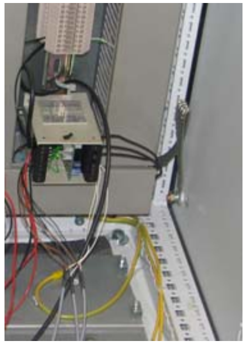
Gun-drilling machine tool, spindle power 3 kW

Drill, Ø 2 mm

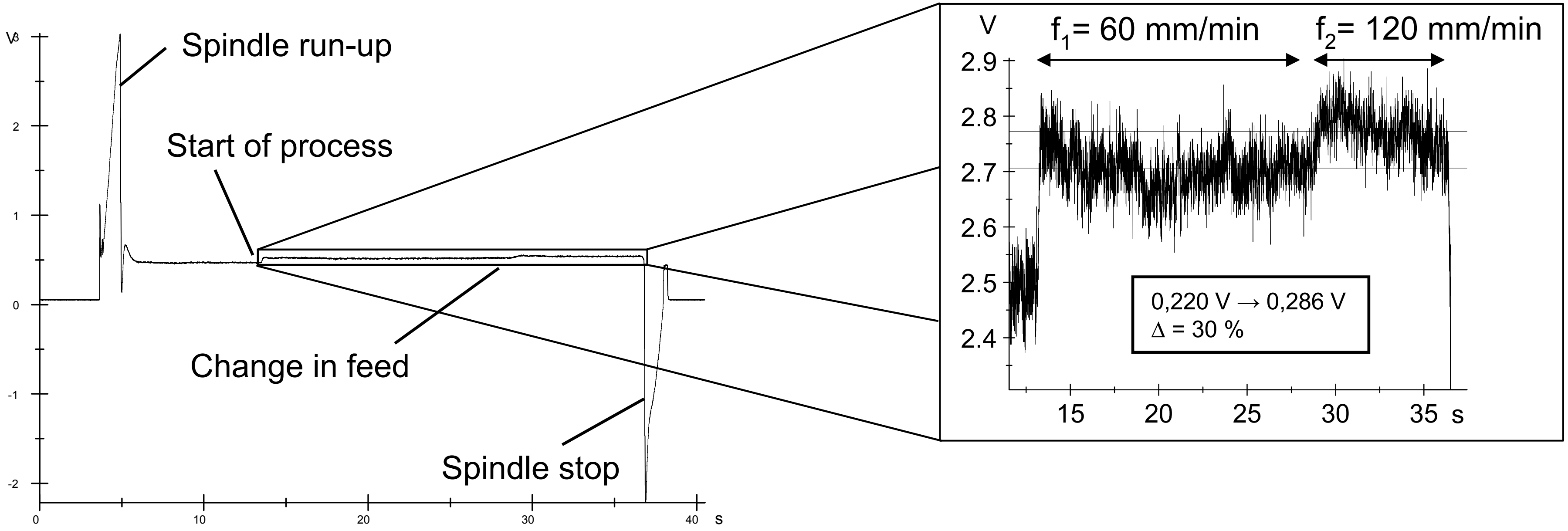
Feed: f_1= 60 mm/min, f_2= 120 mm/min



Hall sensors



Ext. Real power device



Gesamtprozess

Effective power - Evaluation

Power Measurement:

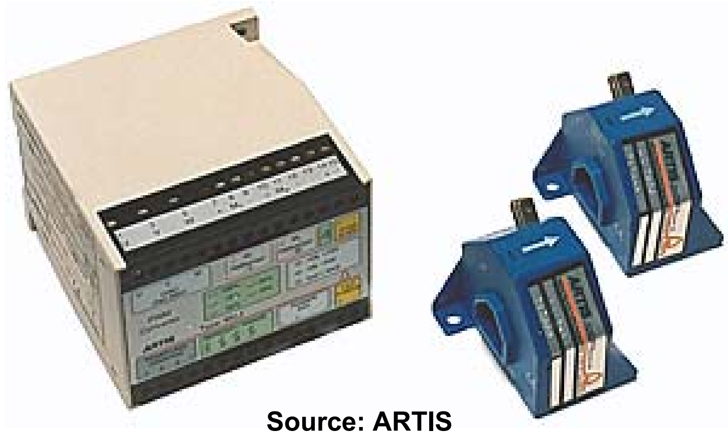
- Measures are current, voltage and the phase angle
- The actual *true power* is calculated
- The torque can be computed from the true power
- No devices in the machine‘s workroom

Disadvantages:

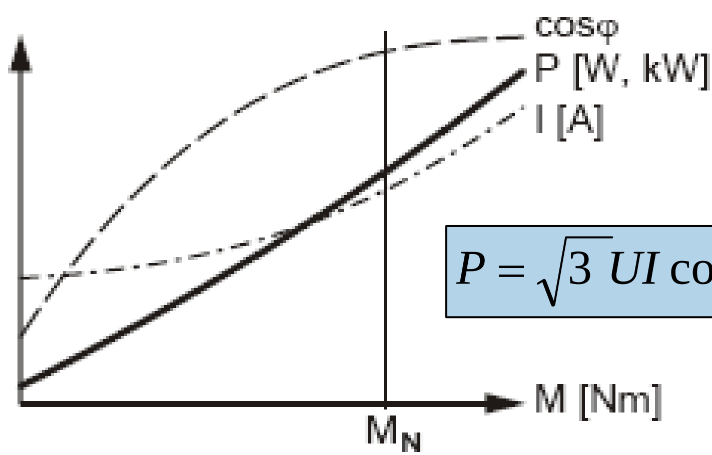
- The content of information in the signal abates with decreasing ratio between the power needed for the process and the machine power
- Signal-smoothing due to moments of inertia in the power train

Hall Transducer

Hall Sensors



Source: ARTIS



$$P = \sqrt{3}\ UI \cos\varphi$$

Measuring Process Variables

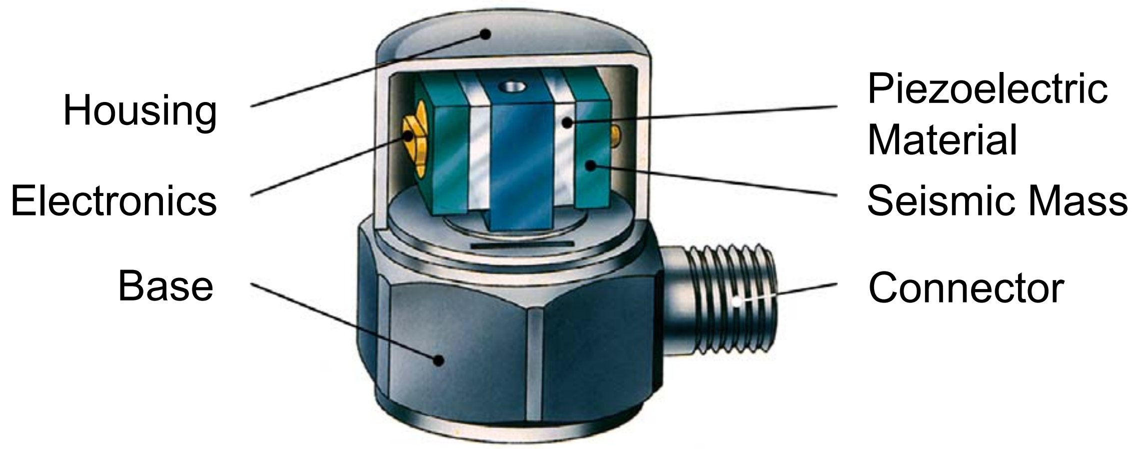
- Force & Torque (direct and indirect)
- Real Power
- Acceleration
- Acoustic Emission

Measuring acceleration

Vibration Measurement:

(by means of accelerometers)

- For static and dynamic measurements
- High linearity within the working-range (common 50 g 3-axis acceleromters to 5 kHz, special variants to 25 kHz)
- Velocity and displacement can be calculated by integration of the acceleration signal
- In case the vibrating mass is known the force can be calculated with the aid of NEWTON‘s law



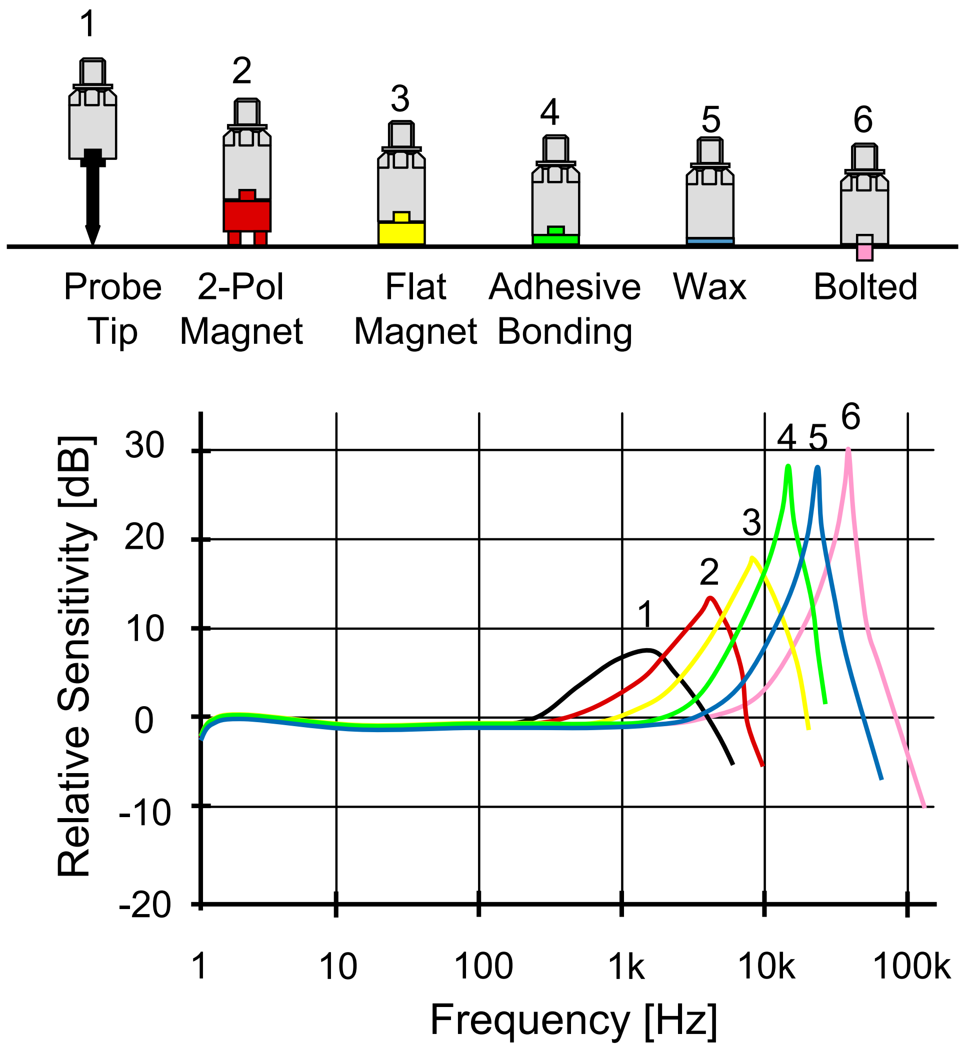
Disadvantages:

- No measurement of static forces
- Quality of calculated velocity and displacement is strongly dependent on the quality of the measured acceleration signal
- In complex systems the vibrating masses are difficult to determine

Modes of attachment to the structure

Vibration Measurement:

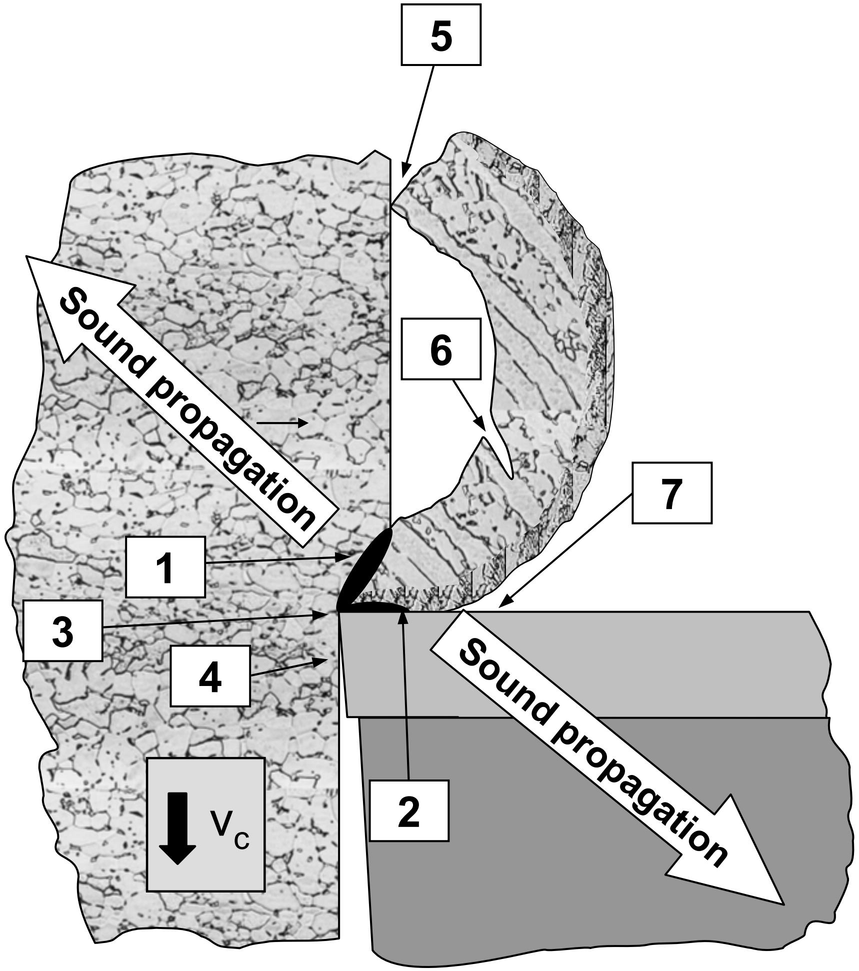
- In order to get a good signal quality the sensor has to be mounted as close to the tool-workpiece interface as possible
- The installation mode has a significant impact on the signal quality
- All parts close to the sensor should be well clamped (loose parts can vibrate and influence the signal)
- For the analysis it is helpful to know the natural frequency of the adjacent parts



Measuring Process Variables

- Force & Torque (direct and indirect)
- Real Power
- Acceleration
- Acoustic Emission

Causes for Acoustic Emission



1 Plastic Deformation in the shere-plane

2 Friction between chip and tool surface

3 Crack formation and crack progress

4 Friction between tool and workpiece

5 Impact of a chip on the tool or workpiece

6 Chip rupture

7 Friction by impact of the chip on the tool surface

2.2.3: Definition of PM-System for Tool Life Testing and Failure Modes

<u>Acoustic Emission Measurement</u>:

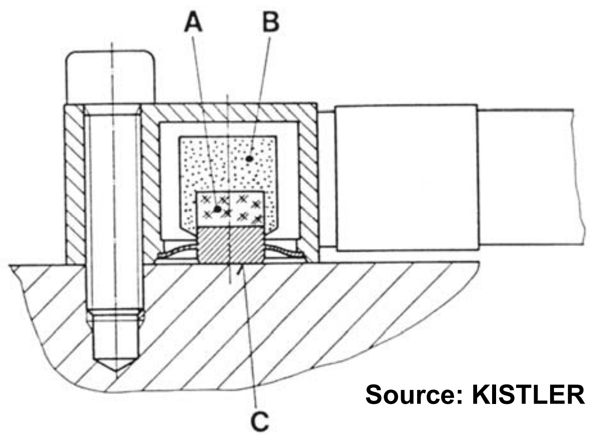
(by means of piezoelectric AE-sensors)

- Common range of detection: 50 - 500 kHz (high- and low-pass filter can be selected in advance)
- Generation of RMS (<u>R</u>oot <u>M</u>ean <u>S</u>quare) signal in order to keep the sample rate in a reasonable range
- Adjustable time-constant for the RMS-generation
- Detection of high frequent short-time events (such as fracture of tools or brittle material etc.)

<u>Disadvantages:</u>

- No suitable calibration method – only signal characteristics can be investigated

A - Piezoceramic Cylinder
B - Tungsten Powder
C - Sensor Diaphragm

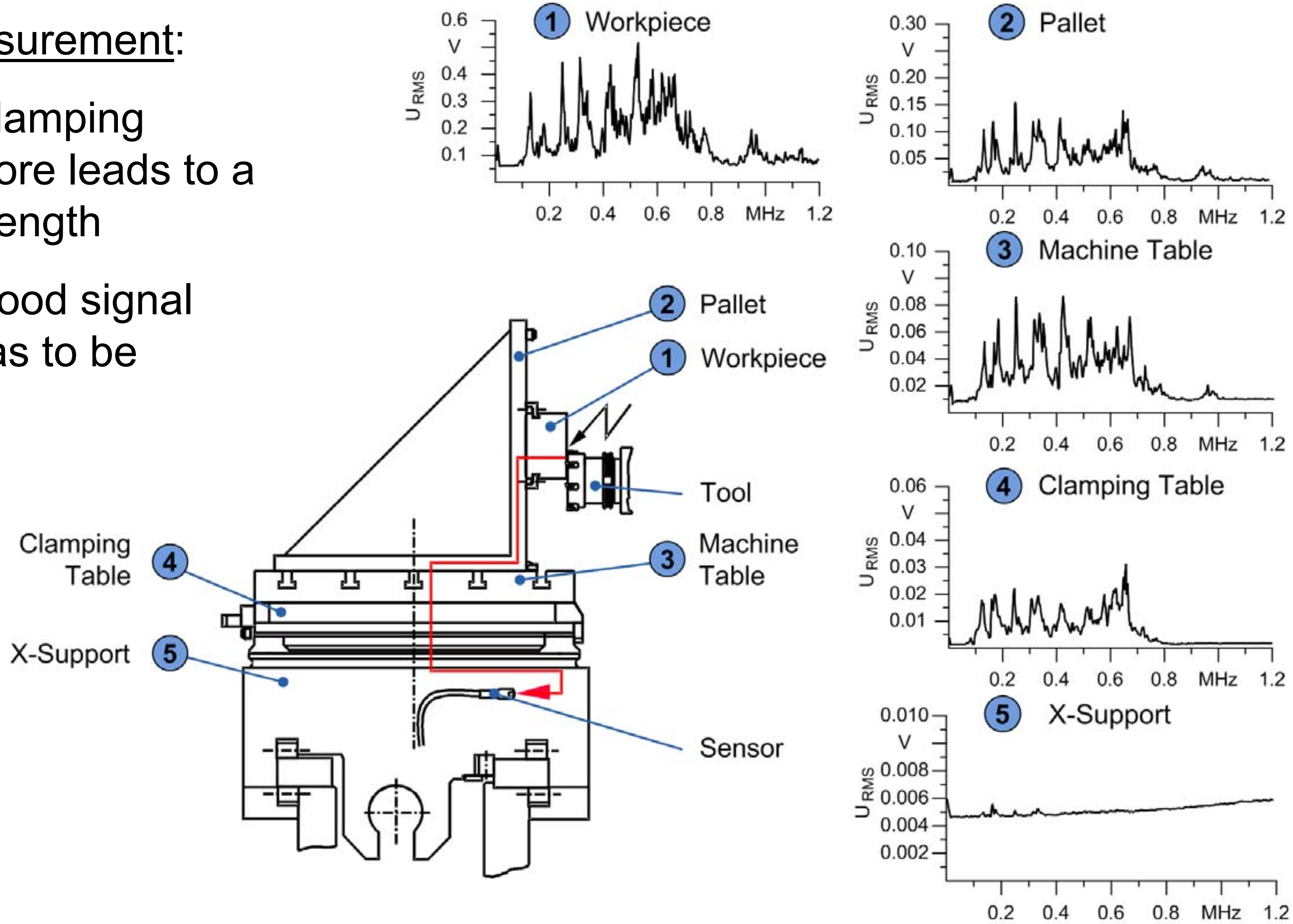


Source: KISTLER

2.2.3: Definition of PM-System for Tool Life Testing and Failure Modes

Acoustic Emission Measurement:

- Any interface has a damping behaviour and therefore leads to a decreasing signal strength
- In order to obtain a good signal quality, the sensor has to be mounted as close to the tool-workpiece interface as possible



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Application: Drilling

<u>Hole Making:</u>

- *Spindle Power* correlates with tool-wear and is capable to detect breakage or chipping (process/machine power-ratio!)
- *Vibration Signal* detects collisions, breakage, chipping and wear
- *Acoustic Emission Signal* is able to identify high frequent, short-time events such as chipping, small tool break-outs
- *Force-* and *Torque Signals* acquired by means of dynamometers provide detailed information about the process such as the precise feed force and torque at the drill apart from smoothing effects caused by the power train

- Dynamometers can only be used within the lab trials – no use under normal production conditions

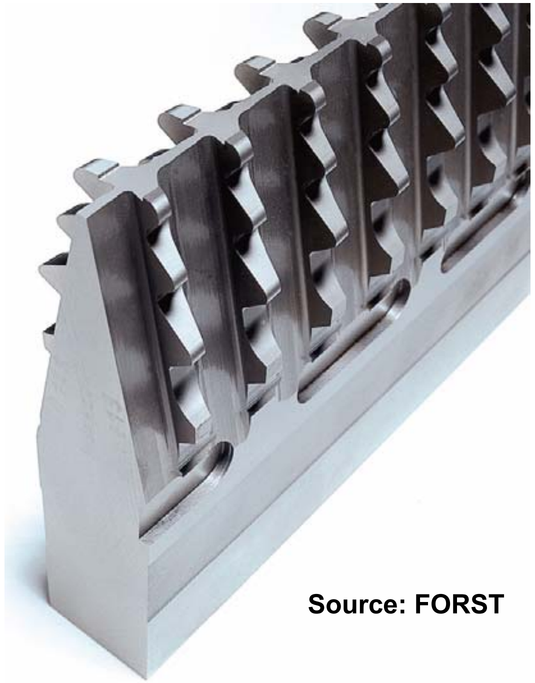
  → Loss of stiffness

Application: Broaching

Broaching:

- *Spindle Power* for the correlation between stroke force and thus tool wear
- *Vibration Signal* for detection of collisions, breakage, chipping and wear
- *Acoustic Emission Signal* for detection of clamped chips in the chip-space between the single teeth

  → Has not been investigated, yet



Source: FORST

- Dynamometers can be used within the lab trials in order to measure the real forces occurring and to calibrate the correlating spindle power – no use under normal production conditions

  → Loss of stiffness

Gliederung

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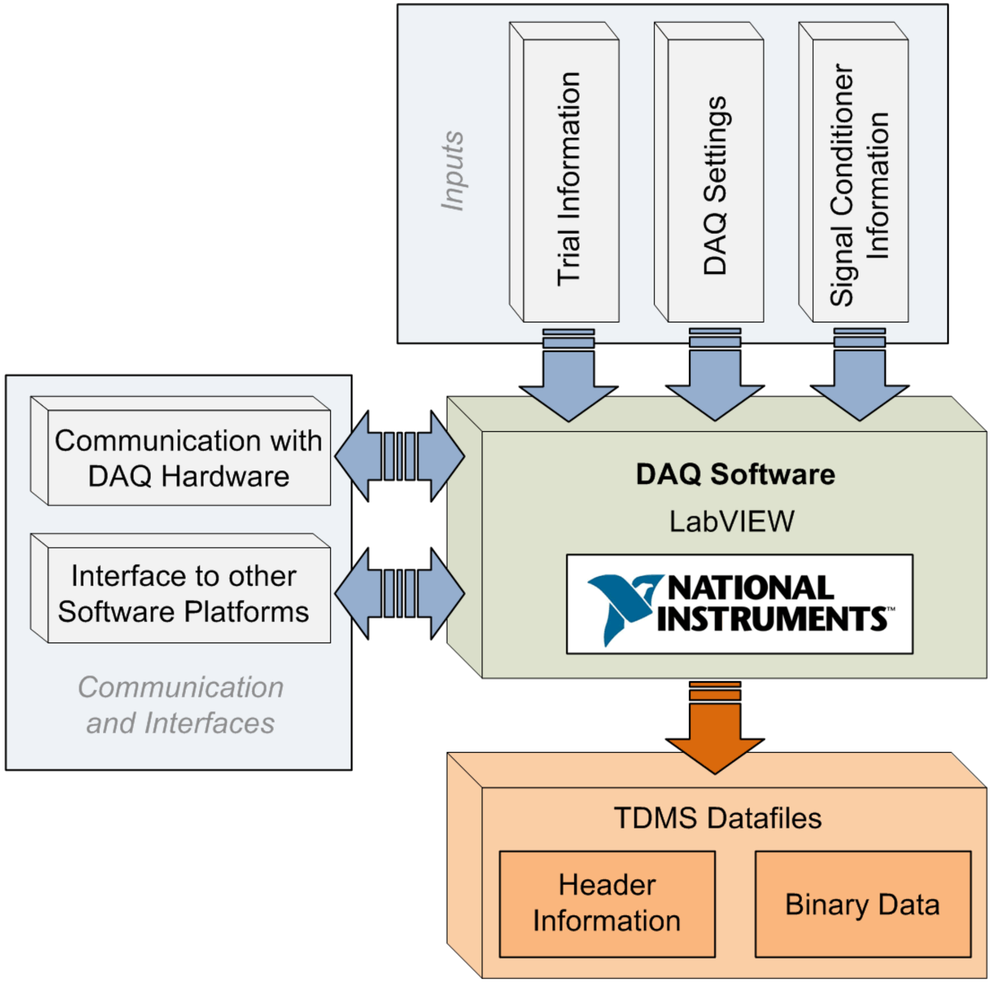
Software Structure Model

Introduction to the Software Model:

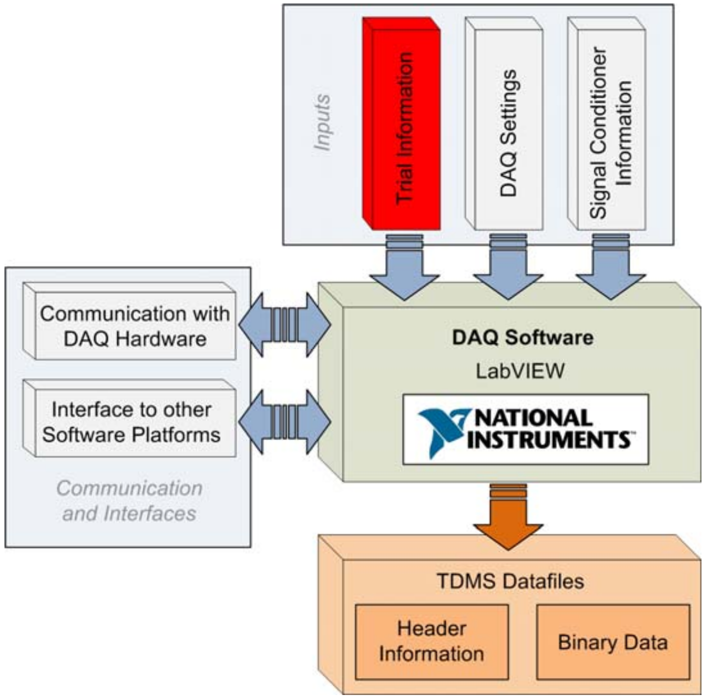
- Inputs to the software contain information about the trials, the data acquisition settings as well as information about the signal conditioners
- The software has interfaces in order to communicate with the data acquisition hardware and is able to run on other software platforms
- The output are binary TDMS-data files that provide the input information in the header



Trial Information

Trial Information:

- All information about the certain trial, e.g.
  - Process
    - Drilling
  - Material: Inconel718
  - Parameters
    - Cutting Speed
    - Feed
  - Tool
    - Solid Carbide
    - Coating
  - Lubricant
    - Specification
    - High Pressure Cooling
  - …

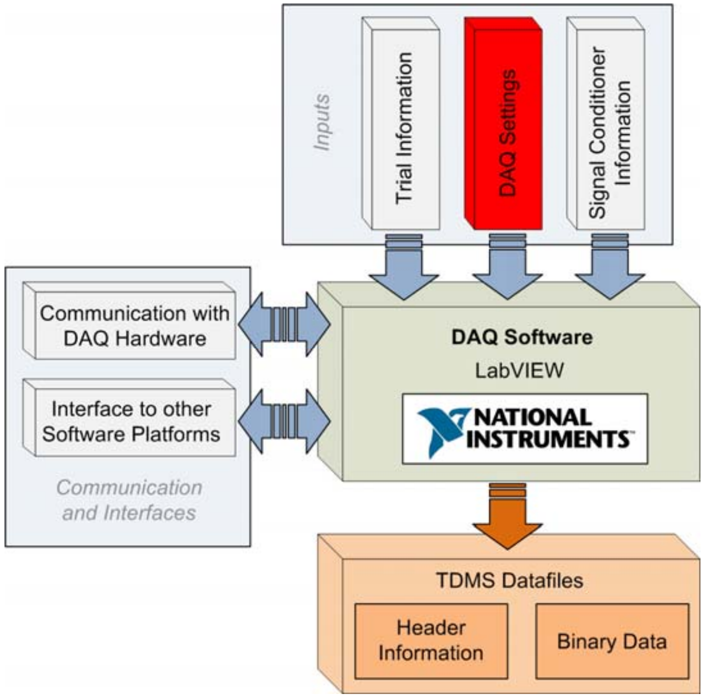


- Trial information has to be standardised in order to guarantee exchangability among project partners

DAQ Settings

DAQ Settings:

- Data acquisition settings for the trial, e.g.
  - Channel 1: Spindle Power
    - Type: ARTIS MU4
    - Sample Rate: 25 kHz
    - Range: +/- 10 Volt
  - …
  - Channel 3: Acoustic Emission
    - Type: Kistler
    - Sample Rate: 25 kHz
    - Range: +/- 5 Volt
  - …

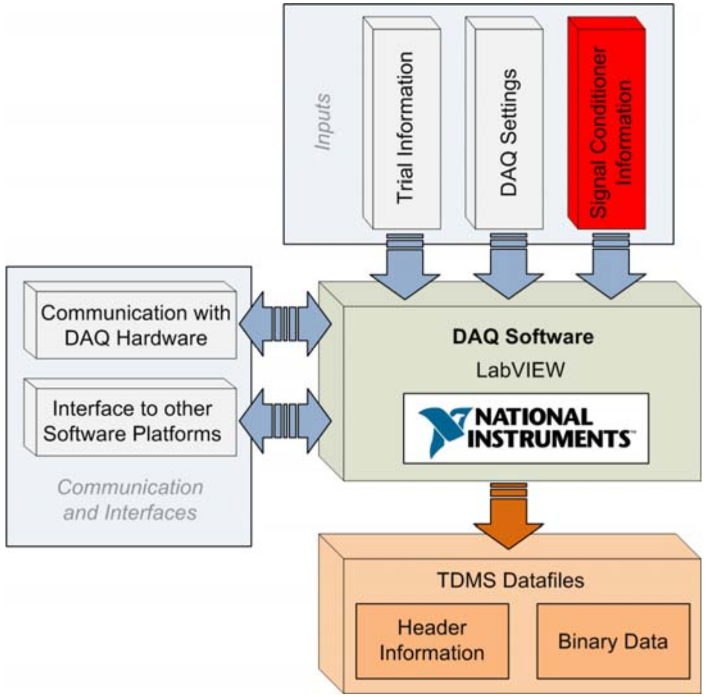


- Trial information has to be *standardised regarding its features as well as its order* for all trials done within the project → monitoring equipment used has to be determined
- Predefined settings are directly applied for the trial

Signal Conditioner Settings

<u>Signal Conditioner Settings</u>:

- All adjustments and setting that have been made at the signal conditioners, e.g.
  - Channel 1: Spindle Power
    - Type: ARTIS MU4
    - Number of Coils: 2
    - Smoothing Factor: 3
  - Channel 2: 3-Comp. Force Dynamometer
    - Type: KISTLER Charge Amplifier
    - Amplification Level: 2
  - Channel 3: Acoustic Emission
    - Low-Pass: 500 kHz
    - High-Pass: 50 kHz
    - Tao_RMS: 0.012 ms
  - …

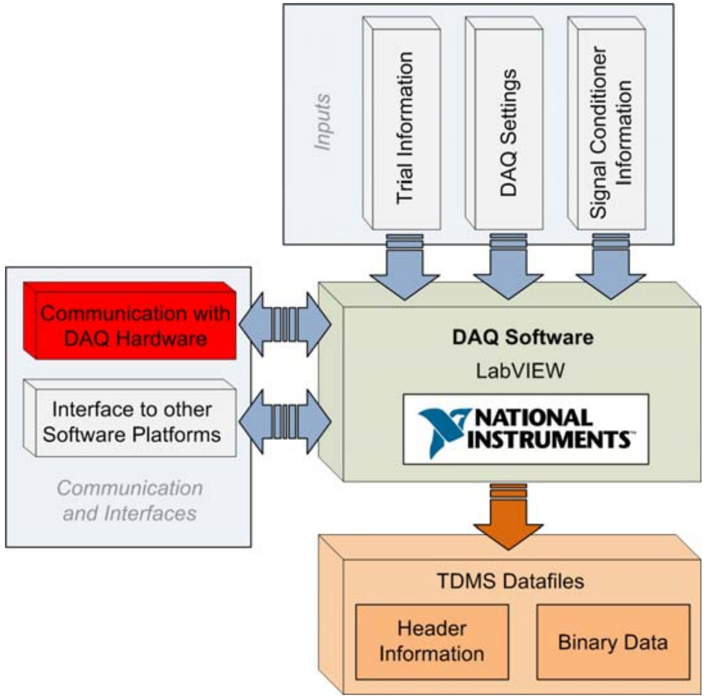


- Trial information has to be standardised in order to guarantee exchangability among project partners

Communication with DAQ Hardware

Communication with DAQ Hardware:

- The software is supposed to have standardised interfaces to hardware components
- Note: the resolution, sample rate for each channel as well as the total sample rate achieved is dependent on the hardware used

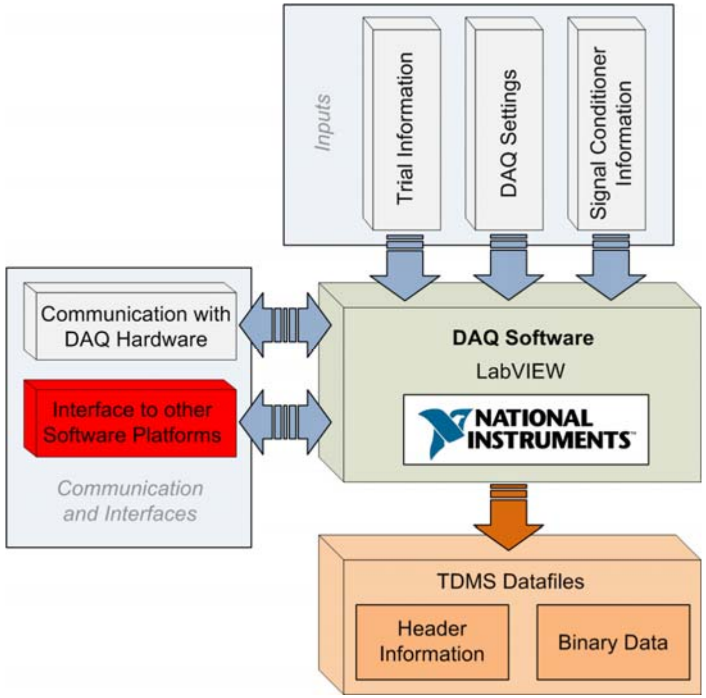


Interface to other Software Platforms

Interface to other Software Platforms:

- The software is based on NATIONAL INSTRUMENTS LabVIEW and can be included into any other platform capable of dealing with dll-libraries

  → in case data has to be edited using other software solutions: the programmed SubVI's (VI: Virtual Instrument) run within the dll-supporting software such as MatLab etc.



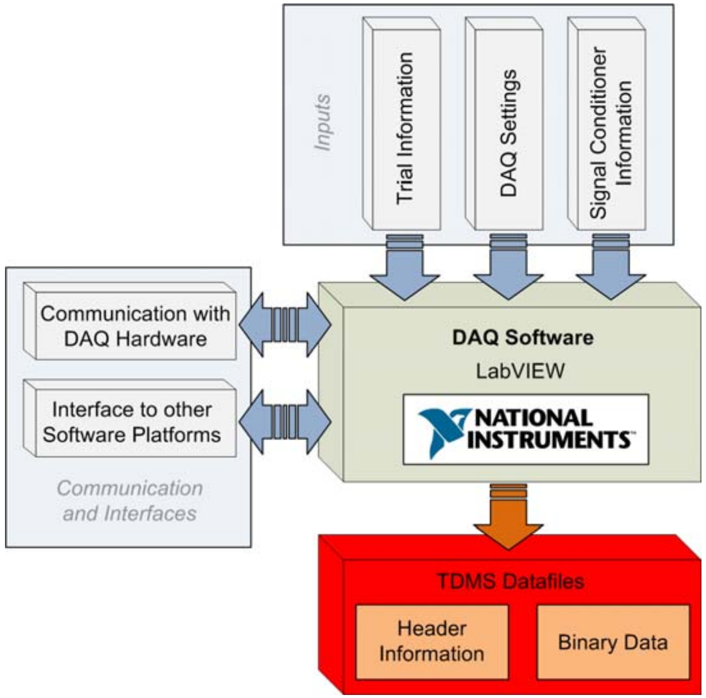
TDMS Data Files

<u>The TDMS Data Files</u>:

- The TDMS data file format provides the opportunity to create binary files

  → Advantage: small file size

- If needed, the data can easily be converted into ASCII-code
- The data files contain two parts of information:
  - HEADER: all input information
  - DATA: the measurement data



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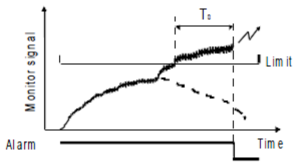
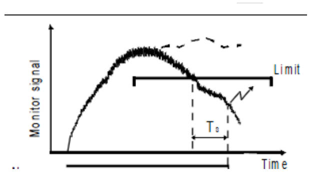
Overview Current PM Strategies

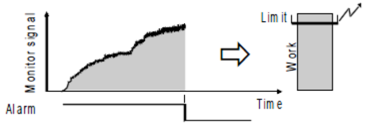
■ Overload



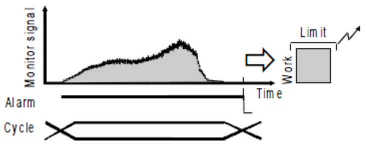
■ Underload



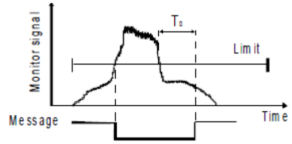
■ Work Over



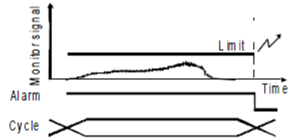
■ Work Under



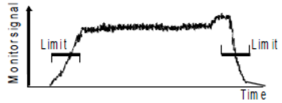
■ Contact



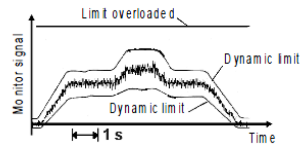
■ Missing



■ Rising Through/Falling Through



■ Dynamic Limits



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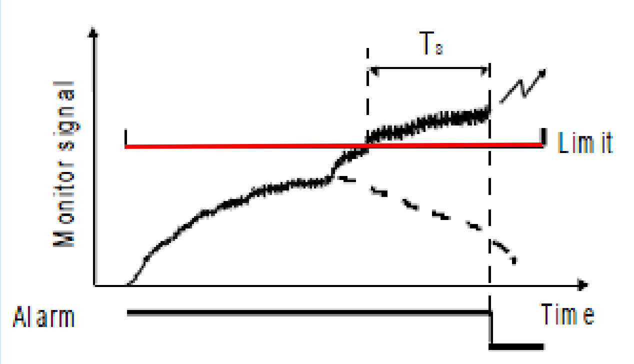
RWTH AACHEN

Limit Type: Overload



- Alarm when limit is exceeded for response time T_s at least

Limit Type Description

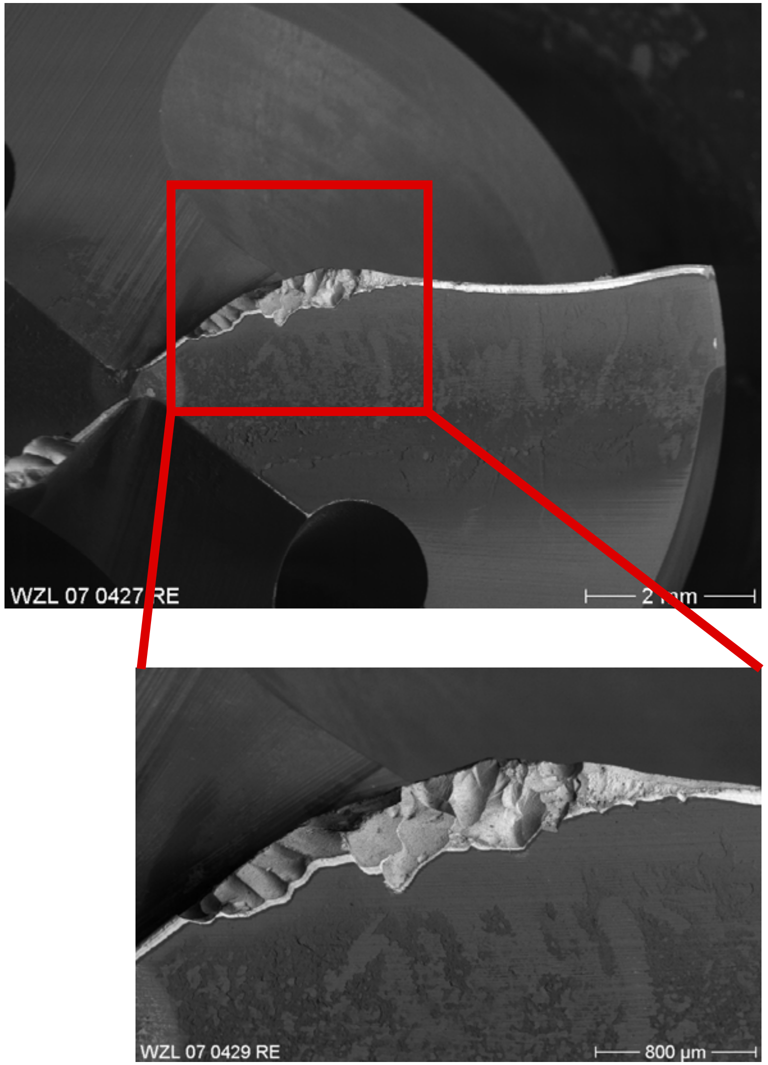
Examples

Steeply rising monitor signal, eg in case of:

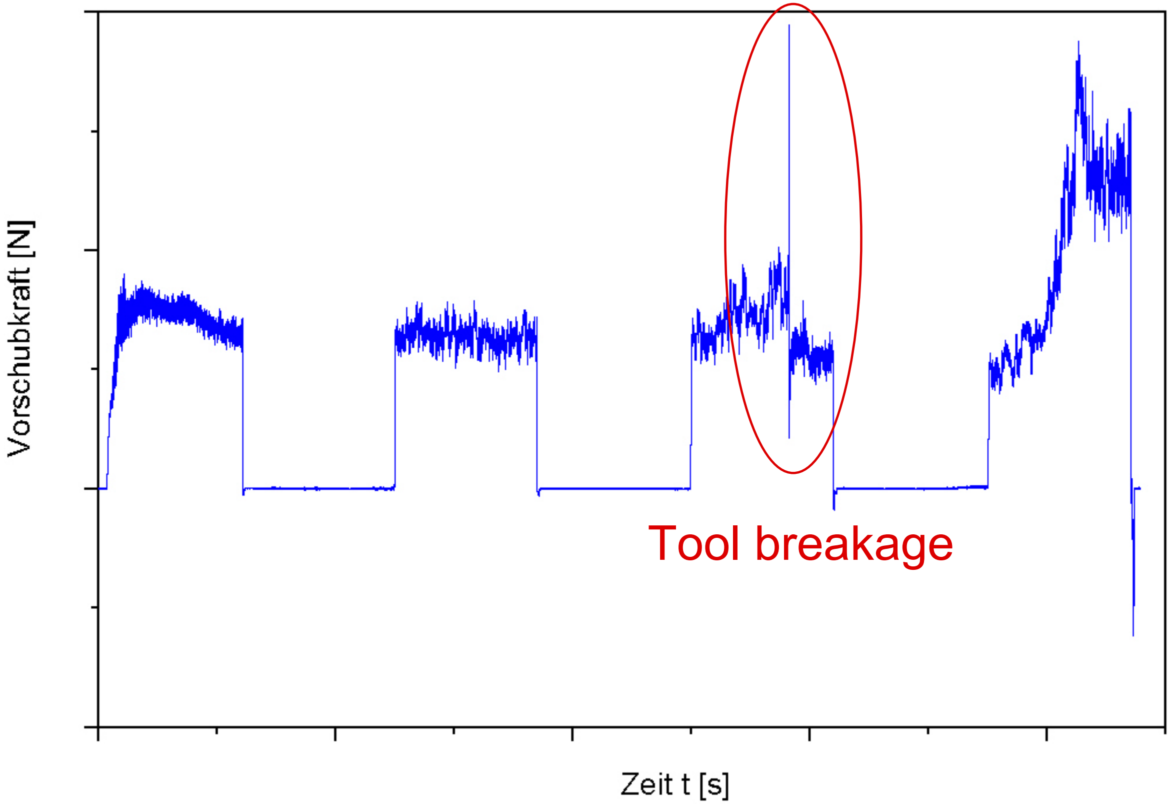
- tool breakage
- tool or machine overload (e.g. excessively large parts or operating error on machine
- machine collision

Source: Prometec

Detection of tool breakage



Identification of a tool breakage in the recorded feed force signal



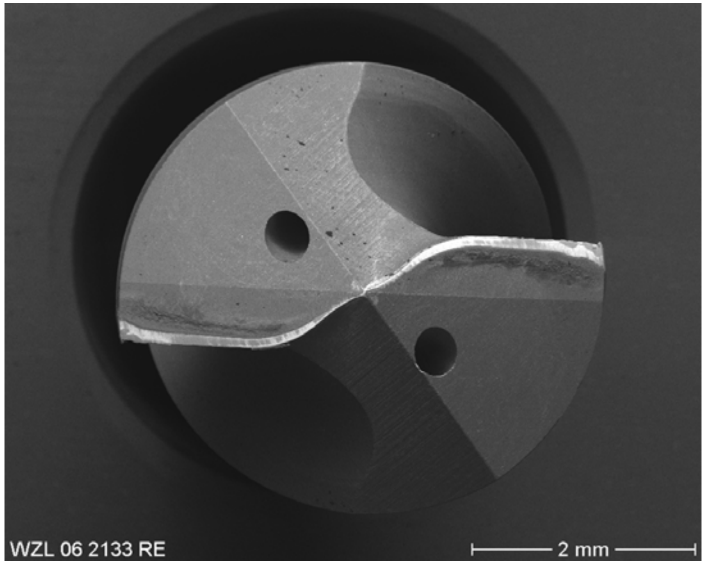
Process monitoring strategy: upper limit

- <u>Failure Identification:</u>

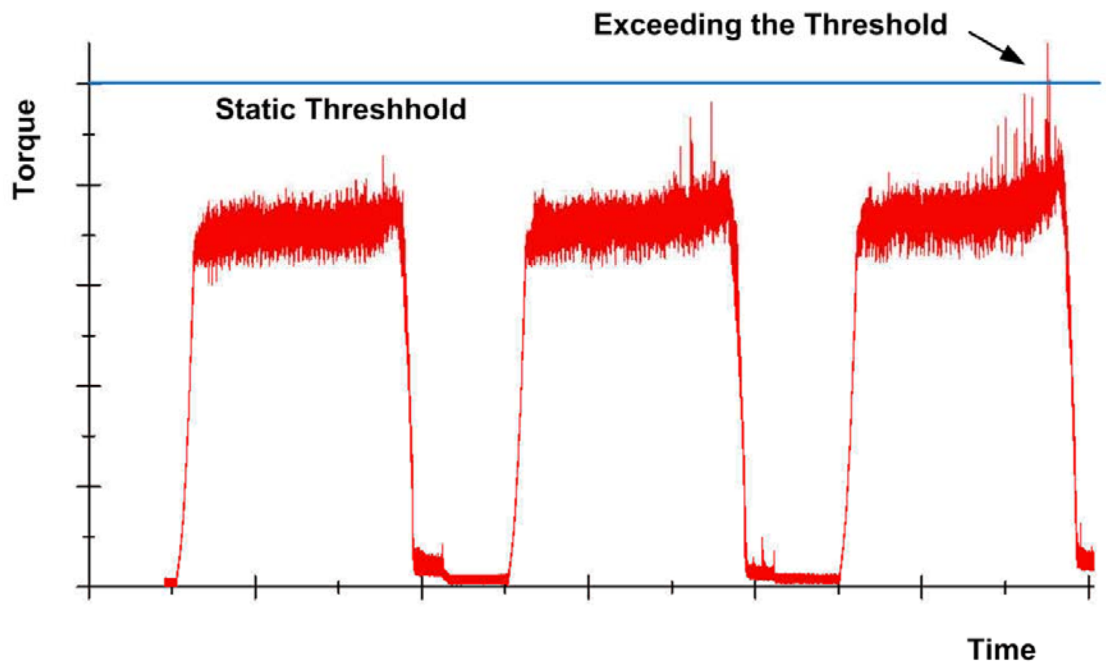
  In order to identify failures, the monitoring signals are *online* compared to reference values.

At the third hole, the acquired signal exceeds the static threshold.

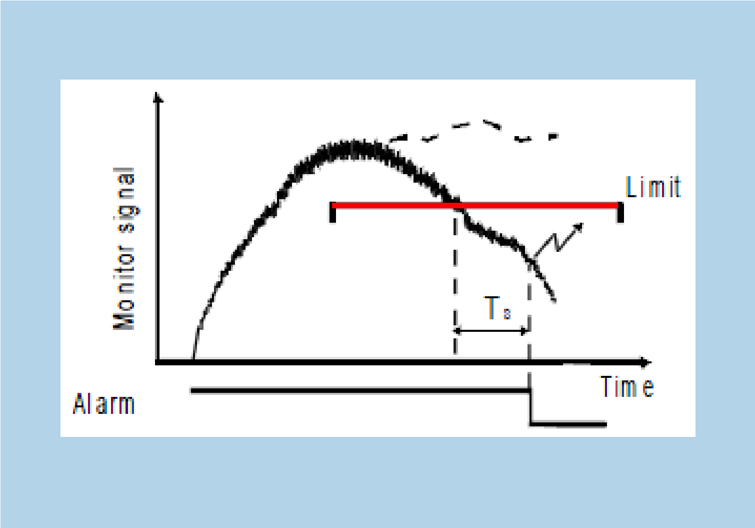
- <u>Example:</u> *Static Threshold* for drilling process



Significant Tool Wear at Drill



Limit Type: Underload



- Alarm when the signal remains below the limit for response time T_s at least

Limit Type Description

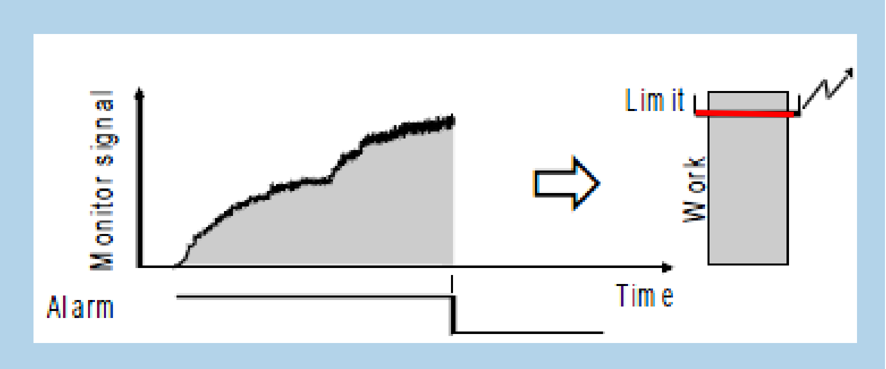
Examples

Falling monitor signals eg in case of:

- tool breakage (broken –off part tool is spun away)
- Incorrect workpiece dimensions (eg excessively small parts)

Source: Prometec

Limit Type: Work Over



- Alarm when upper limit for the work value is exceeded

Limit Type Description

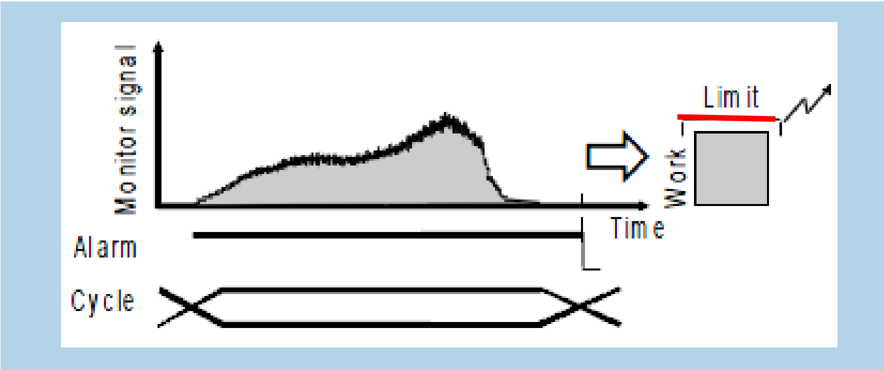
Examples

Work values too large for:

- blunt tools
- tool breakage or chipping

Source: Prometec

Limit Type: Work Under



- Alarm when the work value remains below the lower limit up to the end of the cycle

Limit Type Description

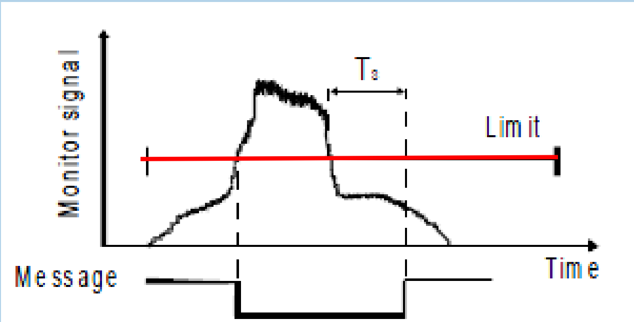
Examples

Work values too small for:

- tool breakage
- incorrect workpiece dimensions
- tool or workpiece missing

Source: Prometec

Limit Type: Contact



- Message output as soon as the limit is exceeded
- Message is reset when the signal remain s below the limit for the response time Ts at least.

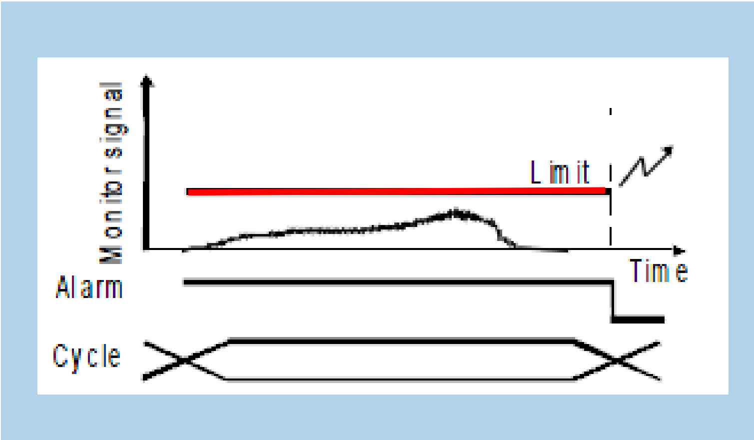
Limit Type Description

Examples

- Detection of contact between tool and workpiece or grinding wheel and workpiece to minimise machining times in air (GAP-Reduce)

Source: Prometec

Limit Type: Missing



- Alarm when the limit is not exceeded by the end of the cycle (idle pass)

Limit Type Description

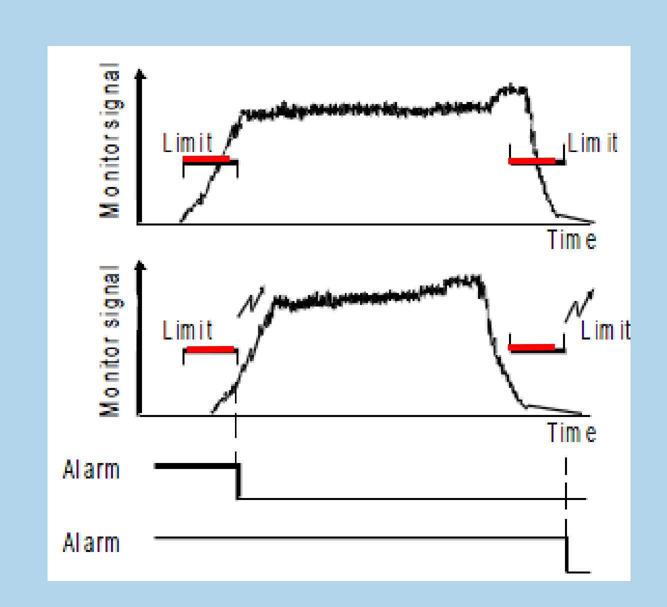
Examples

Excessive low monitor signals due to:

- missing parts, eg parts drop out of holders
- missing tool eg broken-off tool

Source: Prometec

Limit Type: Rising Through/Falling Through



- Alarm when the time defined limit is passed, but the signal does not pass through the limit in rising or falling mode

Limit Type Description

Examples

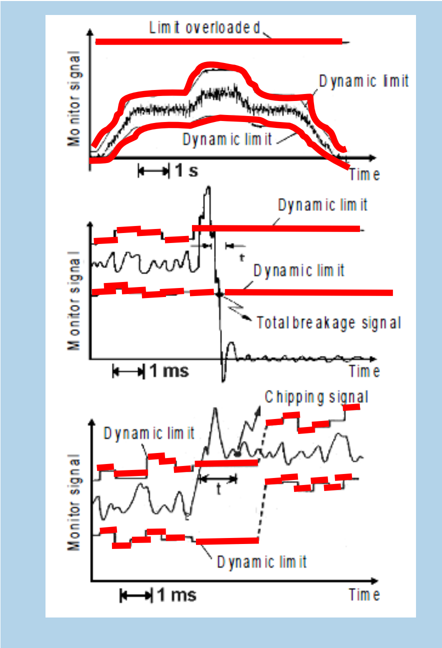
Time displaced monitor signals due to:

- broken, shortened tools
- missing tools or work pieces
- incorrect tools or workpieces

Specific monitoring of start and end of cut with tolerance of full cut. Chip jamming or other major changes in the monitoring signal do not result in false alarms

Source: Prometec

Limit Type: Dynamic Limits



- Continous following of upper and lower limit at limited adaptation speed
- Frozen limits (rendered static) for extremely fast crossing

Limit Type Description

Examples

Sudden load changes due to:

- Total tool breakage
- Tool breakage
- Tool chipping

Slow but large load changes due to variations in cutting depth such as occur during initial cuts. The fast detection of breakages via dynamic limits leads to a drastic reduction in false alarms and substantially shorter signalling times after breakage.

Source: Prometec

Gliederung

PM Systems Vendors

Techna-Tool Inc.

OMATIVE systems

Montronix®
Protecting your manufacturing processes

ARTIS®

PROMETEC®
Monitoring Solutions

KISTLER
measure. analyze. innovate.

BRANKAMP

argotech GmbH

CARON ENGINEERING

NORDMANN
Online Tool Monitoring

ARTIS GmbH

Source: Artis GmbH

CTMV3

Application

- Tool monitoring system for the detection of missing, broken and worn tools in metal-cutting production facilities
- expandable with functions for machine condition monitoring

Use

- Series productions and small-lot productions are the field of application monitoring system
- In contrast to a post process in-process monitoring system is the constant inspection of the production processes

Function

- monitoring system integrated in open control systems.
- visualization of the monitoring results carried out using the operator panel of the NC system or using an external PC
- The process data is preferably retrieved directly from the control system core without the use of sensors

Strategy

- Limited to dynamic thresholds monitoring strategy

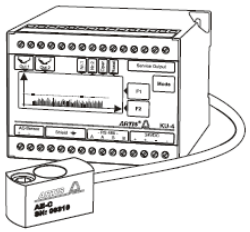
ARTEC 4000

Application

- variant of the tool monitoring system CTM. Unlike the CTM system, the ARTEC 4000 system is not integrated in open machine control systems
- No limitations with respect to the NC system with which it is to be used in a chip-forming machine tool.

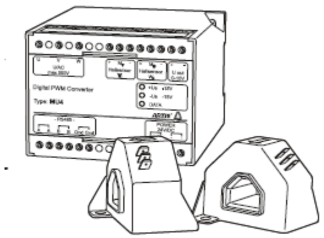
Use

- Usage together with true power (rotating tools), force (rotating and grinding machines), torque (tapping operations), acoustic emission (breakage of small drilling tools) and vibration velocity plus acceleration (unbalance and collision, collision in preparation) possible.

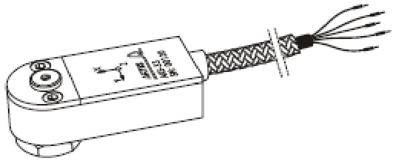


Acoustic emission sensor system

for drill breakage monitoring



Power sensor system for tool breakage monitoring



Force sensor system to measure forces in extremely rigid machine frames for tool monitoring

Three components in directions X, Y and Z.

Source: Artis GmbH

ARTIS Gesellschaft für angewandte Meßtechnik mbH

DDU4

Application

- measures torques and feed forces in the tool holder non-contact transfer of the measurements and energy supply

Use

- tool monitoring in the case of drilling and tapping operations. This system can be used as a stand-alone system for the purpose of monitoring for tool breakage and
- Can be used used in
- combination with the tool monitoring system CTM
- detection of tool breakage in the case of rotating tools

Limitations

- 2 component measurement system (feed force / torque)
- Most effective in one axis manufacturing process like drilling and tapping applications
- Measurement range (5 kN)

Source: Artis GmbH

Brankamp GmbH - Modular machine and tool protection for cutting processes

Machine Tool

Sensor Modules

Device Modules

BRANKAMP Power Sensor [BPS]
Measures the power of motors on machine tools

One/Three- Component-quartz [3C quartz]
Measures the lateral force flow

Acoustic Emission Sensor [AE]
Measures high frequency noises

Vario sensor
Measures the force within a borehole

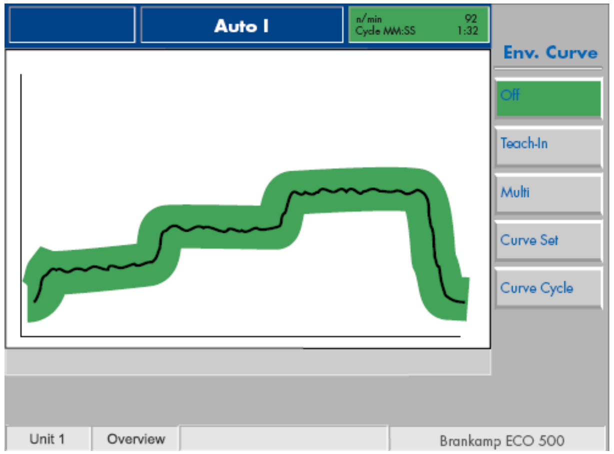
One- or Three-component-quartz
sensor with integrated rapid changer

Piezoelectric sensor [PDA]
Measures the strains on the surface of the machine body

Source: Brankamp GmbH

Source: Brankamp GmbH

Brankamp GmbH



Application

– Process Monitoring for multi-spindle lathes, transfer lines, drilling and rotary machines

Use

– Crash, wear, trend and idle run control
– Multi-sensor usage (Force, Power, Acoustic)

Function

– unit records forces for up to 6 stations during the cut and monitors the process against free adjustable limits.
– Automatic machine stop in case of process deterioration
– Envelope curve analysis with dynamic limits
– Recording and transmitting of production data

Limitations

– Limited to dynamic thresholds monitoring strategy

Source: Brankamp GmbH

Kistler Instrumente GmbH

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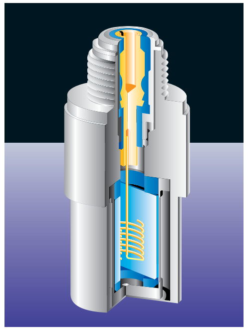
Acceleration

Pressure

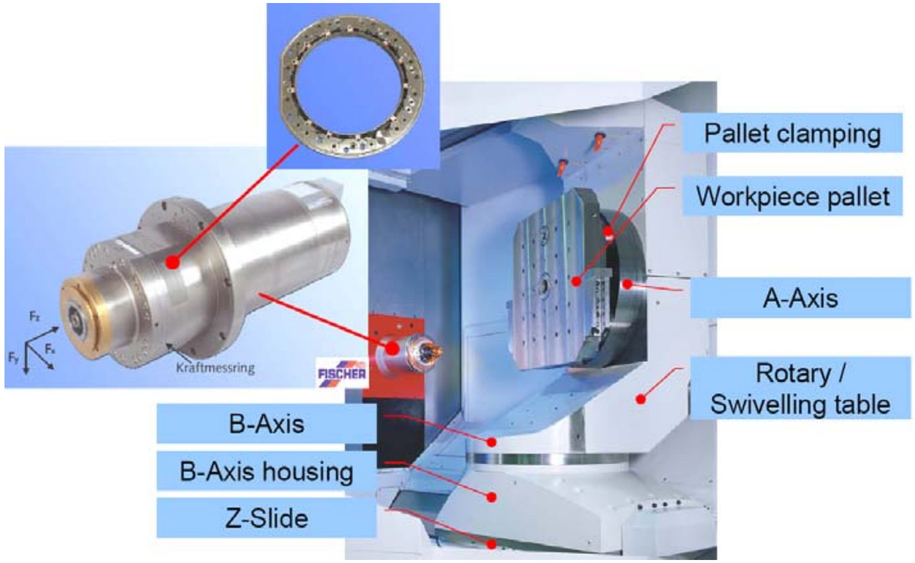


AE- Sensor

Cutting Force Dynamometer

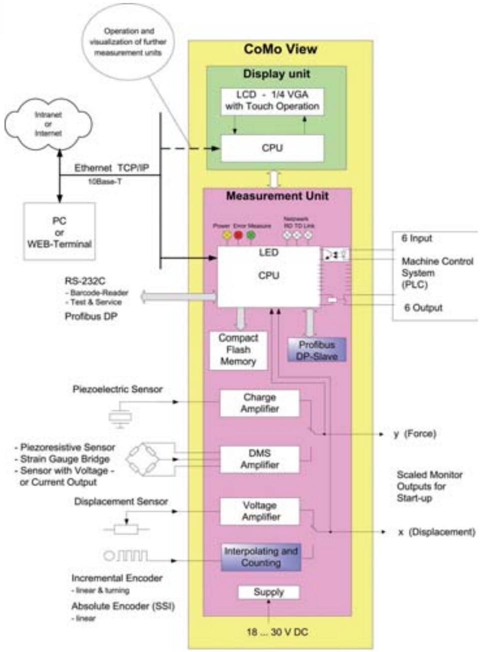
Sensors

- Force, pressure and acceleration sensor (peicoelectric based)
- Recommended for dynamic force applications (piezoelectric crystal)
- Custom made measurement systems (spindle integrated force measurement)



(Source: Kistler)

Kistler Instrumente GmbH



(Source: Kistler)

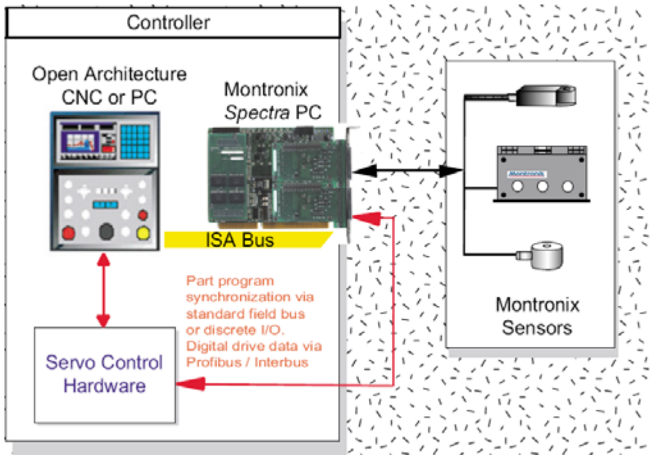
- **Application**
  - Control for the monitoring and classification of industrial processes
- **Use**
  - Limit Value Monitoring in Real Time
    - Real-time thresholds can be used to actuate trigger signals
    - or, for example, to monitor safety criteria (such as overload protection)
- **Function**
  - Measuring mode y(x) and y(t)
  - Measurement and monitoring of, for example:
    - F(t) Force against time
    - F(s) Force against displacement
    - M(t) Torque against time
    - M(φ) Torque against rotation angle
    - s(t) Displacement against time
  - Real-time thresholds for overload protection or speed control
  - 12 different evaluation functions can be freely combined for monitoring threading, curve trace, trend, hysteresis, block force and limit position

KISTLER
measure. analyze. innovate.

Montronix GmbH

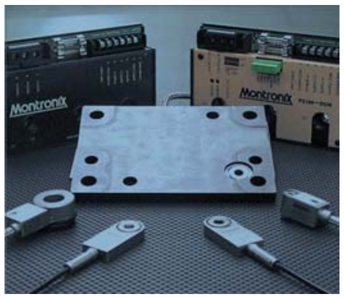
Montronix®
Protecting your manufacturing processes

„Cut with confidence“



Spectra Silver ™

Sensor “pool“

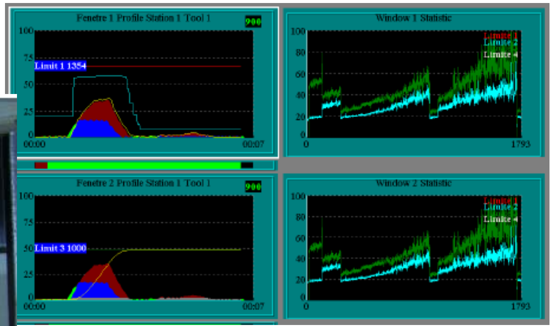


- **Application**
  - Tool and process monitoring utilized in manufacturing industries (mentoring manufacture of nickel-alloy engines parts)
- **Use**
  - Detection and Diagnose of process problems and machine health
    - for transfer lines, custom, or special purpose machines
    - for machines or processes where numerous process variables exist and protection and optimization are necessary
  - Productivity
    - Allowing unattended or semi-unattended machining at higher machining rates
    - Crash, wear, trend and idle run control
    - Reduce of scrap and rework
  - Quality
    - Detecting tool and process faults
    - Decreasing the need of inspection or probing
- **Function**
  - Signal Processing & Limits Monitoring
    - Signal processing (Area, Average, Peak to Peak)
    - Signal monitoring
    - (Fixed, Floating, Stepped) Limits/sensor (2 upper / 1 lower)
- **Limitations**
  - Limited to thresholds monitoring strategy

Montronix GmbH

Protecting your manufacturing processes

AccuTorque™



Spectra Silver ™

- Application
  - Tool and process monitoring utilized in milling processes
- Use
  - Missing tool / Empty cut
  - Broken and chipped tool
  - Excessive tool wear
  - Misalignment
  - Over sized / under Sized tool detection
- Limitations
  - Strain gauge based measurement system (low frequency force measurement)
  - Most effective one axis monitoring process like drilling and tapping applications

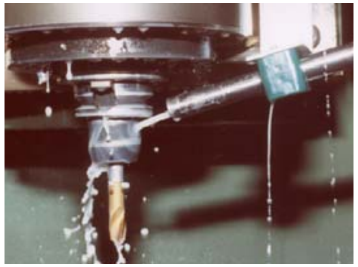
Nordmann GmbH & Co. KG

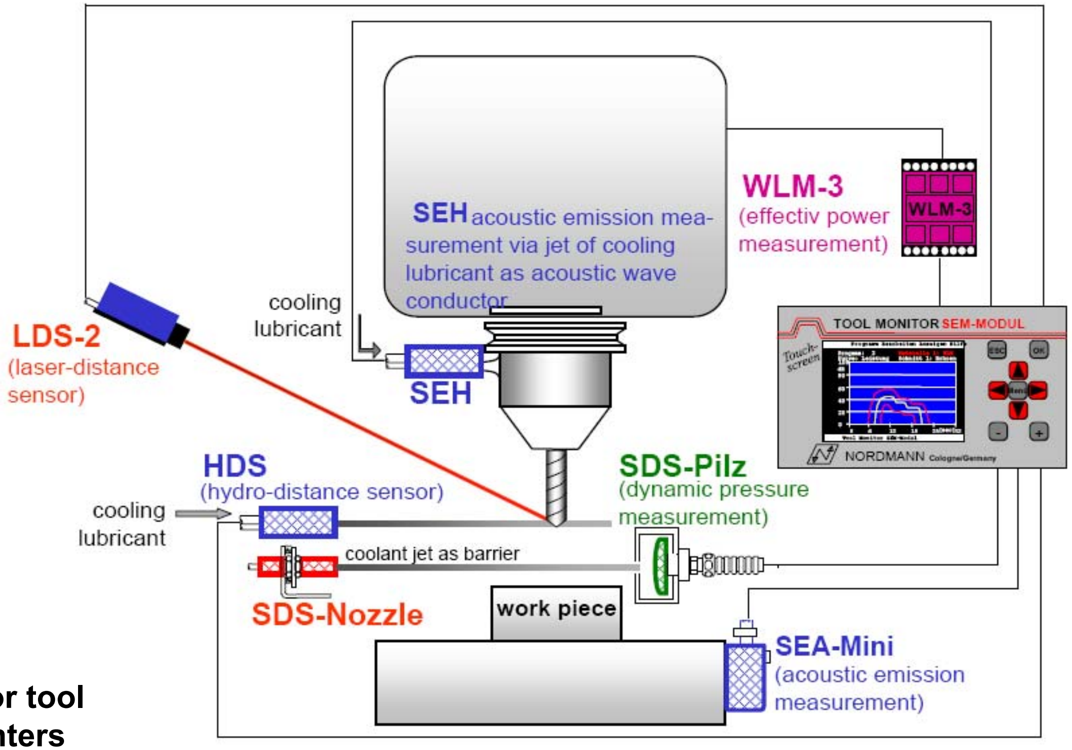
NORDMANN
Online Tool Monitoring

SEH: acoustic emission measurement based on a jet of cooling lubricant for small tools (patented)

HDS hydro distance sensor

Possible sensor positions for tool monitoring in machining centers (Source: Nordmann)





WLM-3 effective power measurement

SEA-Mini: low noise acoustic emission sensor from 0 Hz to 1 MHz

Nordmann GmbH & Co. KG

NORDMANN
Online Tool Monitoring

SEM Modul

SEM-Profibus-Micro

SEM-Profibus

Tool monitoring system SEM-Profibus-Micro connectable with the Profibus in sinumeric controls 840D/ 810D

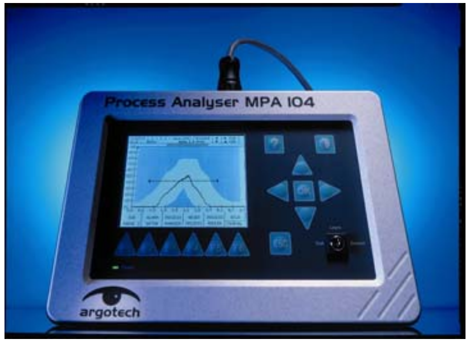
(Source: Nordmann)

- Application
  - Tool and machine protection
  - Quality assurance
  - Process control
  - Reduction in production time
- Use
  - Tool breakage detection
  - Tool wear detection
  - Collision detection
  - Wear and temperature compensation
  - Detection of inadequate dimensions/ positions of work piece
- Function
  - Signal limitation (static, dynamic, manual adjusted)
- Limitations
  - Limited to thresholds monitoring strategy
  - No applicable force sensor solution regarding to manufacturing center monitoring system
  - Acceleration sensor not in product portfolio

Argotech GmbH

Process Analyser PA2

Process Analyser MPA104

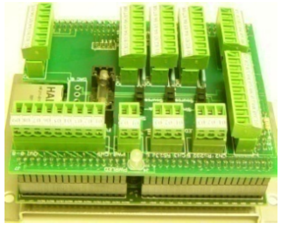


- **Basis of System**
  - The Company installs system on machine, 3 different options: 2, 4 or 256 sensors
  - Teach in during 1 cycle
- **Sensors**
  - company offers deformation-, AE-, acceleration- and power consumption-sensors
  - systems works with any 0-10V sensor, for other sensors amplifiers are necessary
- **Limitations**
  - 2 basic types of limits, multiple limits can be monitored at once
  - envelope limits (vertical or horizontal)
  - box limits (3 types: box which the signals mustn't pass, box with 2 horizonal "must-pass lines" and 2 vertical "mustn't-pass lines" and box with 2 horizontal "mustn't-pass lines" and 2 vertical "must-pass lines")
  - no adaption of change due to wear, excessive tool wear is only identified by box limits
  - different alarms / alarm levels / types of stopping the machine: immediately, at end of cycle, at end of production process etc

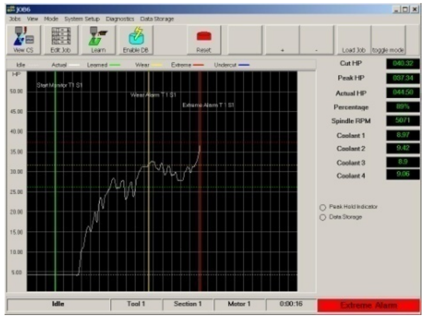
(Source: Argotech GmbH)

Caron Engineering

Main Controller



TMS Display Software



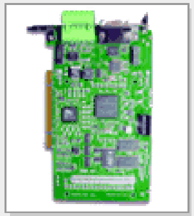
Horsepower Transducer

- **Basic Principle**
  - Monitors true horsepower instead of current as most CNC load meters do.
  - Measures the horsepower of a new tool during a cut
  - Determines whether a tool is worn or broken by comparing the cutting horsepower to user programmed limits
  - Adaptive control overrides the feed rate automatically to maintain constant horsepower
- **System Features**
  - Tool Monitoring
  - Adaptive control
  - Coolant Flow and Spindle Speed Monitoring
  - Network connectivity
  - Data logging
  - Alarm reporting

Techna Tool Inc.

MODEL 101

MODEL 3200



MODEL PCI

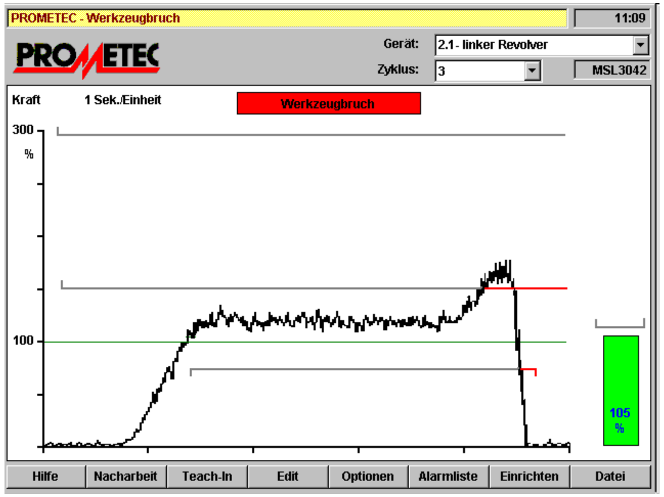
MODEL PM-1

- **Limitations**
  - fixed upper and lower limit (absolute or %)
  - area under signal
  - missing tool
  - stepped limits
  - alarm delays possible: limit has to be violated for a certain period of time, in order to call up an alarm
- **Sensors**
  - System uses true power

(Source: Techna Tool Inc.)

Prometec GmbH

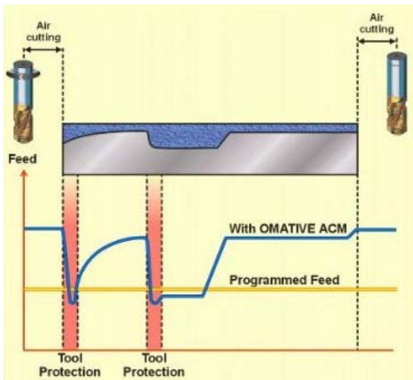
PROMETEC Monitoring Solutions



(Source: Prometec)

- **Sensors**
  - force
  - torque
  - displacement
  - strain
  - position
  - hydraulic pressure
  - effective power
  - acoustic emission
  - structure-borne sound
  - vibration
- **Limitations**
  - fixed upper and lower limit
  - area under signal
  - rising through, falling through limit
  - dynamic limits
  - missing tool

Omative Systems



(Source: Argotech GmbH)

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Table of Process Monitoring Opportunities

	Force	Torque	Power	Acceleration	Acoustic Emission	Pressure	Flow Rate	Temperature	Position	Strain
Tool Condition										
• wear	(●) ⦿	(●) ⦿	(●) ⦿	⦿	⦿	○	○	⦿	(●) ⦿	⦿
• breakage	● ⦿	● ⦿	● ⦿	● ⦿	● ⦿	○	⦿	X	● ⦿	⦿
Machine Condition										
• wear	X	X	X	(●) ⦿	⦿	X	X	(●) ⦿	⦿	⦿
• dynamics	● ○	⦿ ○	○	● ⦿	● ⦿	X	X	(⦿)	X	⦿
Product										
• material quality	(●) ⦿	(●) ⦿	(●) (⦿)	(●) (⦿)	(●) (⦿)	X	X	⦿	X	X
• geometry finish	⦿	⦿	⦿	(●) ⦿	⦿	X	X	X	● ⦿	X
• dimensional / form control	X	X	X	X	X	X	X	X	● ⦿	X
Fixture Condition										
• clamping / coupling	● ⦿	● ⦿	X	● ⦿	(⦿)	X	X	X	● ⦿	● ⦿
• dynamics	(⦿)	(⦿)	(⦿)	● ⦿	⦿	(⦿)	○	○	⦿	(⦿)
Coolant Condition • supply • (chemical composition)	X	X	X	X	X	● ⦿	● ⦿	● ⦿	X	X

●	Common Application
⦿	Science Topic
○	No Common Application
X	Not applicable
( )	limited

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Systems’ Functionality According to Data Sheets

	Artis	Brankamp	Kistler	Montronix	Nordmann	Prometec
Tool Condition Monitoring	Detection of missing, broken and worn tools	Crash, wear, trend, idle run control	Overload protection and speed control	Missing tool, broken and chipped tool, excessive tool wear, misalignment, over sized under sized tool detection	Tool breakage wear, collision detection,	Detection of tool breakage, tool wear, air cuts and tool contact
Machine Tool Monitoring	Functionality to perform machine condition monitoring	Machine stop in case of process deterioration	Limit Value monitoring / Overload protection	Detection and Diagnose of process problems and machine health	Machine protection	Rapid detection of machine collision with the minimization of the resulting damage
Dynamics monitoring			Recommended for dynamic force applications			
Coolant Monitoring	Detection of dry running and overload of the coolant pump			Ability to add analog sensors	Limited possibilities	
Fixture Monitoring	Detection of low clamping-pressure	Force / Strain measurement on surface of clamping device	Force / Strain measurement on surface of clamping device	Ability to add analog sensors	Detection of inadequate dimensions / positions of work piece	Detection of the hydraulic pressure

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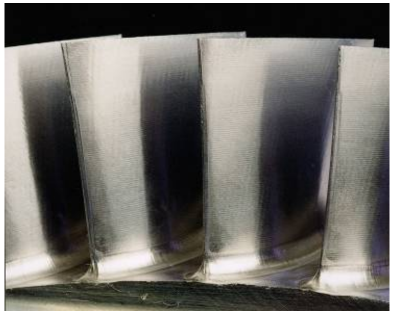
Gliederung

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

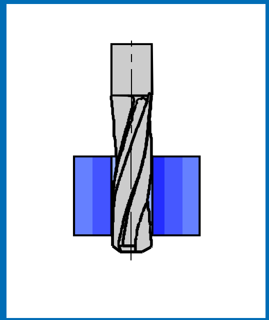
Process-Material Combinations

- Work of this project will refer to

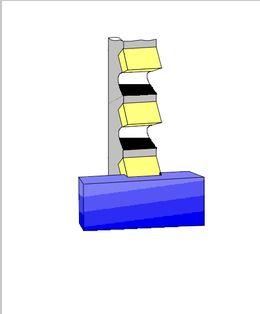
  Drilling Processes
  Broaching Processes

- 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



Broaching processes

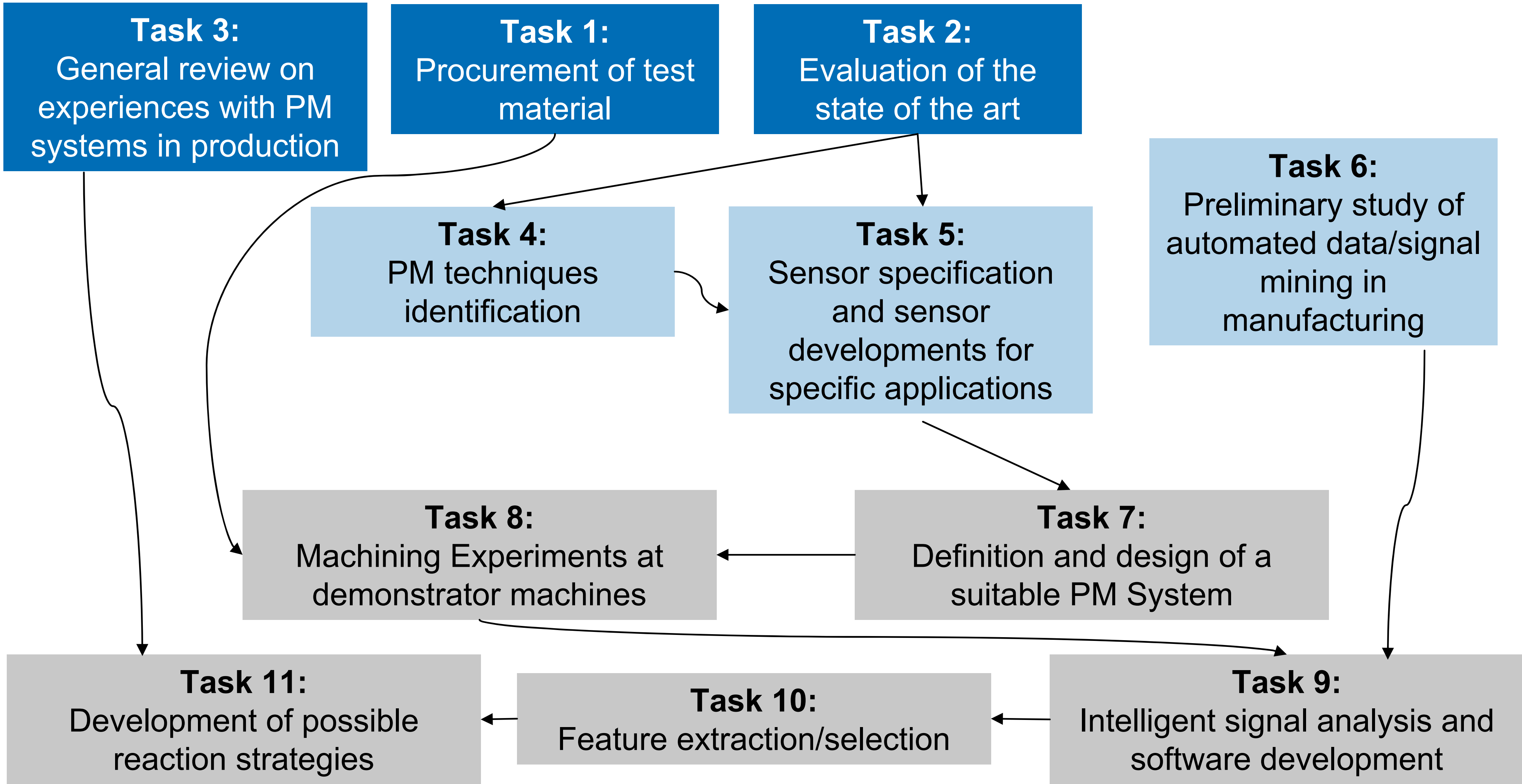


Nickelbased Alloy


source: Lycoming


source: MTU

Task Content and Interaction



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Planned Trials at Partner Locations

Process Monitoring Strategy for Drilling and Broaching

Rolls-Royce | VOLVO AERO | MTU Aero Engines | Avio propulsione aerospaziale | GE | Pratt & Whitney | Honeywell

Demonstrator trials close to production

Data from production

Provision of test material

Development of possible reaction strategies

Methodology

- **Study of basic physical functionality between machining and SI**
- **Intelligent signal analysis and software development**
- **Feature extraction and study of capable signals to predict SI**
- **Validation and capability test with „real" production data**
- **Small scale test of suitable PM System**
- **Test with PM System in Production**

Gliederung

Project Leader

Dipl.-Ing. Dražen Veselovac

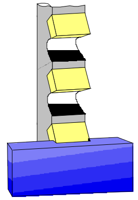
Head of Department Monitoring and
EDM/ECM

Laboratory for Machine Tools and
Production Engineering (WZL)
Steinbachstraße 19
D-52074 Aachen
☎ +49 241/ 80 27432
🗎 +49 241/ 80 22293
✉ d.veselovac@wzl.rwth-aachen.de

Research Associates

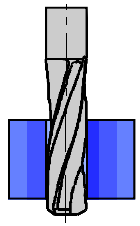
Dipl.-Ing. Sascha Gierlings

Monitoring Group
Laboratory for Machine Tools and
Production Engineering (WZL)
Steinbachstraße 19
D-52074 Aachen
☎ +49 241/ 80 20522
☎ +49 172/ 8882850
🖹 +49 241/ 80 22293
✉ s.gierlings@wzl.rwth-aachen.de



Dipl.-Ing. Matthias Brockmann

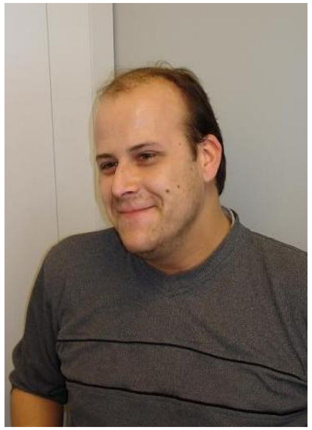
Monitoring Group
Laboratory for Machine Tools and
Production Engineering (WZL)
Steinbachstraße 19
D-52074 Aachen
☎ +49 241/ 80 20255
☎ +49 160/ 97370053
🖹 +49 241/ 80 22293
✉ s.gierlings@wzl.rwth-aachen.de



Programmer and Technician

Robert Seidner

Monitoring Group
Laboratory for Machine Tools and
Production Engineering (WZL)
Steinbachstraße 19
D-52074 Aachen
☎ +49 241/ 80 28386
🗎 +49 241/ 80 22293
✉ r.seidner@wzl.rwth-aachen.de



Sascha Kamps

Monitoring Group
Laboratory for Machine Tools and
Production Engineering (WZL)
Steinbachstraße 19
D-52074 Aachen
☎ +49 241/ 80 27469
🗎 +49 241/ 80 22293
✉ s.kamps@wzl.rwth-aachen.de

Thank you for your attention!