



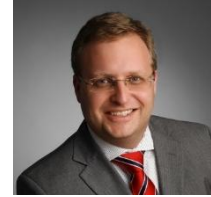
How PiezoBolts outcompete standard load cells

Operational experience with sensoric fasteners

September, 15th – 16th 2026 in Darmstadt, Germany

Strain gauge based sensor-bolts	20..
Foundation of ConSenses with M. Brenneis	12
Release of <i>PiezoBolt</i>	13
Market entry Japan / first devices	14
Machine fingerprints	16
Standard in first machine	16
Devices "Gen. B"	17
Devices "Gen. C"	19
Rollout ManufacturingDataSuite	24
Standard in machine evaluation and purchasing	24
	25

Dr. J. Stahlmann



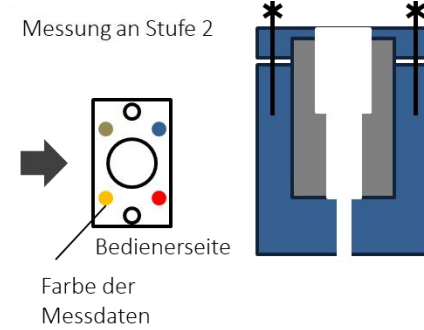
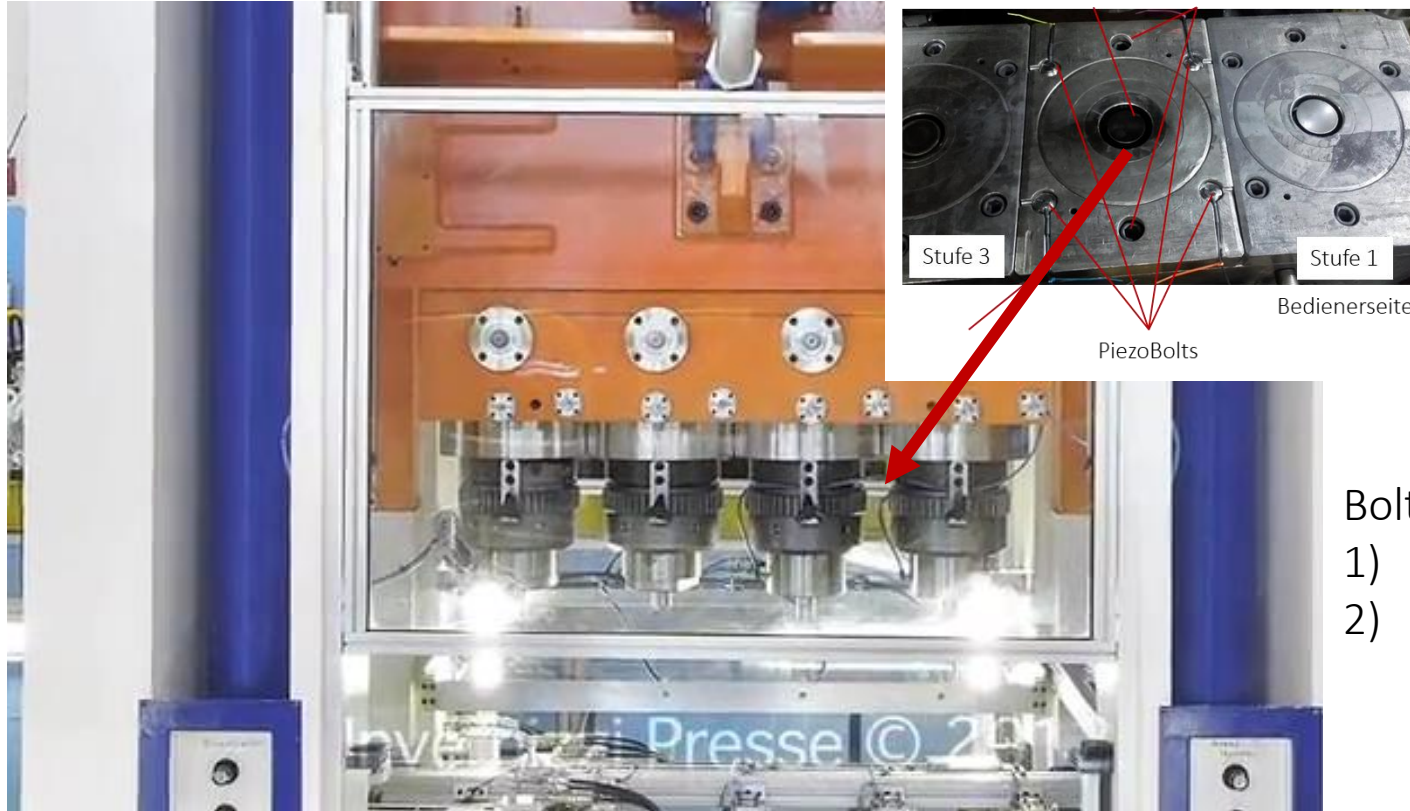
Dr. M. Brenneis



Markets / installations



- Business cases: Measuring in bolts vs. measuring with bolts
- Functionality of PiezoBolts
- Force measurement in technical systems
- Comparison between load cells and PiezoBolts
- Embedding multisensor / multiphysics-systems



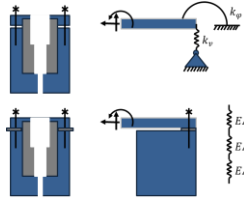
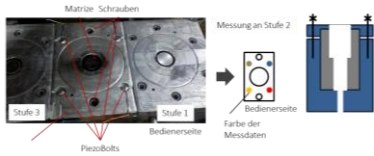
Bolt failures →

- 1) Expensive damages
- 2) Machine shutdowns for protective changes...

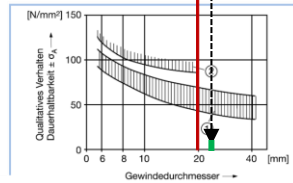
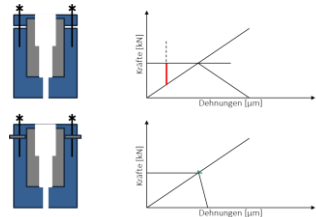
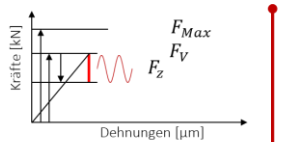
Measuring in bolts

→ Understand bolted connection

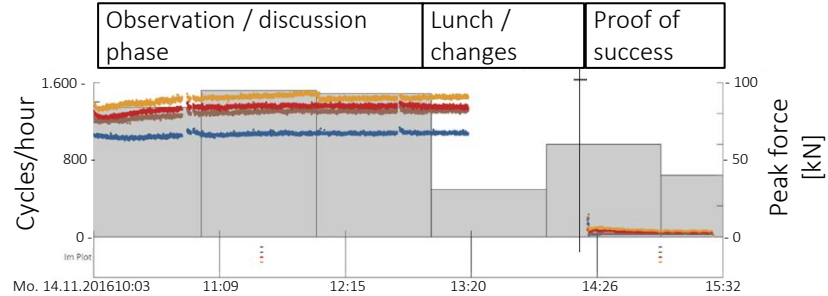
Tightening, loosening, breaking, bolt loads...



Steifigkeit unbekannt,
aber tendenziell weich.



Graph: VDI 2230, Ausgabe 1988
① vergütet, bewittert, nicht-vergütet
(Normalspannung)
② unvergütet, nicht bewittert



- Reducing bolt loads from 93 kN to 6 kN
- In one day
- Changes during the lunch break

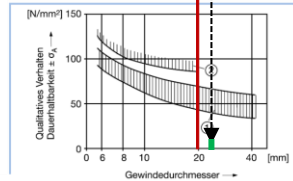
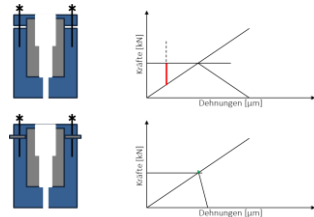
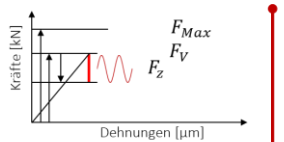
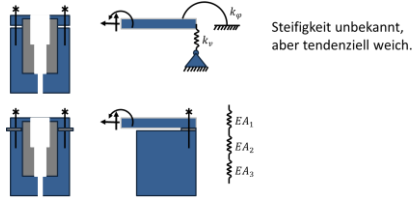
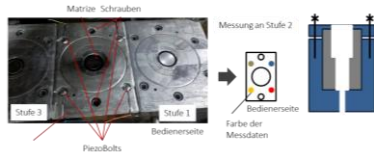
Result:

Fatigue effects eliminated

Measuring in bolts

→ Understand bolted connection

Tightening, loosening, breaking, bolt loads...



Grafik: VDI 2230, Ausgabe 1988
① original, bewährt, geprüft, norm-geprüft
(Normalschraube)
② verbleibt, ungeprüft, norm-geprüft

Measuring with bolts

→ Utilize innovative force sensor

Machine / Product

- Specification
- Design
- Analysis

- Adjusted designs
- More performance
- Less material
- Faster development

Process

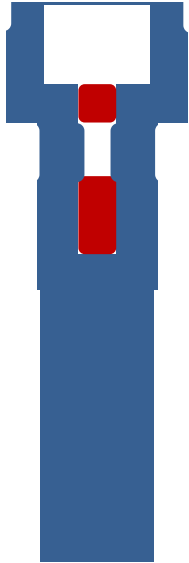
- Understanding
- Design
- Control

- Targeted adaptations
- Better timing
- Knowledge transfer

Damage

- Analysis
- Protection

- Root cause analysis
- 24/7 supervision
- Flight box systems



Production

- Standard bolt body
- Geometry cutting
- Insertion of sensor body
- Joining, labeling

Properties

- Robustness
 - Highest piezo-prestress in unloaded bolt situation
 - No polymers in force flow
 - No additional surfaces (like threads)
 - Sealed setup
- Performance
 - Highest resolution example given: e.g. PB16: 10 N .. 100 kN
 - Sample rates up to 40 kHz
 - Built for 24/7 applications

M6

M8

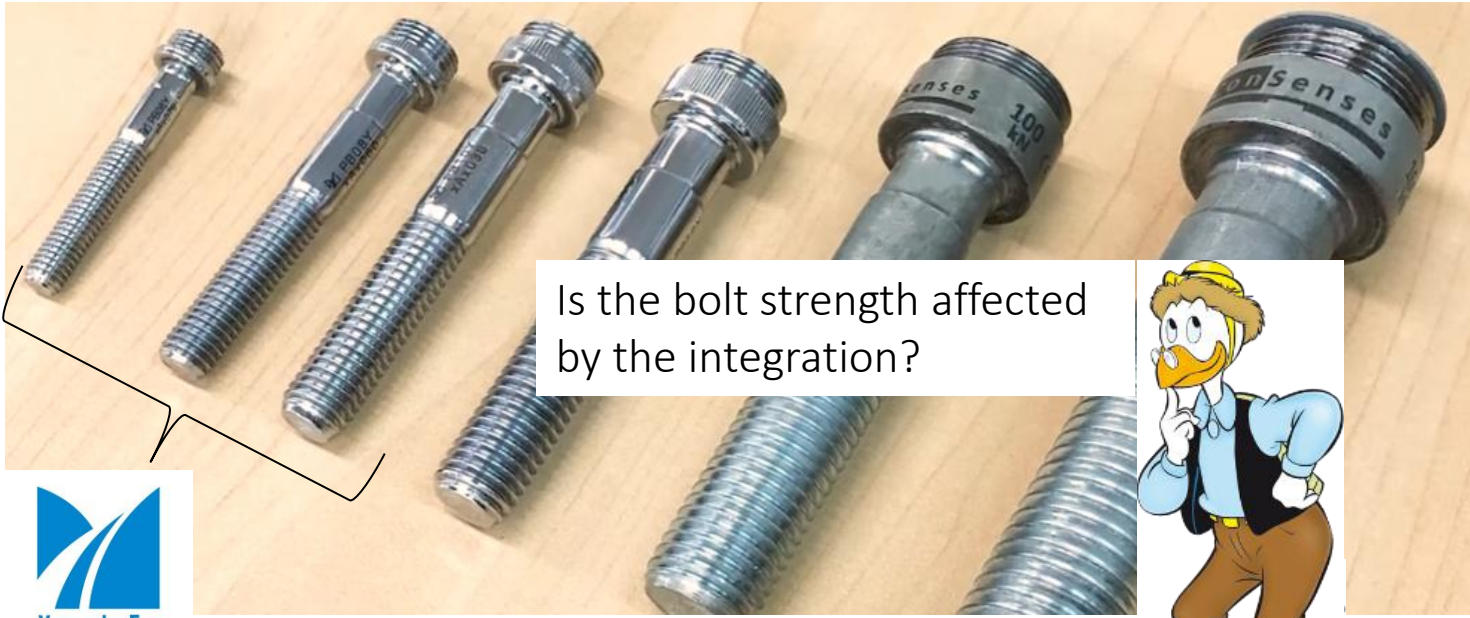
M10

M12

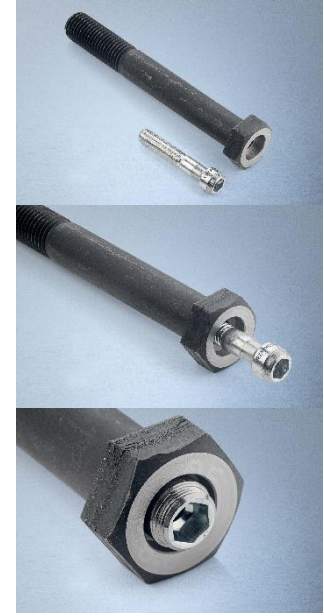
M16

M20

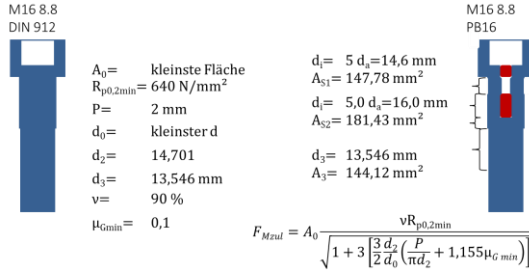
M24 +



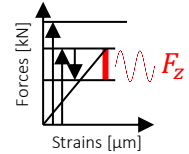
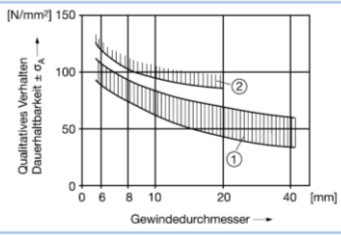
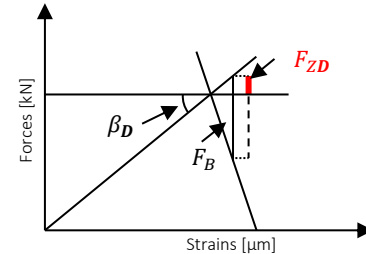
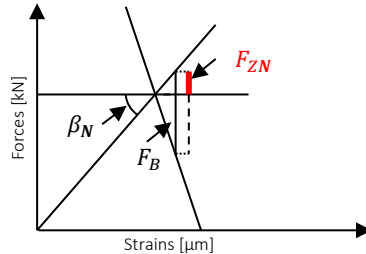
Is the bolt strength affected by the integration?



Static strength



Dynamic strength



$$\beta_D < \beta_N, F_B = const.$$

$$\Rightarrow \underline{F_{ZD} < F_{ZN}}$$

1) Static strength identical

2) Dynamic strength better (refer to Expansion bolts)

3) Tightening factor α (VDI 2230) can be assumed as 1 if bolt tension is measured with tightening tool.

1. Measuring in Machine element $\neq$ Measuring with the machine element
2. Smartly sensorized machine elements do not reduce the system performance

So far any questions, complaints, comments?



In every **mechanical** system...

- 1) Forces **matter** and (as a matter of a fact) forces are **invisible** (and for let's face it a really abstract concept)
- 2) Every force measurement is ALWAYS a strain measurement*
- 3) Usage of force data is mostly numeric (numeric controls, analysis, storage)

Information processing stages

- Force – strain – optic – electric – numeric
- Force – strain – electric – numeric
- Force – strain – time – electric – numeric
- Force – strain – thermal – electric – numeric

→ In most technical systems you want to control strains $\frac{\Delta l}{l} \rightarrow \text{known (mostly high)}$ EA . $\frac{\Delta l}{l} = \frac{\vec{F}}{EA}$

*Situation in systems of fluid dynamics; electrodynamics the situation is different: Particles are moving freely, trajectories can be tracked to calculate forces and strains do not matter.

Did you see the competing targets?

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Information processing stages

- Force – strain – optic – electric – numeric
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- Force – strain – thermal – electric – numeric

Measurement prefers huge strains

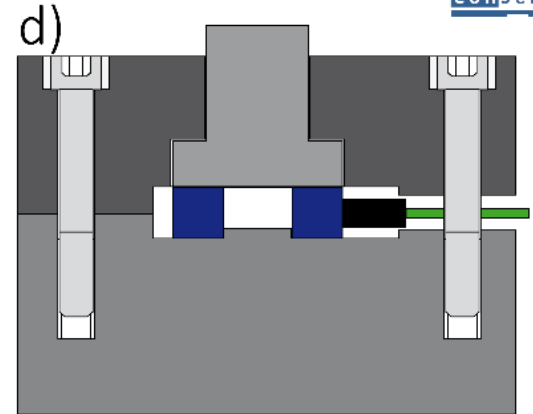
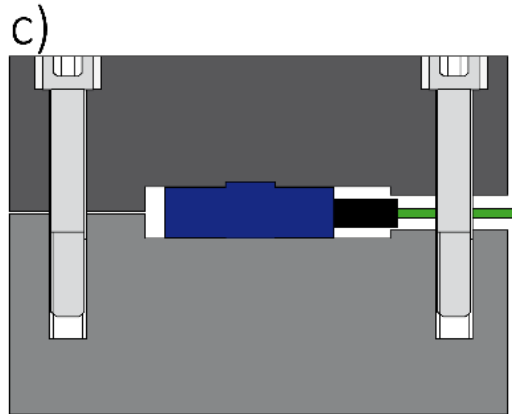
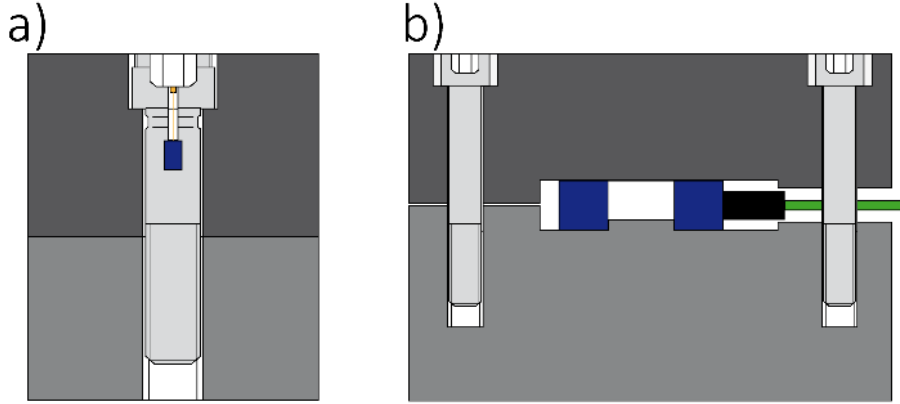


Precise machines prefer small strains

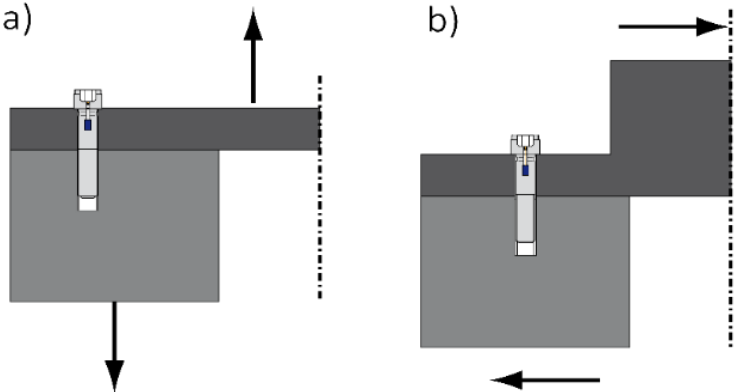
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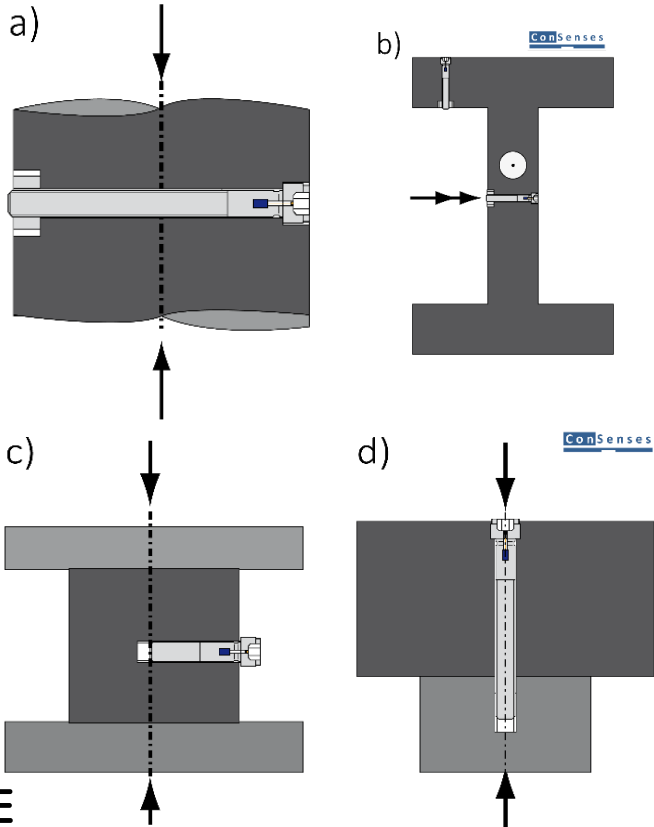
1) Load cells reduce stiffness



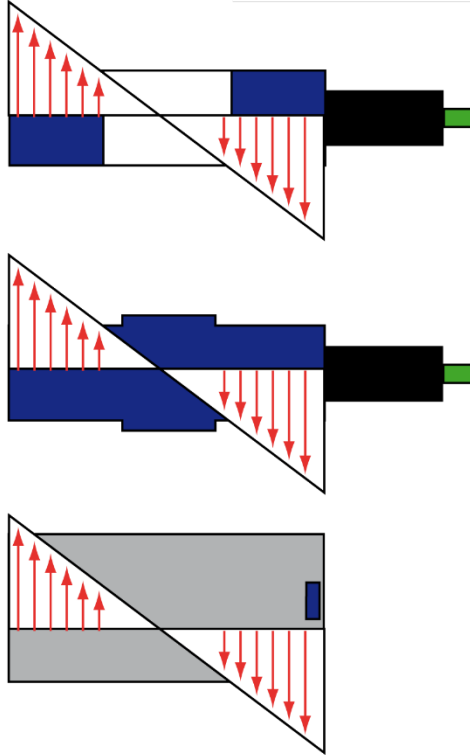
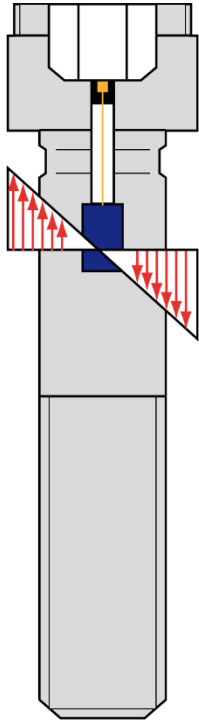
Bolt analysis



Substitution of load cells



2) Considerations on torque and bending an overload



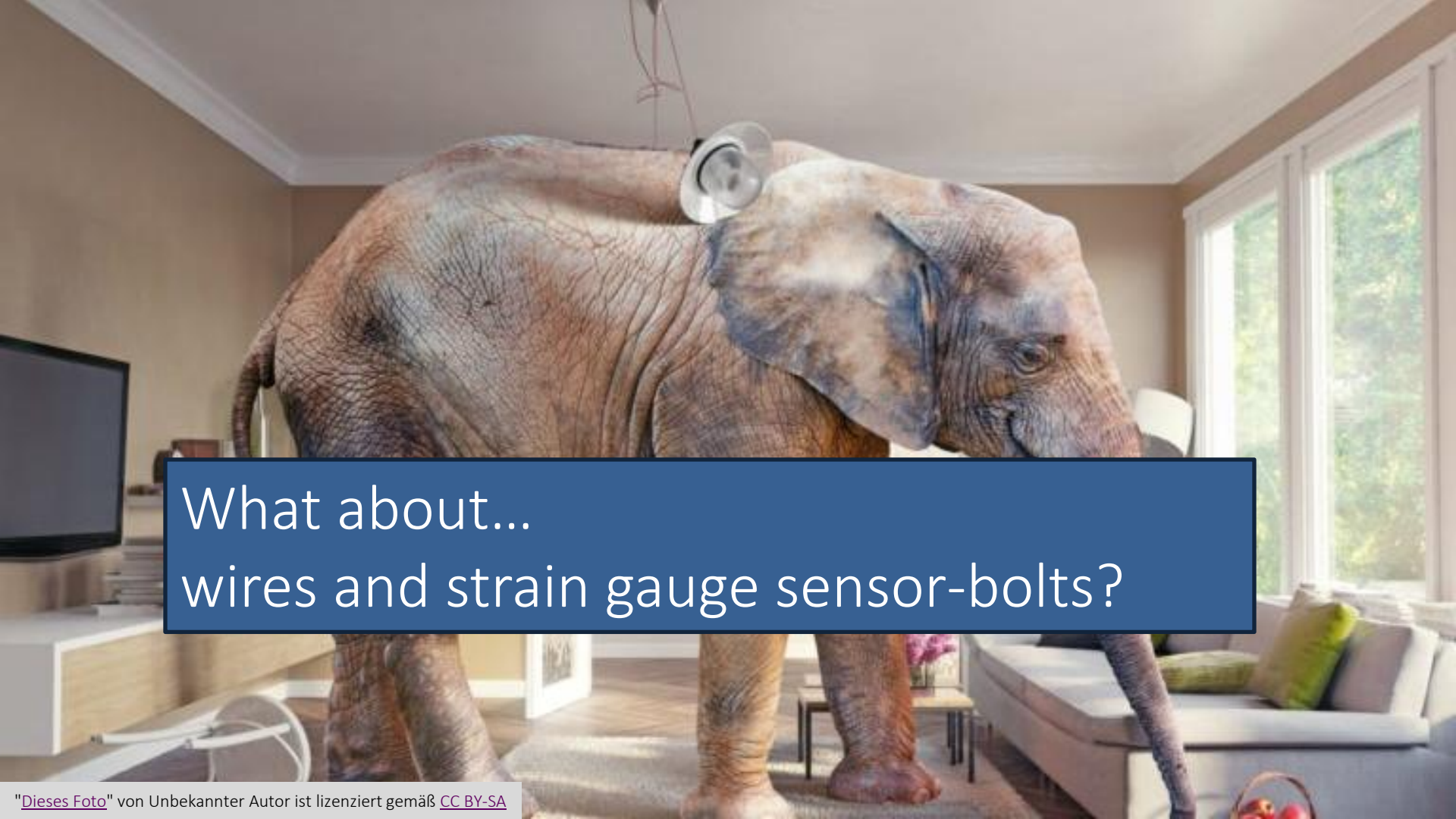
Same sensor material (type and quantity) applied in sensor center sensor will always outperform eccentric location by

- Simplicity
- Robustness
- Precision

	PiezoBolts	Load cells	Strain gauges
Pressure-overload is a risk	 No	 Yes	 Depends
Reduction of system stiffness	 No	 Yes	 Depends
Bending and torque sensitive	 No	 Yes	 Yes
Integration effort	 Depends	 High	 High

Positive side effect:

PiezoBolt shape enhances dynamic bolt functionality

A large elephant is standing in a modern living room. A small, circular, metallic sensor-bolt is attached to its back, connected by a thin wire. The room features a large window on the right, a grey sofa with green and grey cushions, a white coffee table, and a television on the left. The elephant's trunk is visible, reaching down towards the floor.

What about...
wires and strain gauge sensor-bolts?

Wires

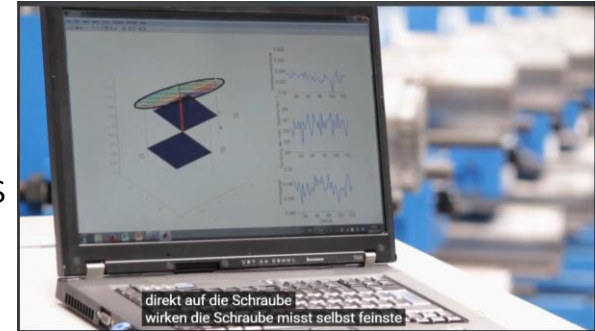
- 1) Deciding about signal transfer is a matter of engineering processes
- 2) Depending on reliability need data throughput and available energy different solutions are considerable
- 3) Robustness and usability is a matter of proper planning during the design stage
- 4) Costs and systems benefits are extremely competitive for proper designed wires

<https://www.youtube.com/@tudarmstadt/search?query=schraube>

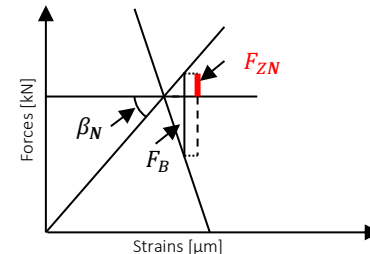


ConSenses

3D
measurements
in bolts 2013



→ Sensor-bolts need extreme amplifications since additional bolt force is by default small!



1. Start reconsidering what matters in the measurement tasks
2. In practice usage of wires is a matter of engineering design and not of faith
3. Commonly used approaches are not naturally the best practice
 - Keep mind: Engineering is not naturally following the herd 😊



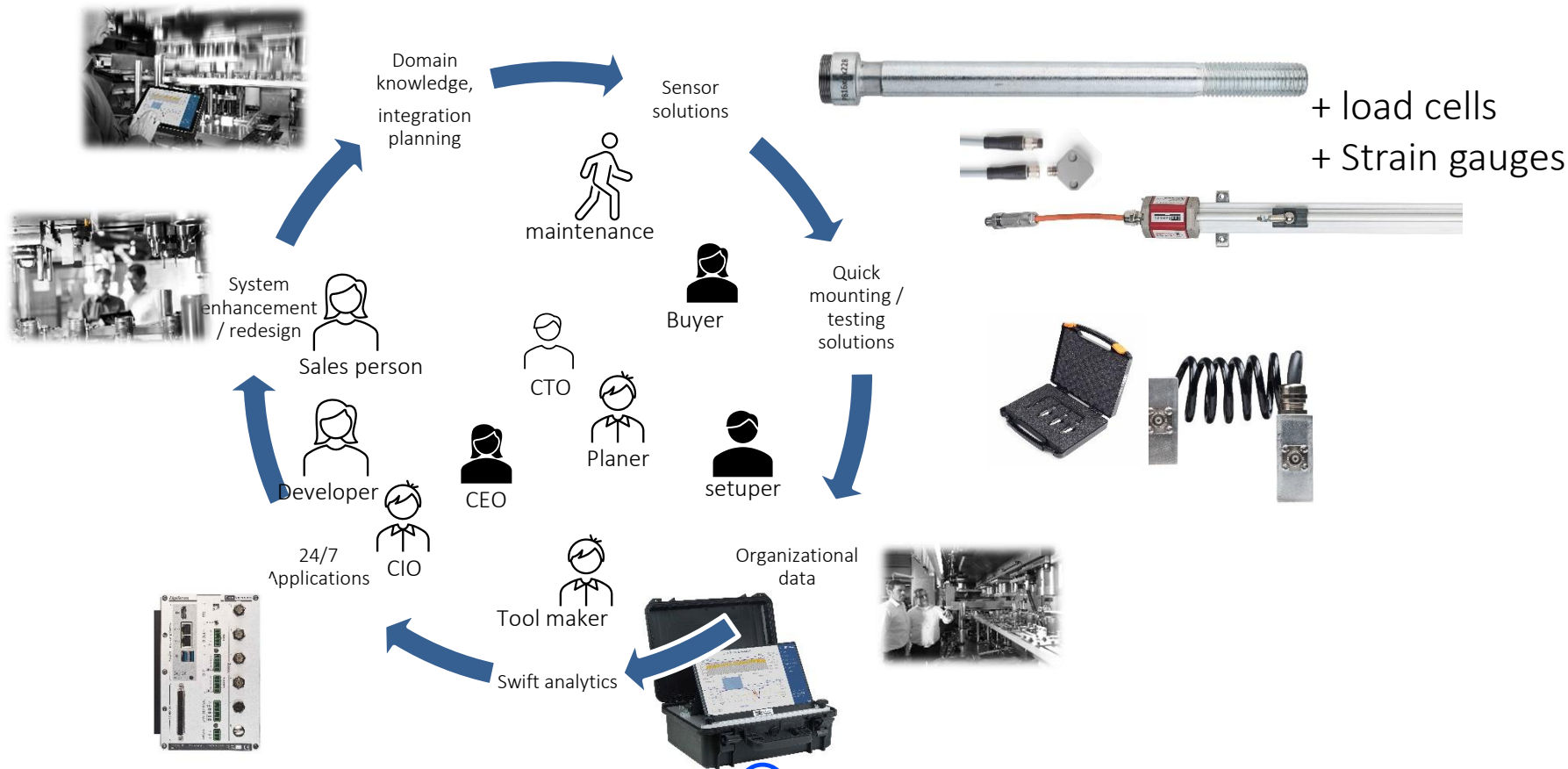
So far any questions, complaints, comments?



ConSenses approach is

--- Giving orientation ---
by

- a) Producing a realistic image of actual machine behavior based on measurement which consists of
 - a) Force, acceleration and precise position data values
 - b) Organizational information for the current state
- b) Prepare, distribute and introduce high value datasets
 - a) Delivering the right information in the right shape at the right time to the right person
 - b) Collaborate with partners to build best possible solutions



Thank you

Questions

Remarks

Comments