Sensors and systems for mechanical process monitoring

Dirk Lange

TOOL & PROCESS Monitoring
APPLICATION FIELDS

Processes
- drilling
- reaming
- turning
- milling
- gear hobbing
- tapping
- grinding
- cracking
- turn-turn broaching
- …

Advantages
- higher productivity
- shorter cycle times
- detection of faults
- reduction of rejects
- tool protection
- process visualisation
- process analysis

Process monitoring
- tool breakage
- missing tools
- tool wear
- depth of thread
- core hole diameter
- damaged threads
- collision/overload
- unbalanced tools
- Spec. P11TF12.

Process optimisation
- cycle time optimisation
- maximum tool utilisation
- process analysis
- process visualisation

Adaptive Control
- cycle time optimisation
- maximum tool utilisation
- prevent tool breakage

Systems
- sensors
- measuring converter
- external solutions
- PC plug-in cards
- software solutions
- wireless sensors

Service
- teleservice
- eService

Condition Monitoring
- bearing monitoring
- collision monitoring
- chip in spindle
- axes monitoring
- sluggishness
- TCO
- LCC

TOOL & PROCESS Monitoring

SCALEABLE MONITORING SOLUTIONS

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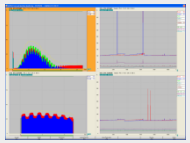
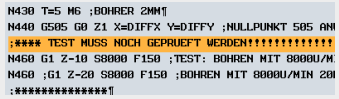
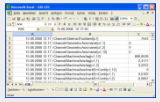
Diagnosis Systems

Service and Application

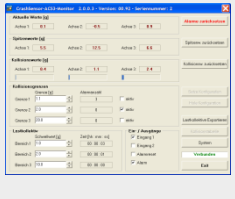
Sensors



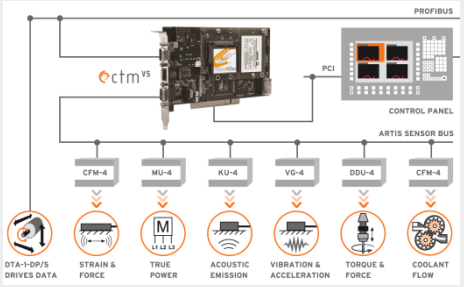




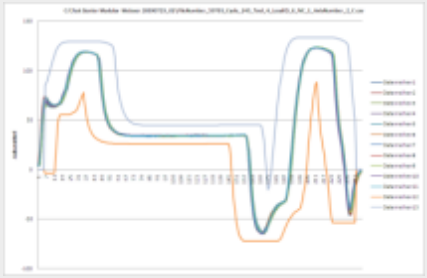
Software Tools



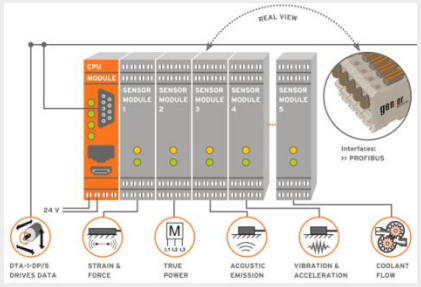
Datalogger



Plug-in Boards



Strategies and Interfaces



Modular Systems

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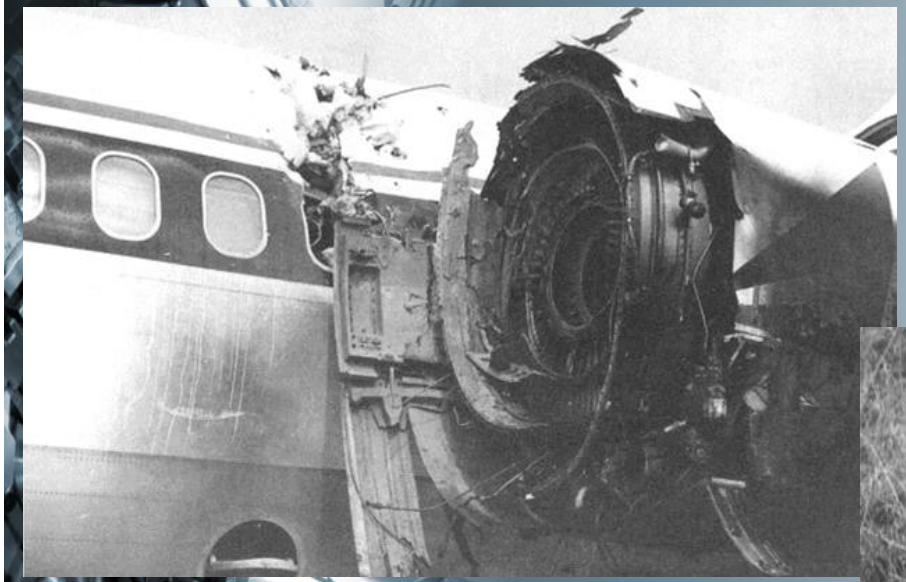
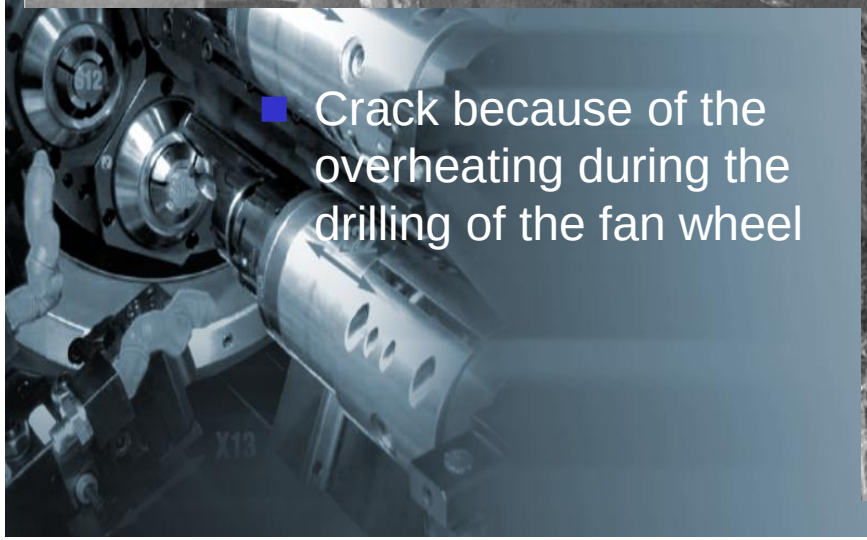


- Part damage after 13835 fly cycles
- 2 people died



- Crack because of the overheating during the drilling of the fan wheel

Source: WZL RWTH AACHEN

TOOL & PROCESS Monitoring
CHARACTERISTICS IN CUTTINGS PROCESSES

MARPOSS

Input parameter	Process	Output parameter

Machining parameters
- feed
- cutting speed
- cutting depth
- ...

System variables
- machine tool
- tool
- workpiece
- auxiliary materials

Disturbances
- internal (motor heat, spindle vibration)
- external (room temperature, floor vibrations

System transmission behavior
(mechanical, thermal)

Process parameters
- forces
- temperatures
- torque
- acoustic emission
- rattle frequencies
- wear
- ...

Workpiece quality
- Geometry (micro and macrogeometry)
- physical properties

Condition of auxiliary materials
(physically, chemically)
- coolant
- process remains (chips, ...)

Tool wear
- geometrically (macro und micro wear)
- physically, chemically (diffusion, ...)

Source: WZL RWTH AACHEN

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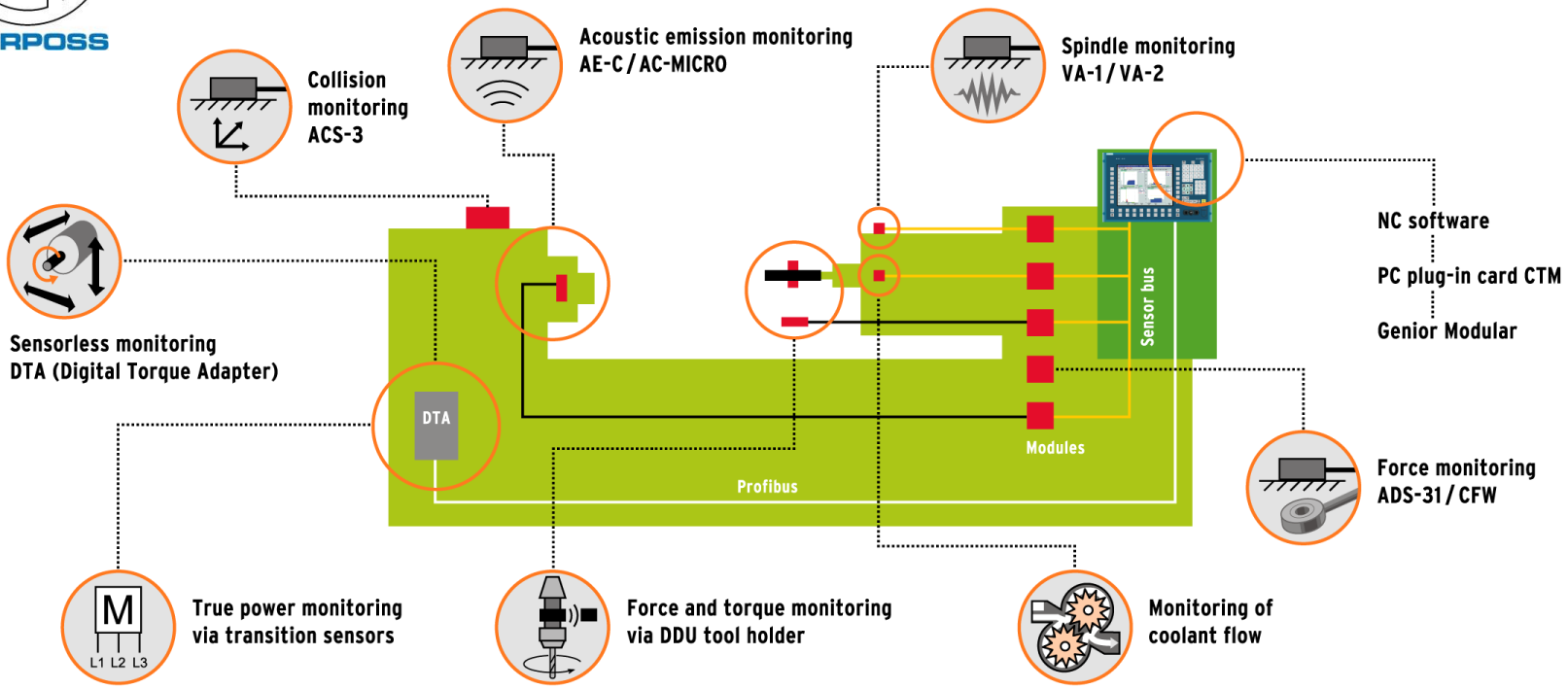
TOOL & PROCESS Monitoring

SENSORS IN MACHINE TOOL AND REQUIREMENTS



Requirements

- Measure the physical quantity
- Reproducible measures
- Robust against disturbances
- Robust against dust, coolant, water, temperature
- Low thermal drift

- Cheap
- Easy to install
- Calibrated
- Robust cabling (trailed)

- No dual use
- EMC proofed
- CE certifed

TOOL & PROCESS Monitoring

Deviations in Tapping Processes

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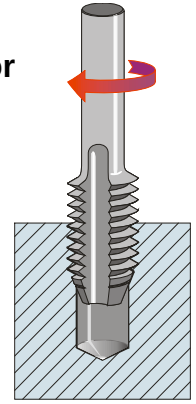
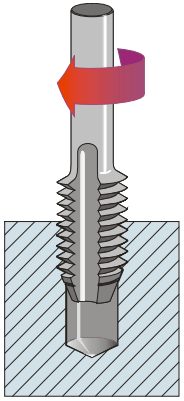
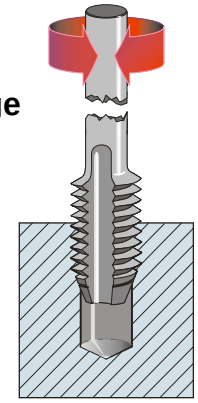
No error



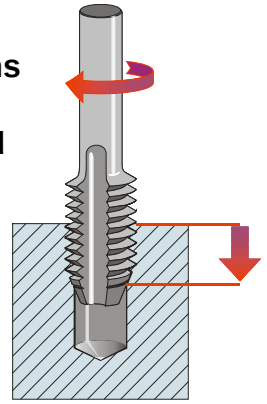
Tool wear



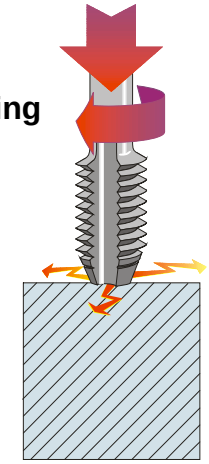
Tool breakage



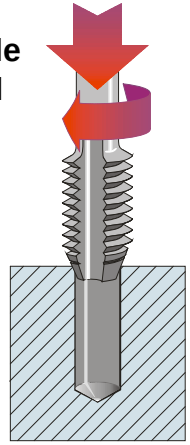
Deviations in Depth of Thread



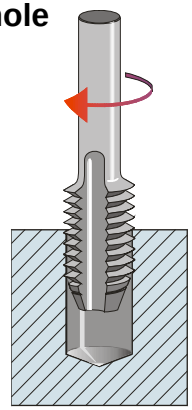
No drilling



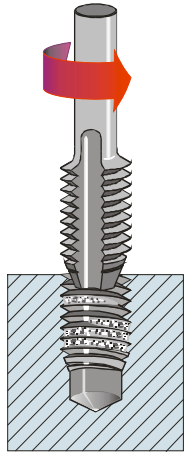
Borehole to small



Borehole to big



Torn out threads



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TOOL & PROCESS Monitoring

Wireless Sensor System for Monitoring

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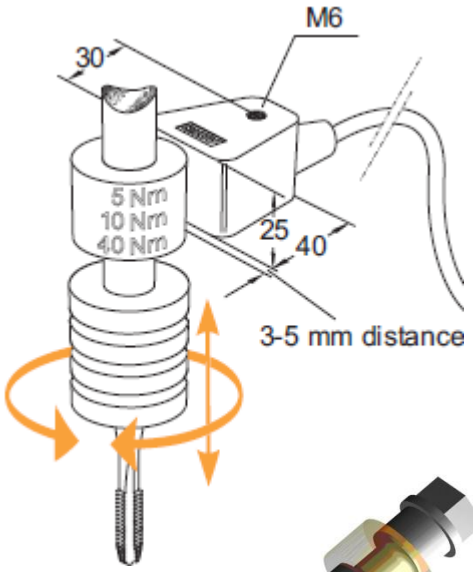

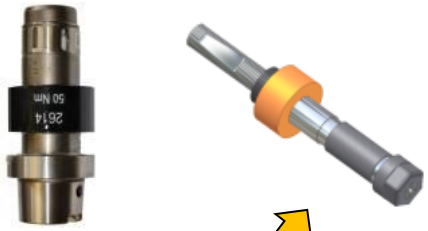

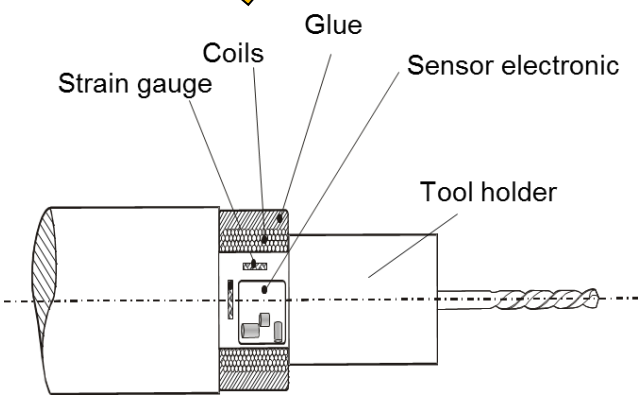

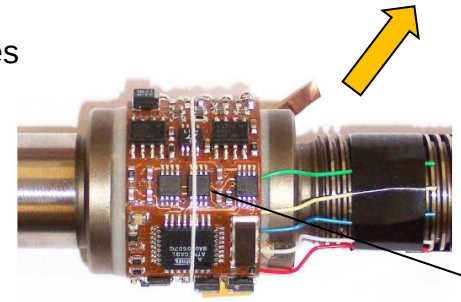

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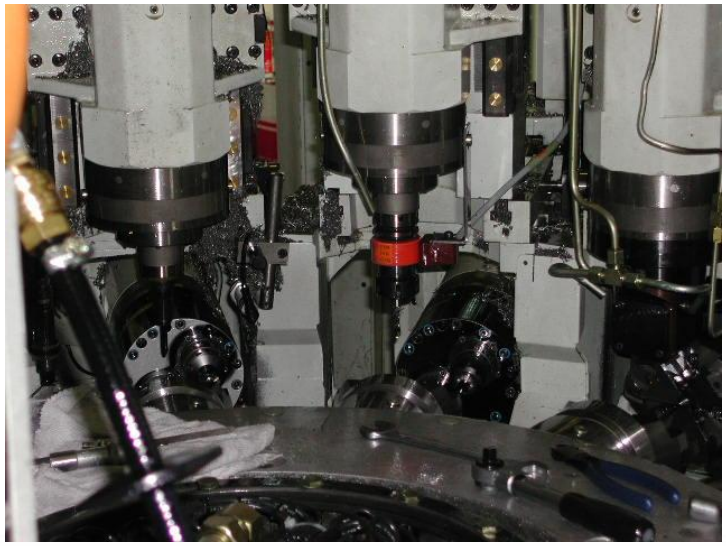
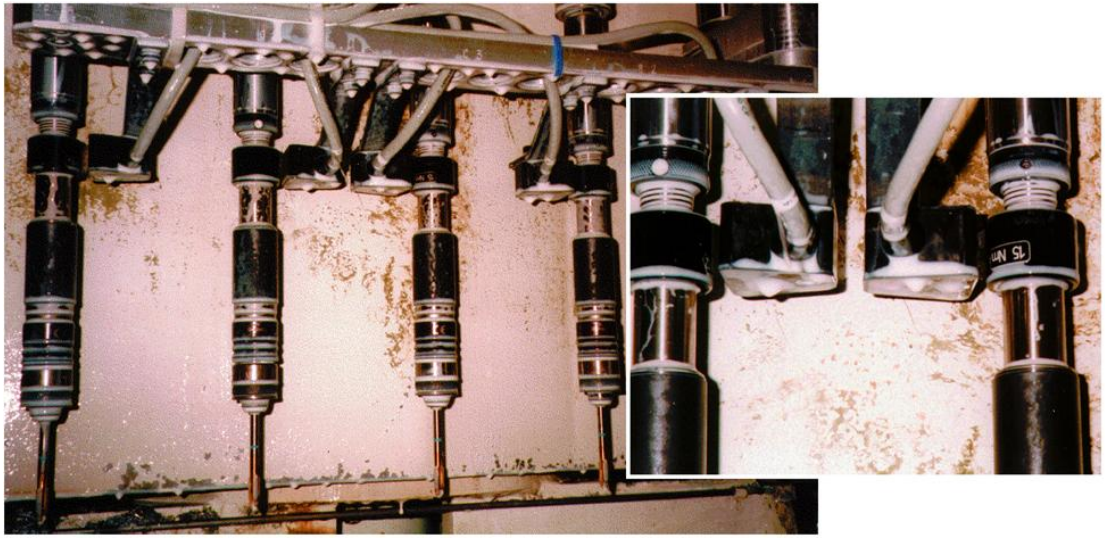
TOOL & PROCESS Monitoring

Wireless Sensor System – Application Examples





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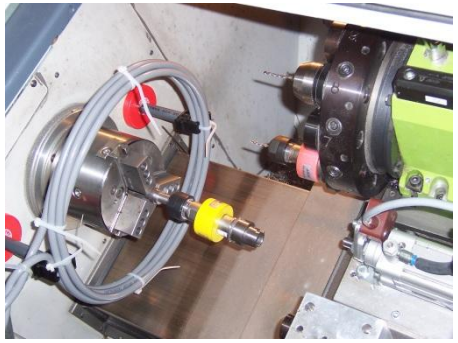
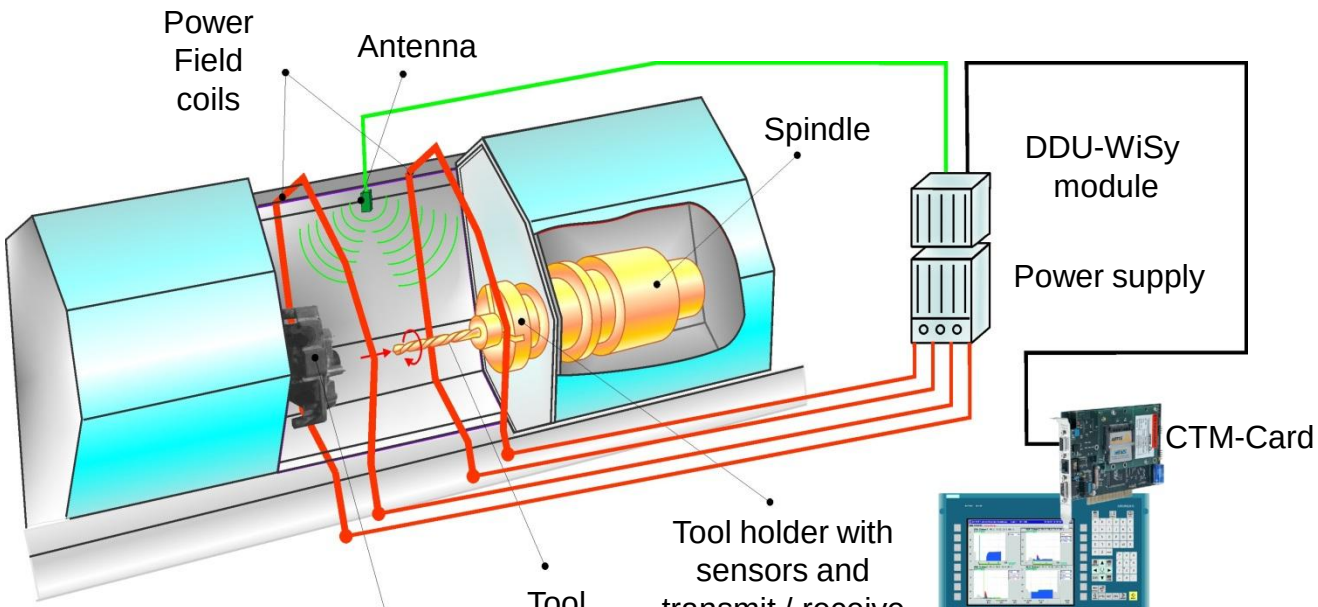
TOOL & PROCESS Monitoring

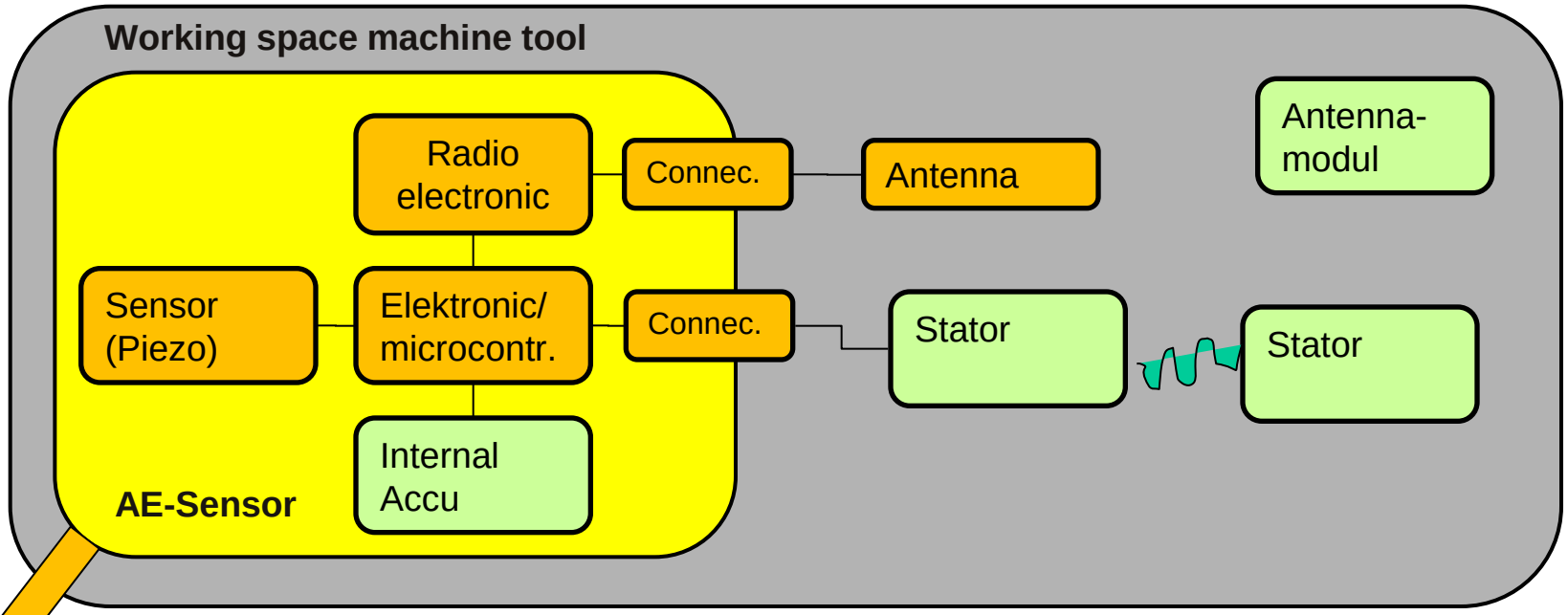
Wireless Sensor System – Idea of DDU Wisy





TOOL & PROCESS Monitoring

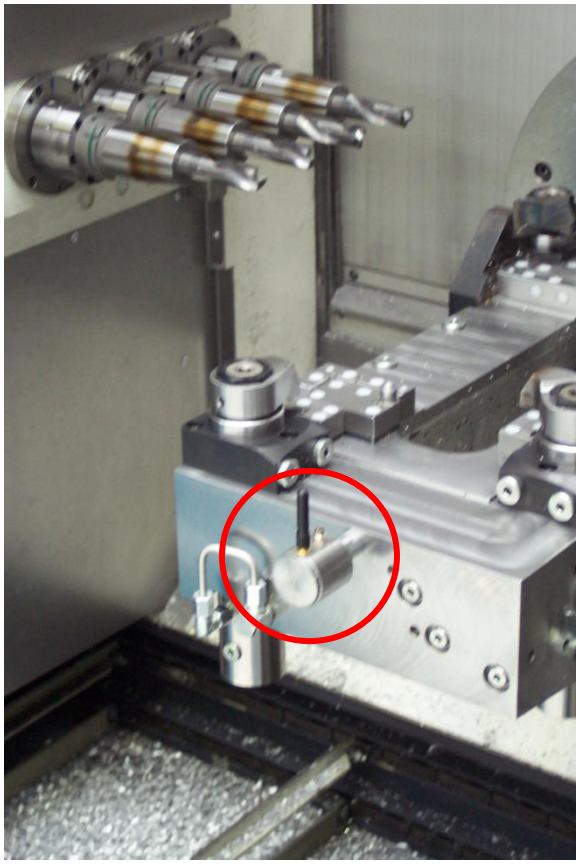
Wireless Acoustic Emission Sensor - AE-WiSy

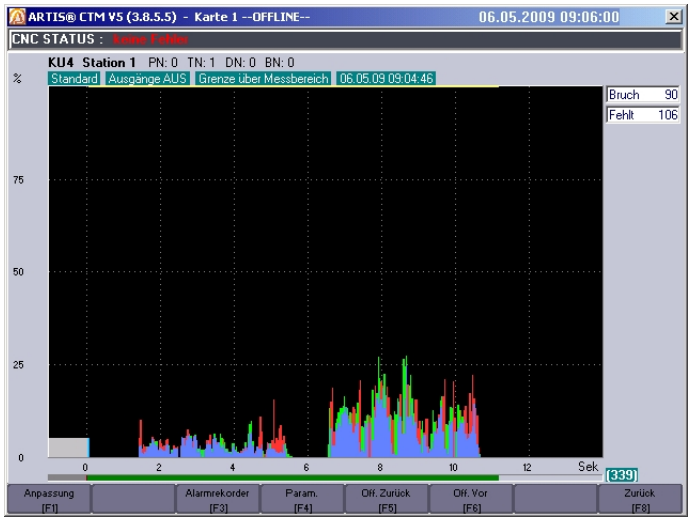


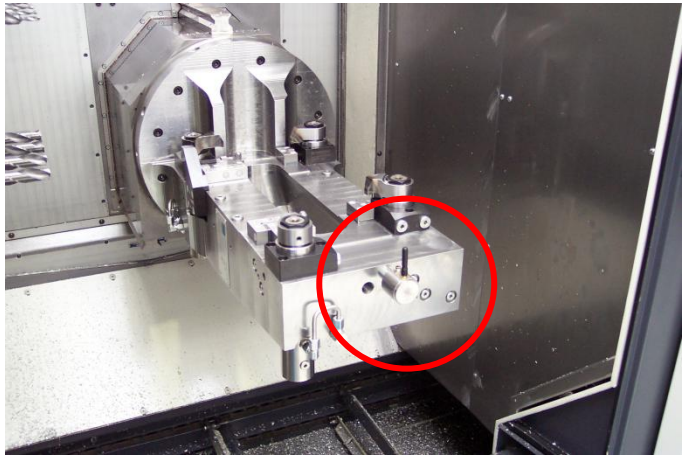
- Internal battery
- External battery up to 2 weeks
- Frequency 868MHz
- 10 channels
- Integrated AE-Sensor

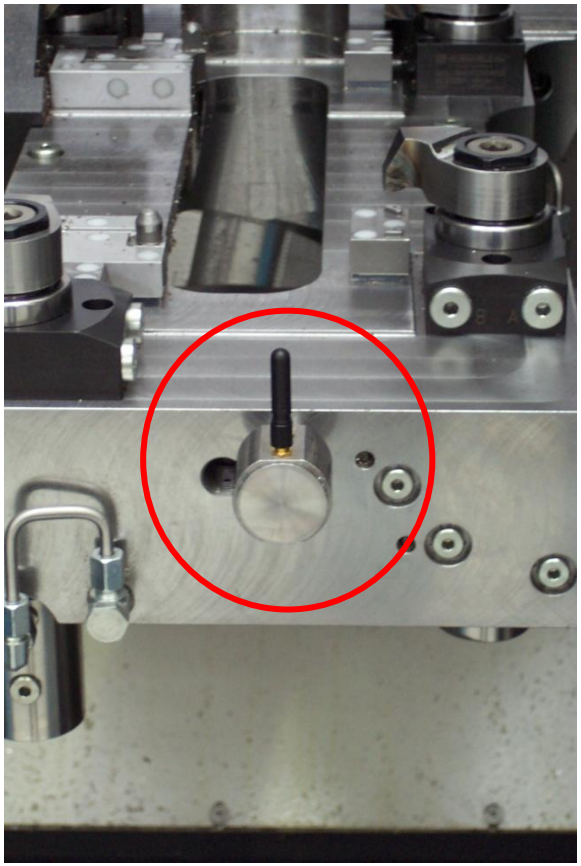
TOOL & PROCESS Monitoring

Wireless Sensor System – Idea of AE Wisy









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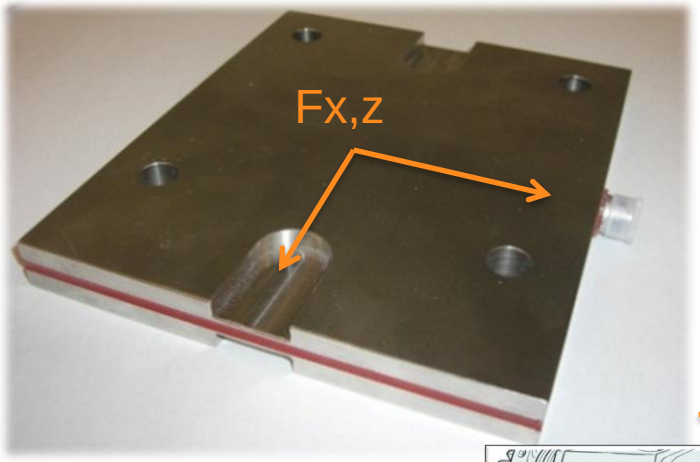
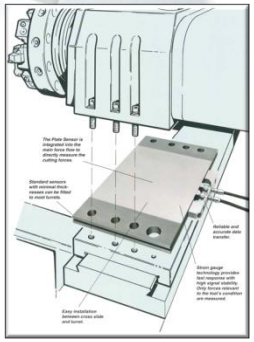
Feed Force Plate - Sensor



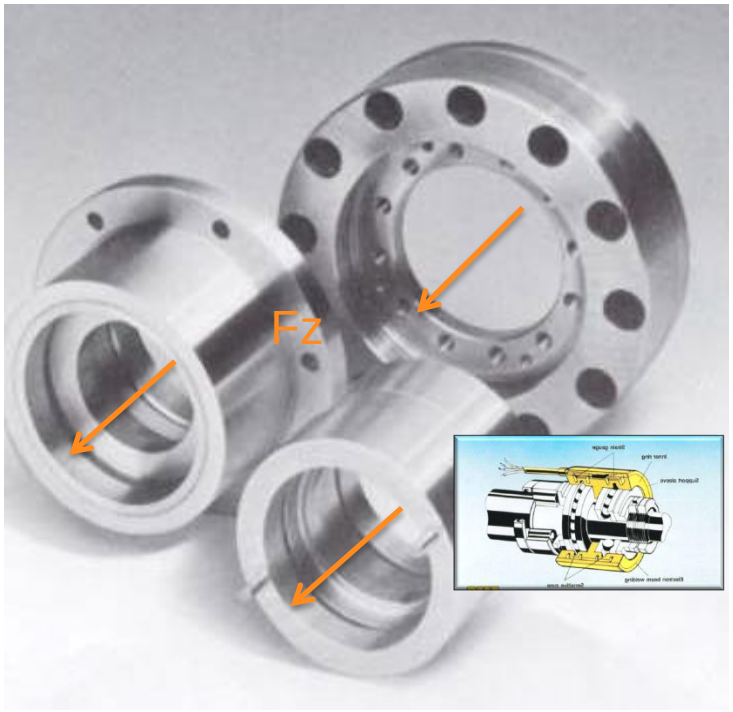
Vout: ±10 VDC

Wheatstone bridge
Preamplifier



Typical Values:
1-2 axis plates, x,z direction
Nominal Force: 10kN to 100 kN
Typical Sensitivity: S ≈ 0,2mV/V
Dimensions: 350mm x 500mm max.
Stiffness about 20µm/nominal load

Feed Force Ring - Sensor



Typical Values:
Nominal Force: 0,5kN up to 350kN
Typ. Sensitivity: S ≈ 0,8 mV/V to 1mV/V
Dimensions: 20mm additional to bearing diameter
Stiffness about 20µm/nominal load

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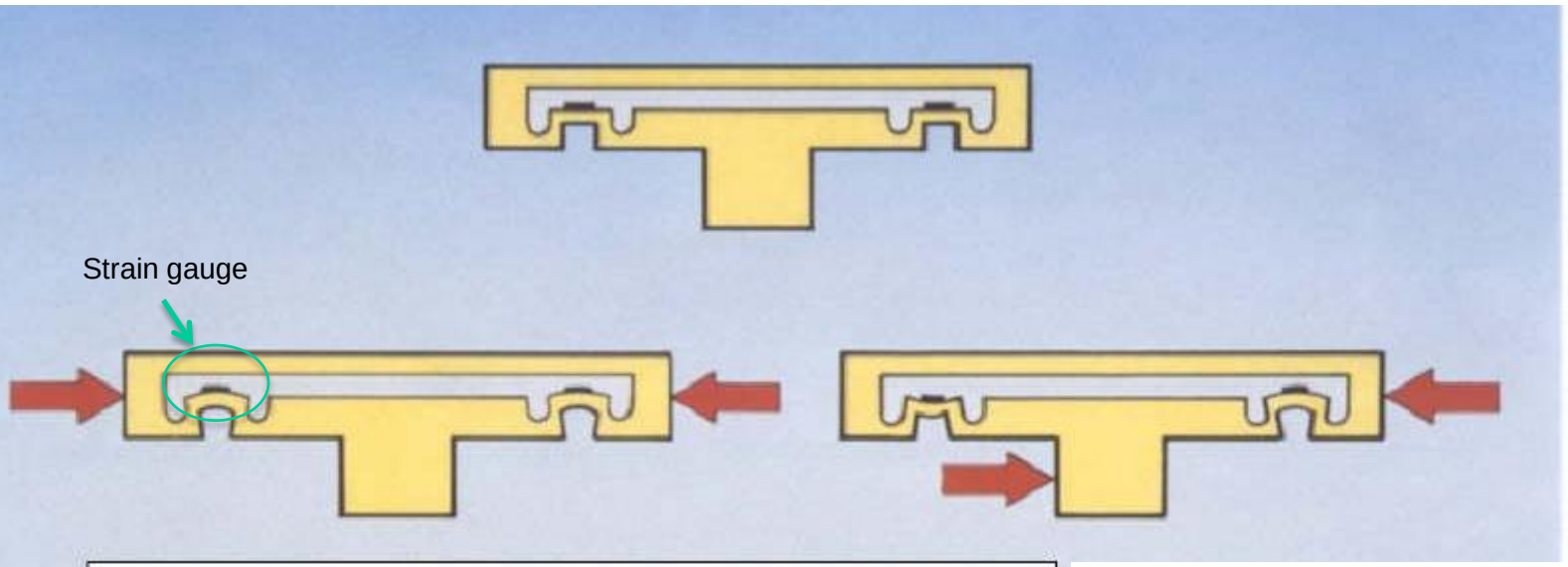
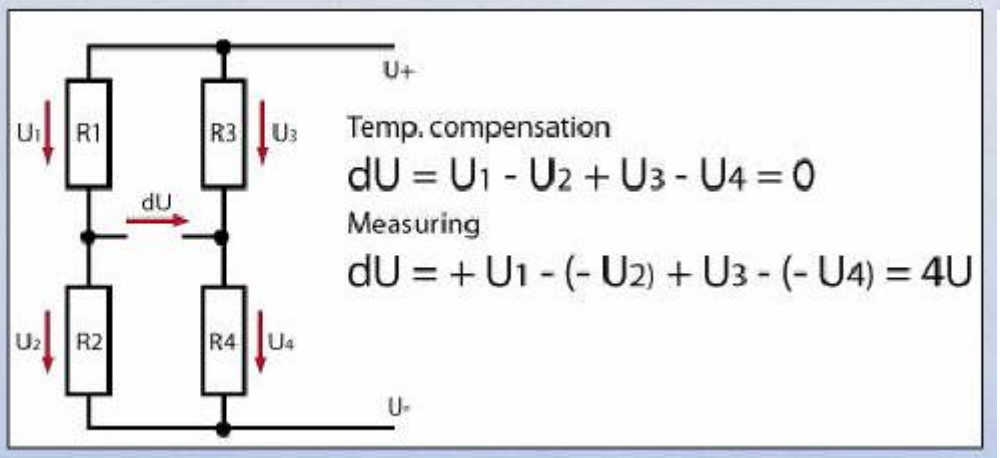
Feed Force Ring - Sensor



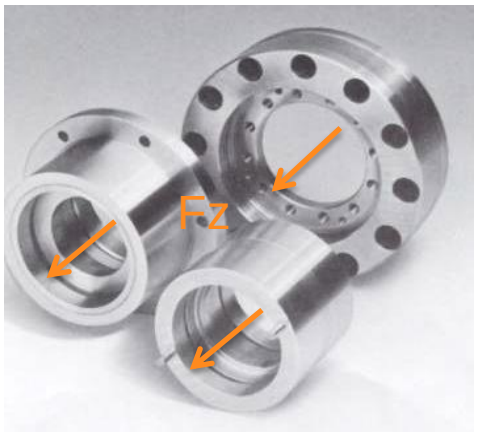


Temp. compensation

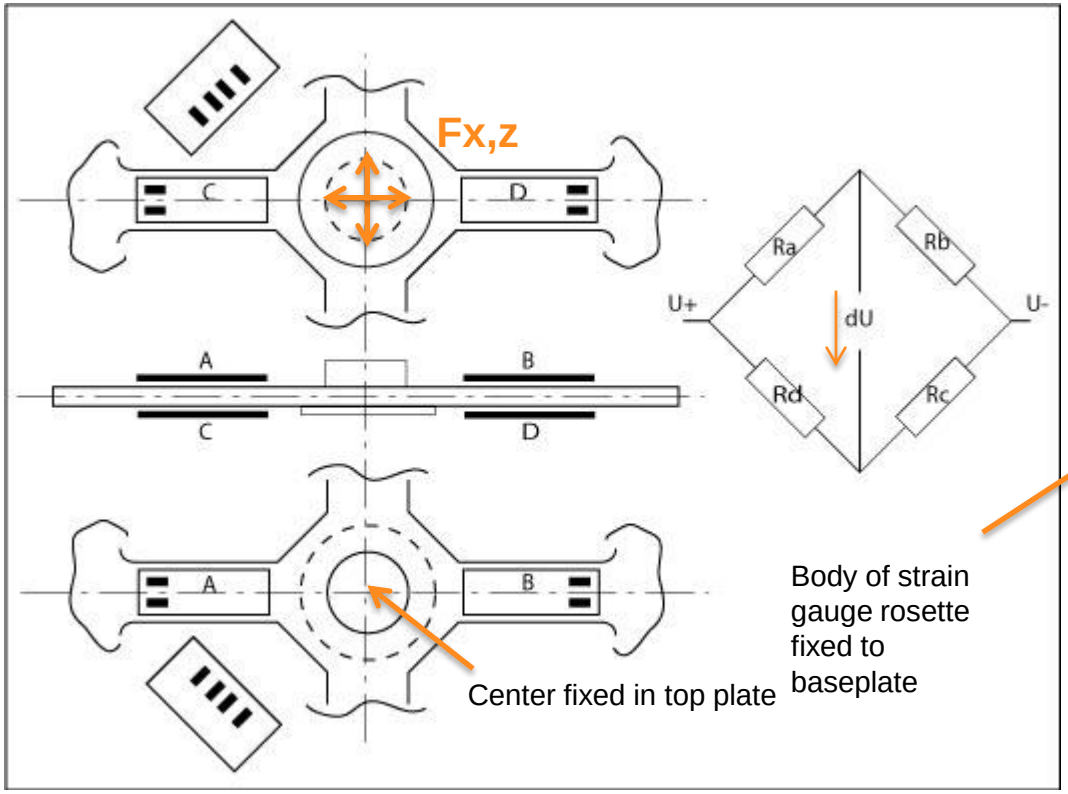
$$dU = U_1 - U_2 + U_3 - U_4 = 0$$

Measuring

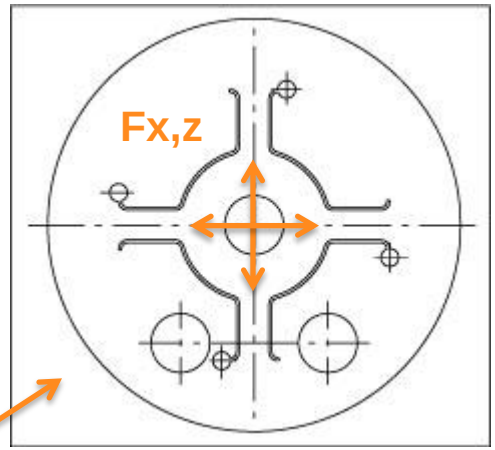
$$dU = +U_1 - (-U_2) + U_3 - (-U_4) = 4U$$

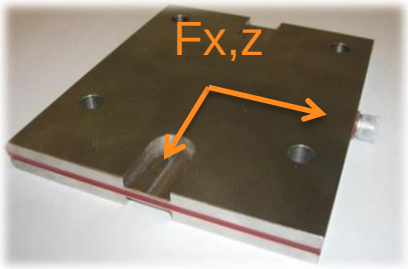


Feed Force Plate - Sensor



Strain gauge rosette





TOOL & PROCESS Monitoring

FLOW SENSOR FOR TOOL MONITORING

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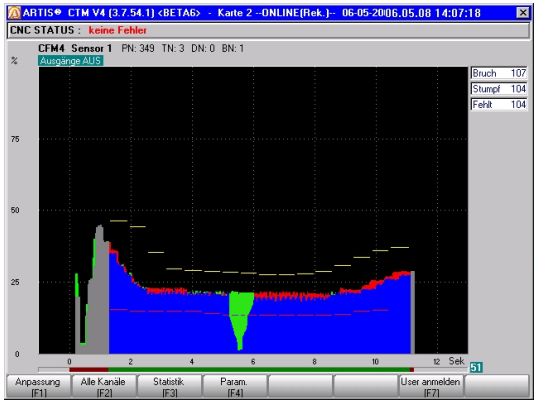
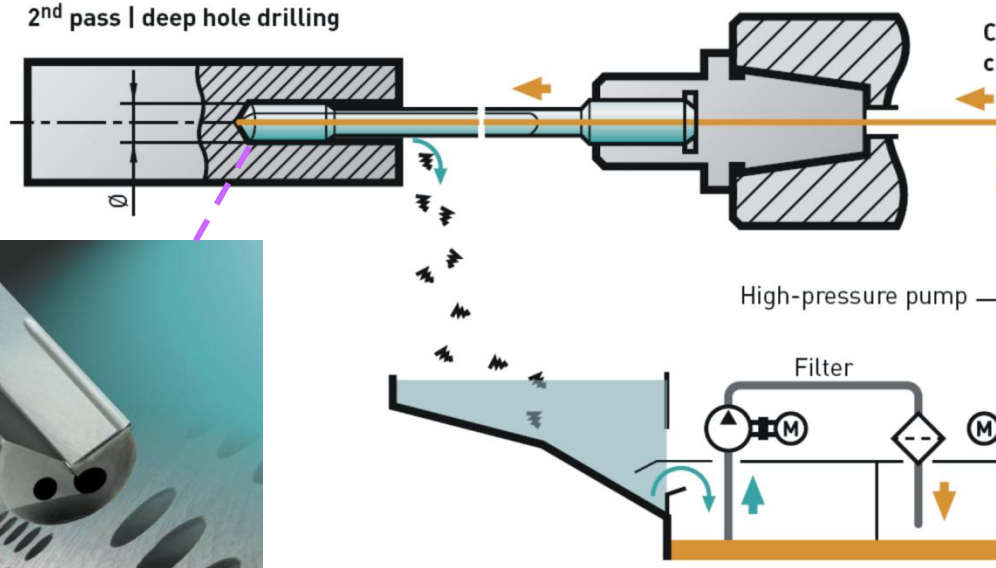


CTM V5

CFM4 Contact



fluid sensor

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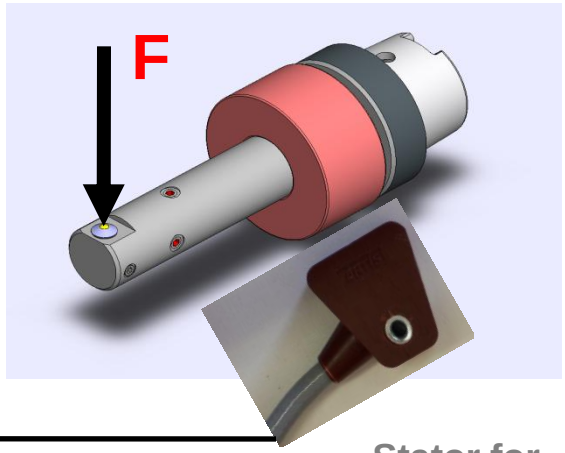
TOOL & PROCESS Monitoring

FORCE PROBE FOR PLANING MONITORING

MARPOSS



Stator for energy supply

Monitoring system CTM

>>> DDU-4 with tool holders

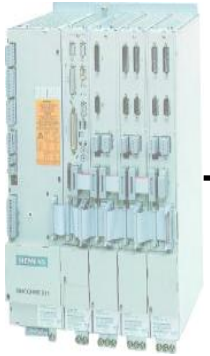
Advantages

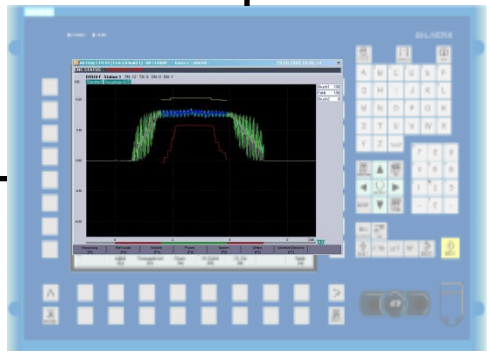
>>> monitoring of planing processes

>>> measuring of planing forces

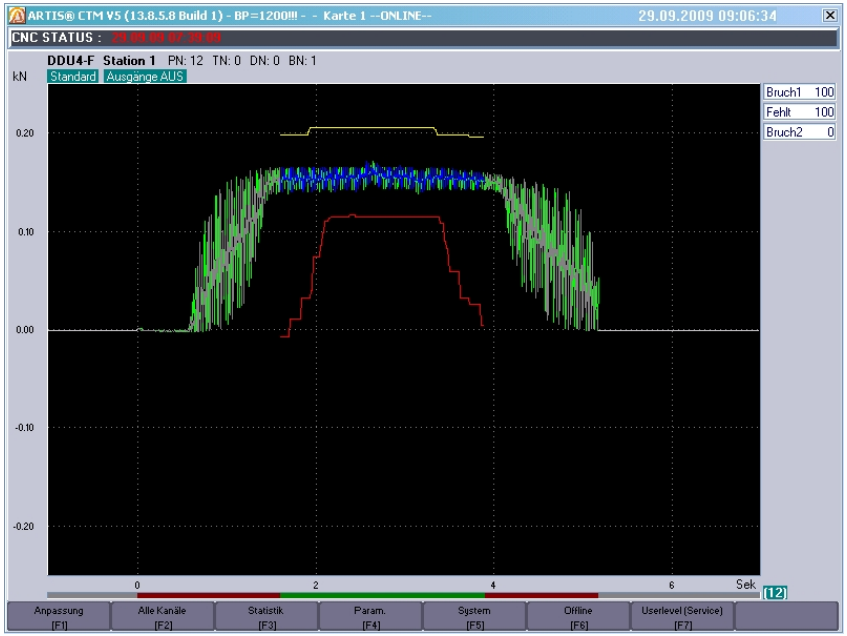
>>> monitoring of infeed

Measurement converter





User panel with monitoring system



Process Visualisation

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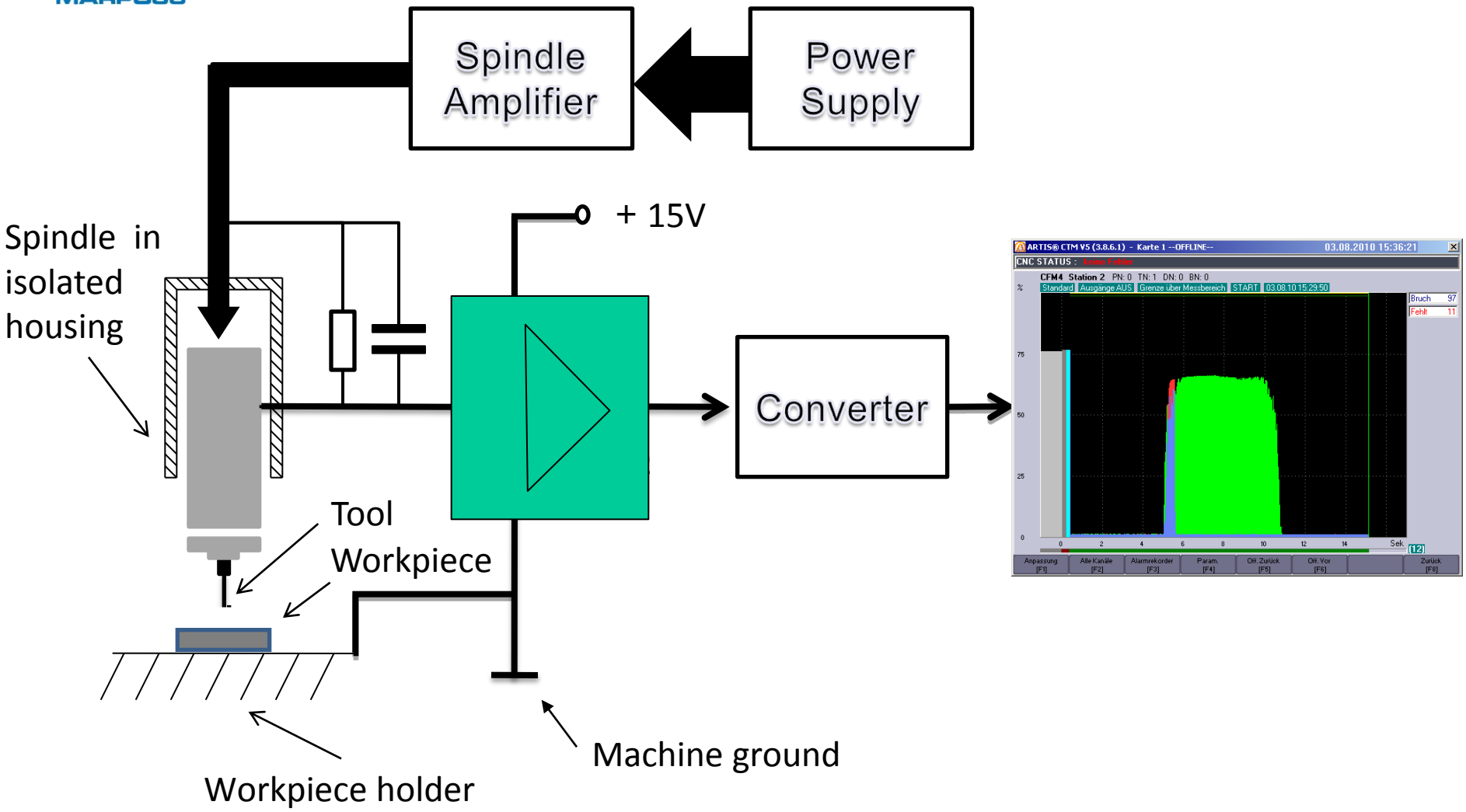
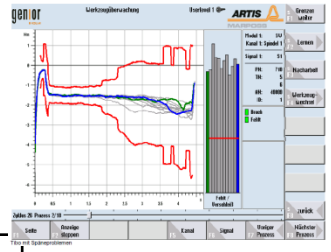
TOOL & PROCESS Monitoring

RESISTOR MONITOR FOR SMALL DRILL MONITORING



TOOL & PROCESS Monitoring

Integration of a Monitoring System



Machine Tool

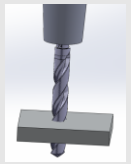
Operator Panel

Visu

Control

PLC/CC

Process



Sensor(s)

Drives
Spindle

Measuring
Converter

Monitoring
CPU

Machine
Interface

HMI
Interface

Data base

Components of a Monitoring System

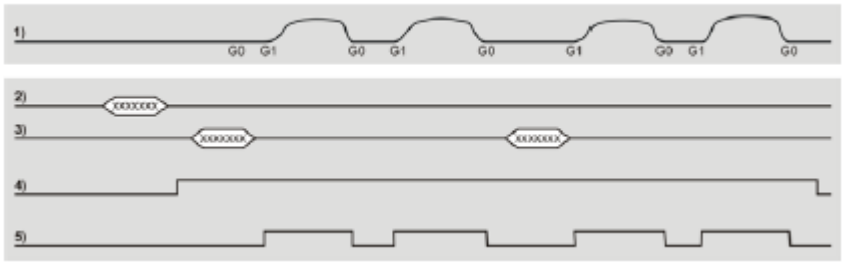
PLC -> Monitoring system

Spindle 1	DWord
X1 axis	DWord
Y1 axis	DWord
Z1 axis	DWord
Spindle 2	DWord
X2 axis	DWord
Y2 axis	DWord
Y2 axis	
Program Number	Word
T-Number	Word
Supplementary number	Word
T-Number for status	Word
Program active	Bit
Learn	Bit
Machine reset + clear alarm	Bit
Alarm incorrect	Bit
Machining active	Bit
Reworking	Bit
Wear active	Bit
AC active	Bit
Thread active	Bit
Clear	Bit
Learning using tool settings	Bit
Tool change	Bit
Tool wear	Bit
Tool clear	Bit
Tool position	Word

Monitoring system -> PLC

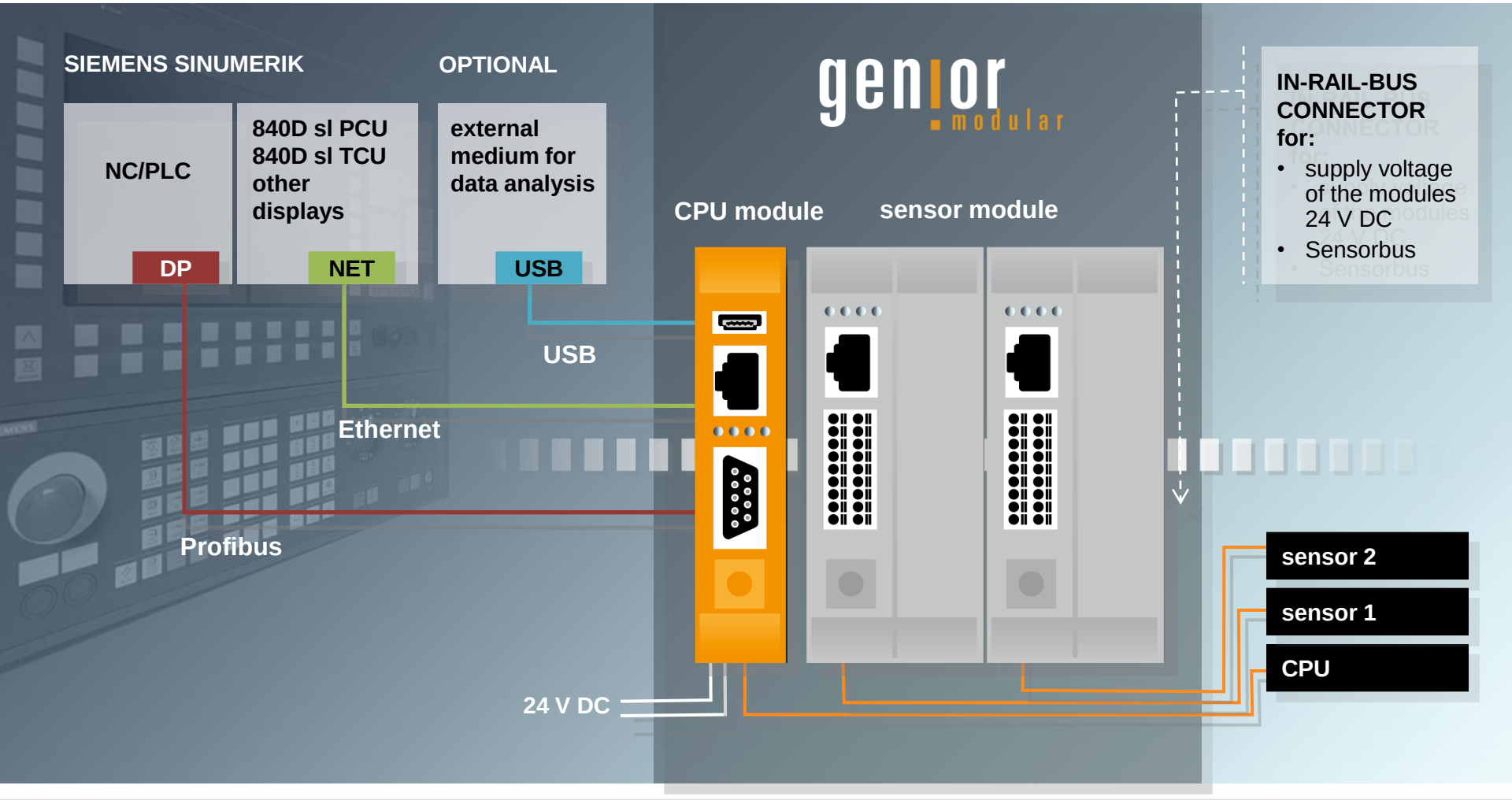
System status	Word
Break alarm	Bit
Wear alarm	Bit
Missing alarm	Bit
Break Level 0 (no monitoring)	Bit
Break Level 1 (not sharp)	Bit
Break Level 2 (sharp)	Bit
Alarm disabled	Bit
Acknowledgement machining active	Bit
AC active	Bit
Wear active	Bit
AC control output	Word

Timing diagram:



TOOL & PROCESS Monitoring

Self learning Monitoring System GENIOR MODULAR - GEM



TOOL & PROCESS Monitoring

Self learning Monitoring System GENIOR MODULAR - GEM

TOOL & PROCESS Monitoring

Self learning Monitoring System GENIOR MODULAR - GEM

torque

or other physical variables

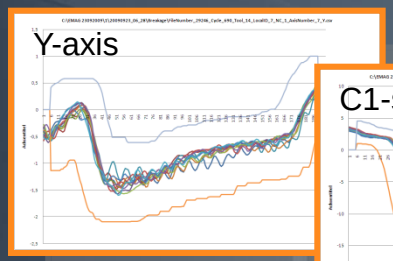
upper limit

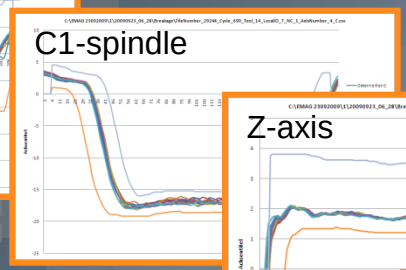
lower limit

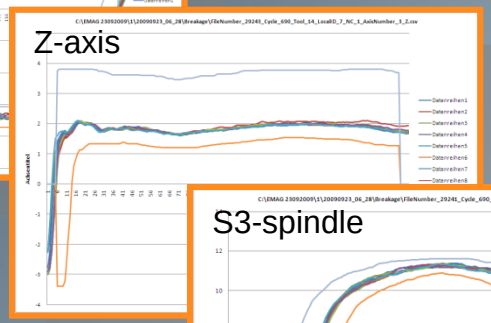
- automatic setting of the limits
- on the history of differrent metal cutting processes limits are set
- if the process is constant, so is the quality of the workpieces
- manual corrections are possible

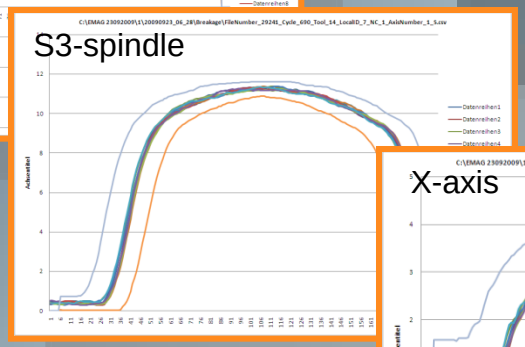
TOOL & PROCESS Monitoring

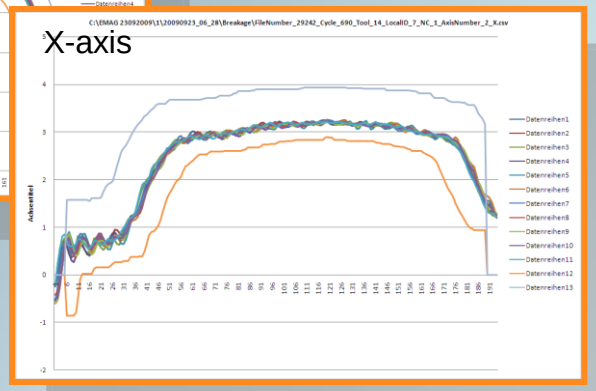
Rapid integration and automatic configuration - GEM









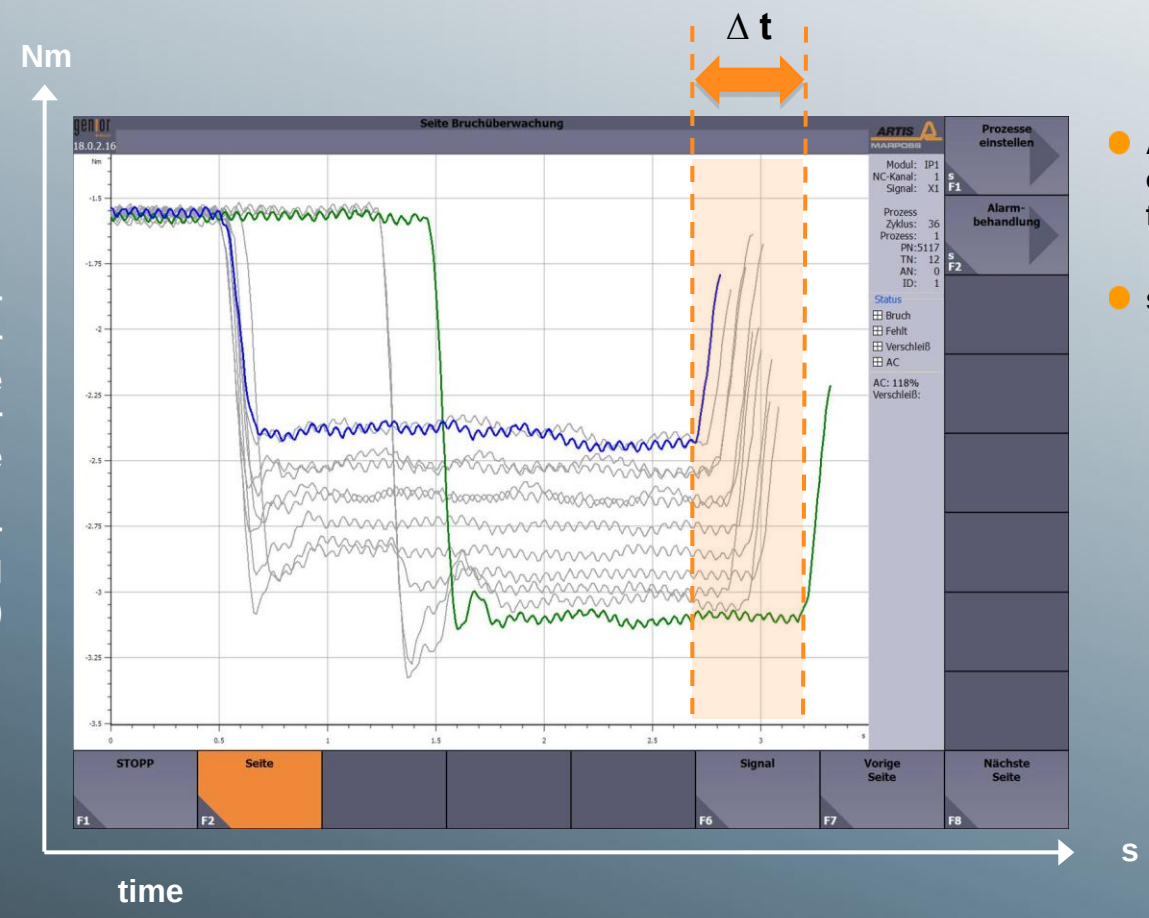


examples of monitoring of several axis and spindles

- monitoring of the axes is automatically configured
- rapid involvment and integration into the PLC program of the machine tool

TOOL & PROCESS Monitoring

Adaptive Control - GEM



- AC control defines the optimal load-dependent force at the cutting edge
- shortening of cycle times

TOOL & PROCESS Monitoring

Adaptive Control – Example for Potenzial

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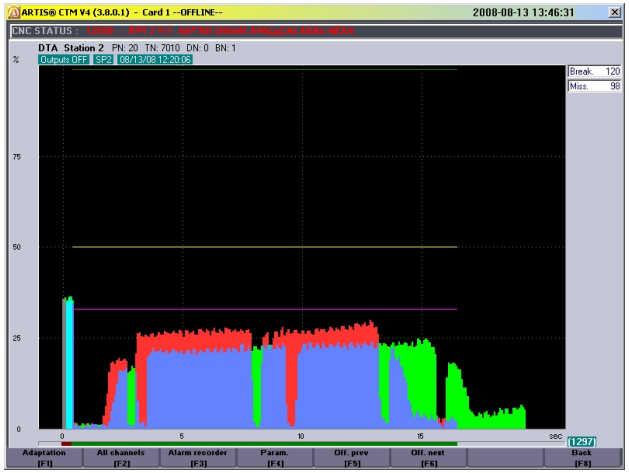
Example: Honsberg, Hyundai, Korea, CTM, Siemens 840D



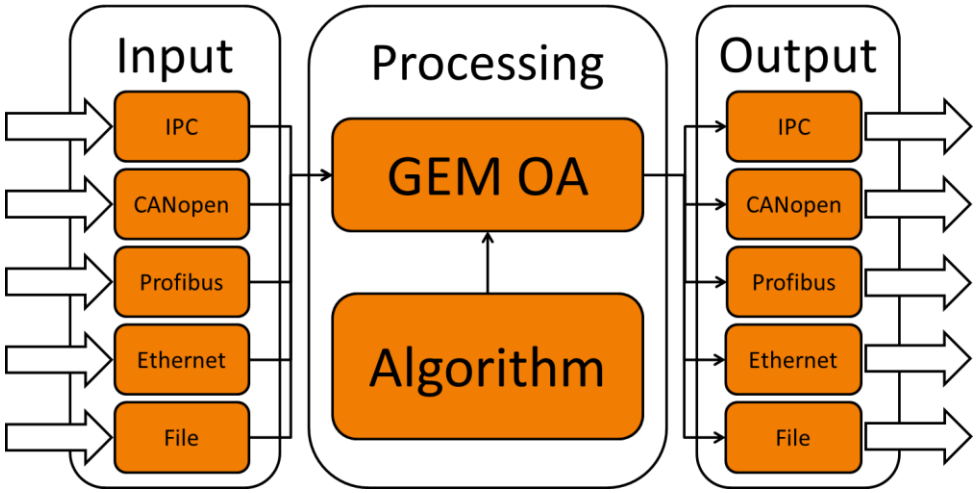
NO	TOOL NO.	DISCRIPTION	RPM/FEED	TOOL LIFE(EA)		Cycle time(sec)			Remark
				Before A.C	After A.C	Before A.C	After A.C	Reduce time	
1	7001	¢ 18 E/MILL	3503/700	200		15	14	1	
2	7002	¢ 30 E/MILL	1497/479	80		40	35	5	
3	7003	¢ 20.4/23.4 DRILL	940/200	80		42	37	5	
4	7004	¢ 40 DRILL/R/M	500/313/160	200		22	18	4	
5	7005	¢ 6.8 DRILL DP19	3747/937	300		39	37	2	
6	7006	¢ 6.8 S/DRILL	3419/684	400		13	11,5	1,5	
7	7007	M8*1.25 TAP	1400/1750⇒1115/1373	400				0	
8	7008	¢ 5.0 DRILL DP17	4500/675	500		7,5	7,5	0	
9	7009	M6*1.0 TAP	1000/1000	700				0	
10	7010	¢ 8.0 DRILL DP85	2588/310	200		19	16	3	
11	7011	¢ 20.5/22.8 BOR'G	1196/478,359	100		17,5	16	1,5	
12	7012	¢ 17.78 DRILL	800/240	1000		7,5	6,5	1	
13	7035	¢ 18.15 BOR'G	3100/150	100		13	11	2	
14	7013	¢ 21.7/22 BOR'G	1202/577/385	120		12,5	11	1,5	
15	7014	¢ 6.0 DRILL	2495/299	500		6,5	5,8	0,7	
16	7015	¢ 27.5 E/MILL	1158/324	80		65	55	10	
17	7016	¢ 11.5 DRILL	2215/731	120		73	70	3	
18	7017	¢ 7/9 S/DRILL	3640/728	250		15	13,5	1,5	
19	7018	¢ 7/10.5 S/DRILL	2730/819	250		27	24	3	
20	7020	M8*1.0 TAP	1100/1100	500				0	
21	7021	¢ 8.5 DR DP25	2997/749	300				0	
22	7023	M10*1.5 TAP	955/1432	500				0	
23	7024	¢ 45 BOR'G	300/90	50		11,5	11,5	0	
24	7025	¢ 49 MILL'G CUT	500/120	200		11,8	10,4	1,4	
25	7026	¢ 53/58/65 MILL'G	300/120,96	300		19	16	3	
26	7031	¢ 16 BOR'G	1800/540	1000				0	
27	7032	¢ 34.5 R/BOR'G	600/288			5,8	5,3	0,5	
28	7033	¢ 39.5/40 BOR'G	524/210			8	6,5	1,5	
29	7034	¢ 35 F/BOR'G	600/192			7,8	7	0,8	
		WORKING TIME OF ARTIS				498,4	445,5	52,9	
		ACTUAL TOTAL CYCLE TIME				757	703	52,9	

7%

ARTIS

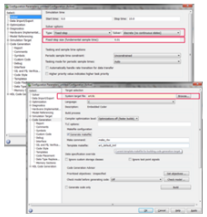
TOOL & PROCESS Monitoring

GEM OA – GEM Open Architecture



Adaption of model → C-Code export → Compile library → Transfer to device

Matlab Simulink



QNX Momentics IDE 4.5

Done by ARTIS if needed

TOOL & PROCESS Monitoring

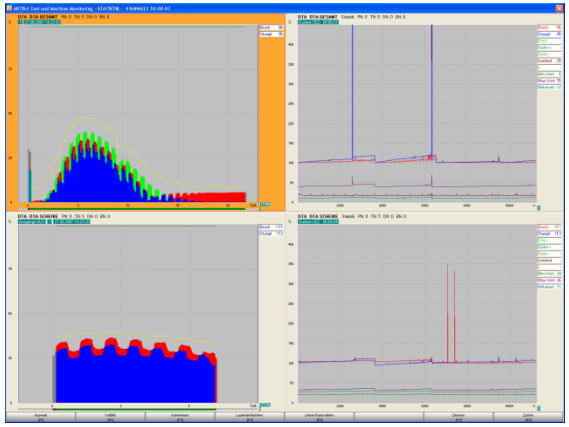
Process data analysation and visualisation

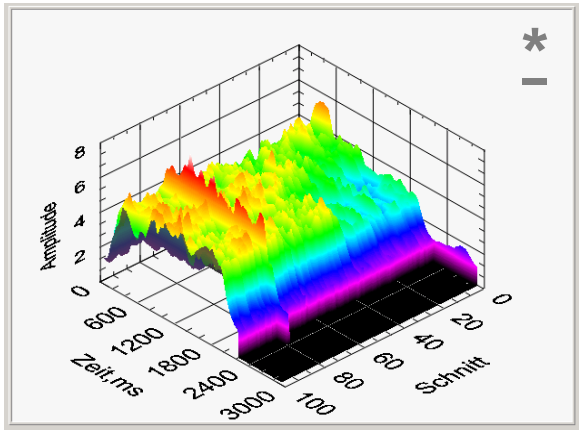
- True Power
- Acoustic Emission
- Vibrations
- Torque
- Forces

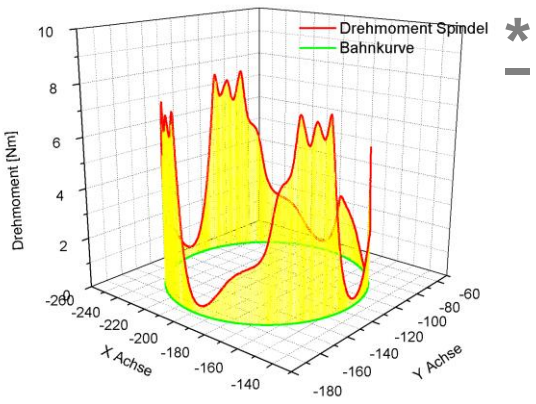
Battery tool holder
(now up to 8h measuring time)

- Torque
- Feed Force
- Bending

Suitcase for process diagnosis







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REQUIREMENTS AND TRENDS FOR THE FUTURE

- Intelligent Sensors
- Small Sensors
- Wireless Sensors (Energy Harvesting)
- Sensors with Bus Systems
- Monitoring Strategies for Single Part Monitoring
- Multi Signal Strategies
- Strategies for Process Documentation
- Cloud Monitoring
- Integration in CAD – CAM Systems
- ...

TOOL & PROCESS Monitoring

Breakage Example

Video

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THANK YOU FOR YOUR ATTENION!

Grazie per la vostra attenzione!