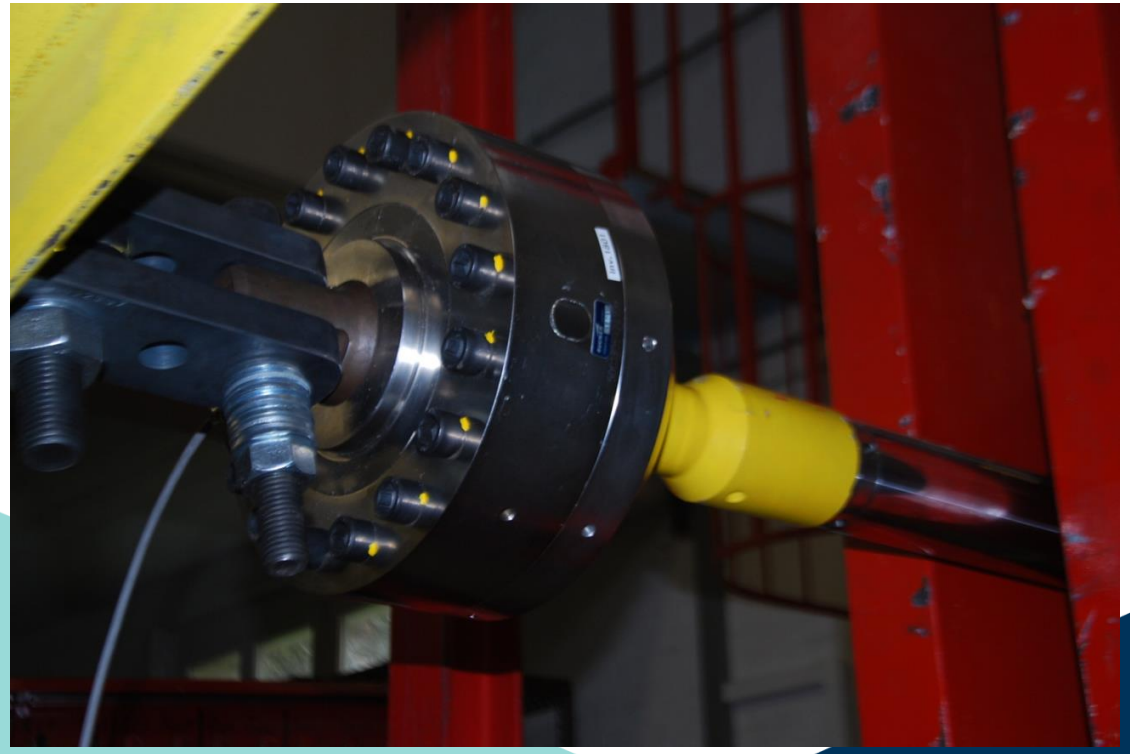
Force sensors
How to choose the right sensor for my application



Today´s speaker

Thomas Kleckers

- **Product manager for force sensors at HBK**
- Engineer for physical technology
- > 10 Jears experience in force measurment technology
- **E-Mail:** Thomas.Kleckers@hbm.com

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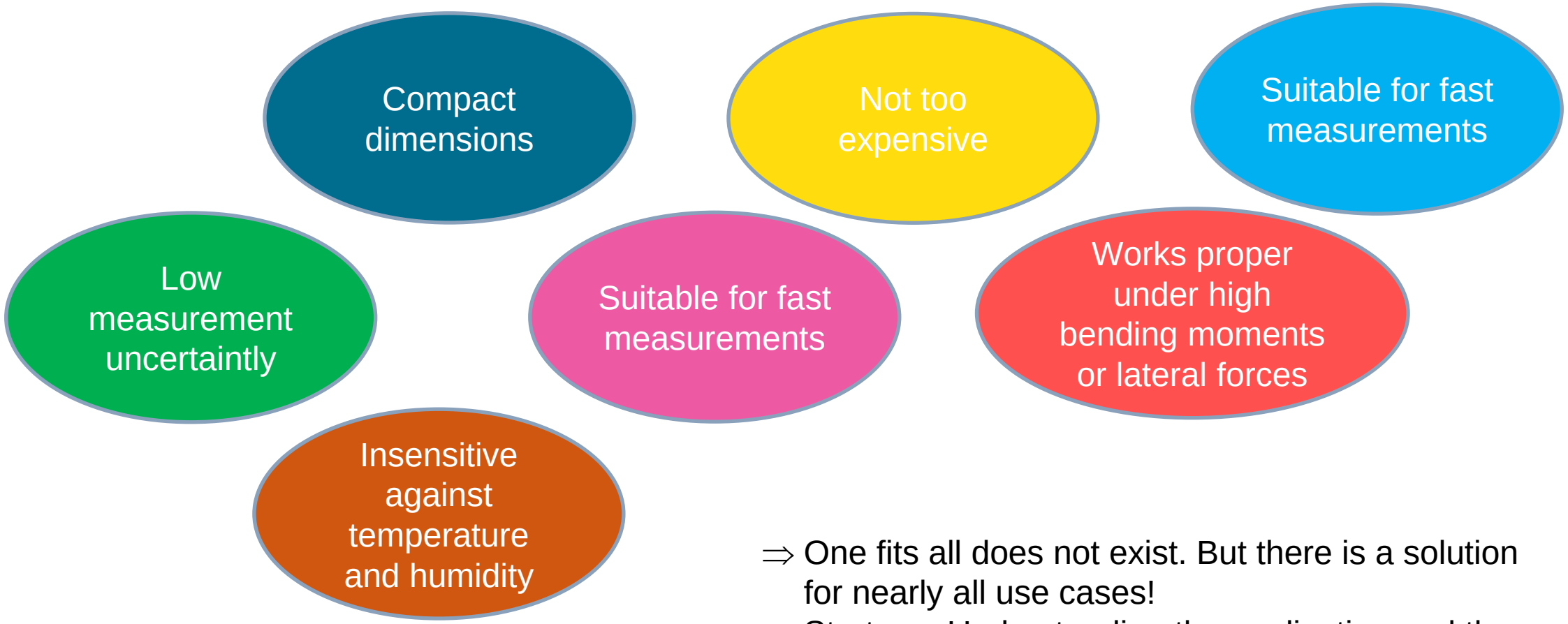
Questions to be asked before choosing a force transducer

- Tensile or compressive forces or both?
- Force to be measured?
- How much space is available for my sensor?
- Can I perform a calibration in mounting position?
- Dynamic or static measurement?
- What is the lowest force I need to measure?
- What is the surrounding of my measurement?

One load cell for all applications?



⇒ One fits all does not exist. But there is a solution for nearly all use cases!

⇒ Strategy: Understanding the application and the load cell characteristics will lead to right sensor

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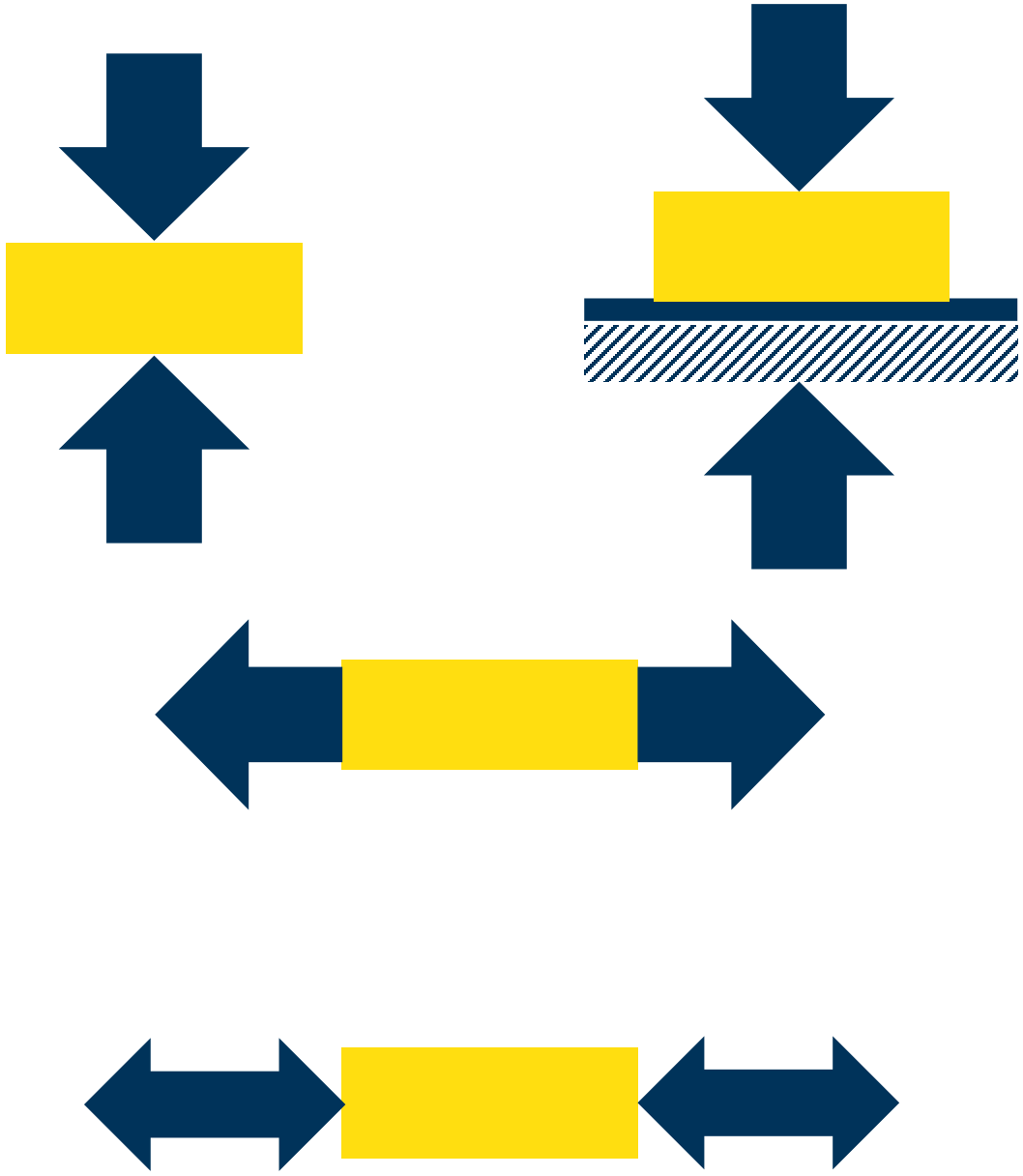
Forces: Direction of the force

Compressive forces:
:
Easy example: Weighing. Common in many force applications: material testing, process monitoring (Welding, forming, rolling,..)

Tensile forces:
:
Mechanical rope or cable tests, reinforcement monitoring, Overload detection in several applications (lifts, cranes,….)

Alternating forces
:
Very often in fatigue tests, component testing.
Sensors used to control servo drives.
Load cells for torque measurement in dynos



Sensors for compressive forces

Spherical load bottom
- Very common
- Precise
- Lateral forces can not be introduced into the sensor

Force washer / Internal holes
- Industrial accuracy
- Repeatability not that good
- Compact

Flange mounting
- Easiest way to mount a load cell
- Common for piezoelectric sensors- for compressive forces

Sensors for tensile, compressive and alternating forces

Internal threads
- Most common
- Withstand lateral forces / bending moment

Internal threads
- Limited lateral forces / bending moments

Flange mounting
- Easiest way to mount a load cell
- Limited in bending moments (in comparison with internal threads)

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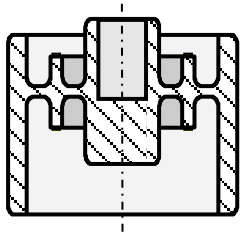
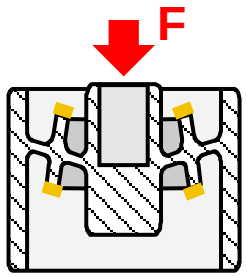
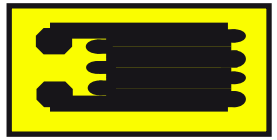
Maximum force to be measured

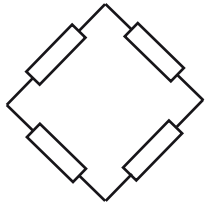


Spring Body





If a force is introduced a strain occurs on the surface of the material.
Strain gauges change the strain into a change of resistance.



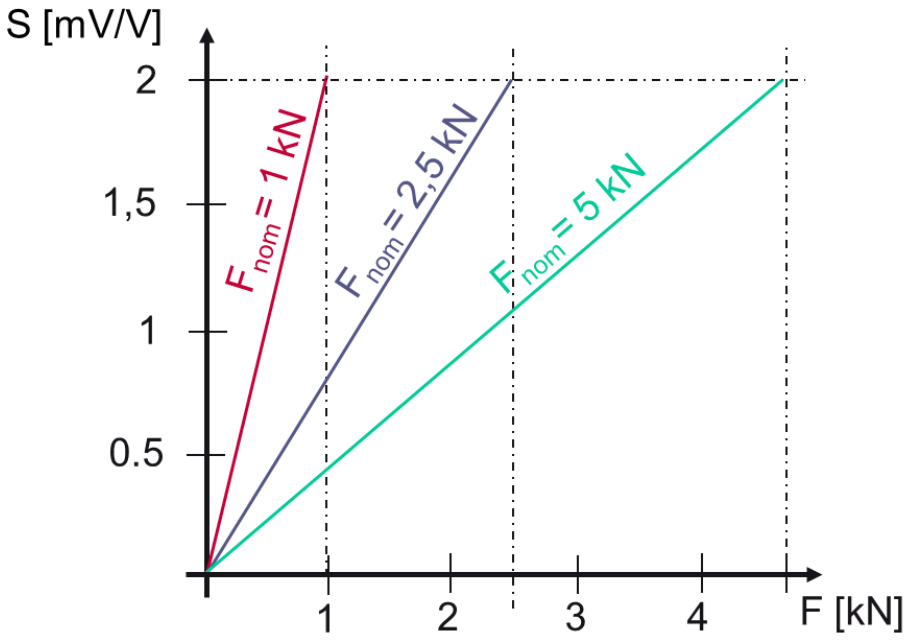
The whetstone bridge converts this change in resistance into a measurable voltage.

⇒ **The relation between force and strain appears is of importance for the sensitivity of a strain gauge based sensor.**

- Higher stiffness: Less sensitivity, higher capacity
- Lower stiffness: More sensitivity, low capacity

The capacity of a strain gauge based sensor is scalable by designing the spring element

Maximum force to be measured



- Output at full load(„rated output“) = A constant value
- Depending on the design this value could be between 0.5mV/V and >4mV/V

C6B: 2mmV/V @ 10 MN

S2M: 2mmV/V @ 10 N

Models up to 60 MN have been produced

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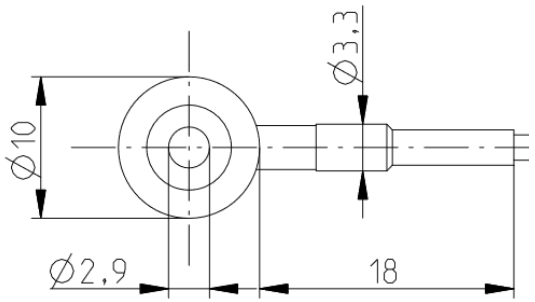
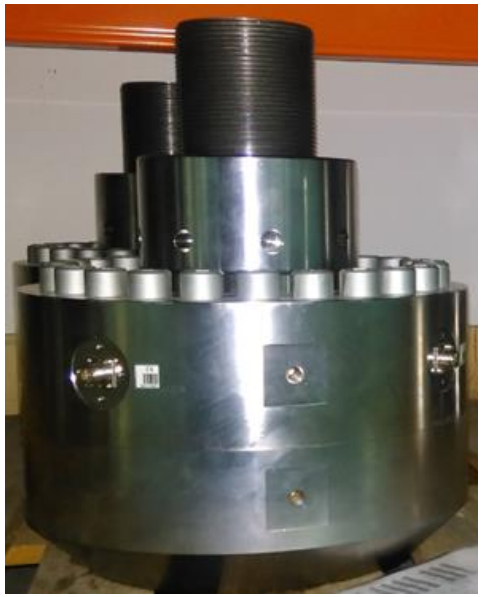
How much space needs a force sensor?



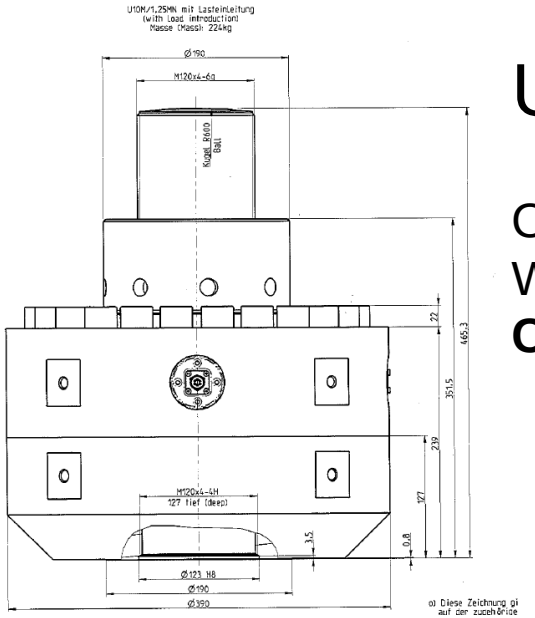
C11:

Outer Diameter	10 mm
Weight:	6.5 g
Capacity:	**500 N**



Big capacities & compact dimensions are a challenge.

Miniature Sensors (app. 26 mm outer diameter) at HBK: 50 N … 20 KN



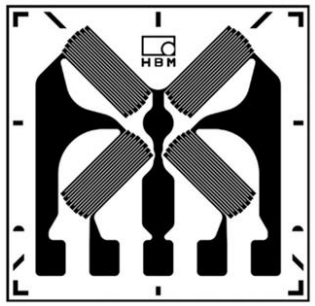
U10M:

Outer diameter:	390 mm
Weight:	186 kg
Capacity:	**2.5 MN**

How much space needs a force sensor? Calibration in mounting position possible?

No space available, huge forces, economical solution required, …

=> Strain links or strain gauges



Strain gauges

Strain sensors with strain gauges

Piezoelectric strain sensors

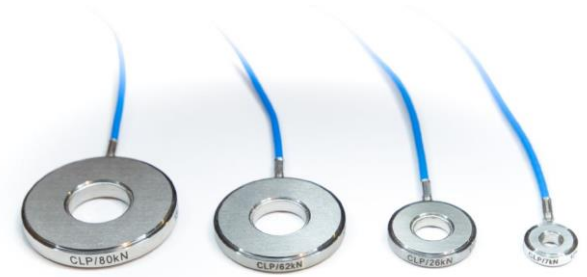
Economical sensor for forces > 500kN
Easy to install, no changes in of the stiffness of the machine
The sensors must be mounted on the object, after this process a calibration is required (if you want to have a result in Kg, N, bar,….)

Another compact solution: Force washer

Strain gauge based force washer:

- Drift free
- Excellent repeatability
- Sensitive against bending moments / Eccentric force introduction

Piezoelectric force washer



Piezoelectric force washer

- Very compact design
- Excellent repeatability
- Insensitive against bending moments / Eccentric force introduction
- Need to be pre- stressed before operation

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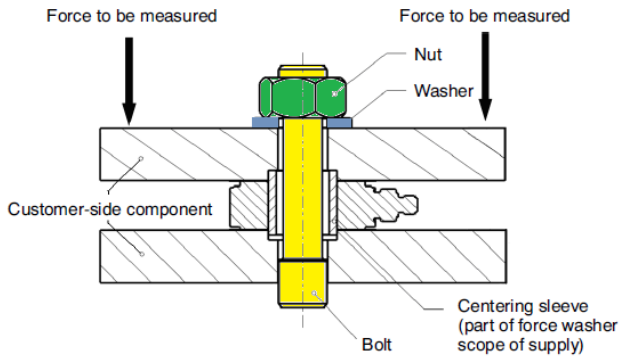
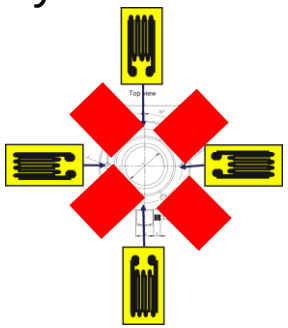
Calibration in mounting situation



Areas with low sensitivity



Piezo technology: A calibration is required because the bolt changes the sensitivity of the measurement point (The sensor is just a part of the measurement point)

Strain gauge technology: A calibration is recommended because areas where no gauges installed have a lower sensitivity.

How can I perform my calibration?

- C6B load cell for press applications
- Filling a silo with water
- Use a traceable reference sensor (very common in assembling, welding, press fit applications)

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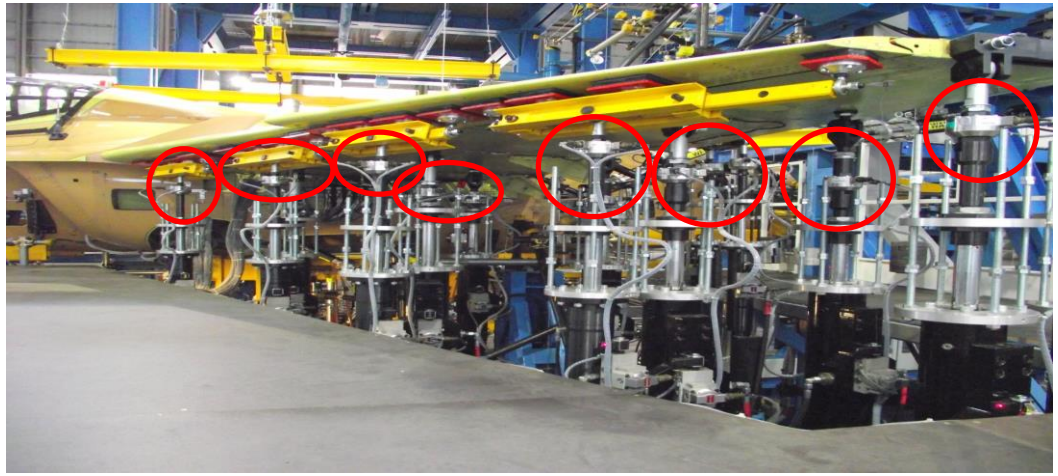
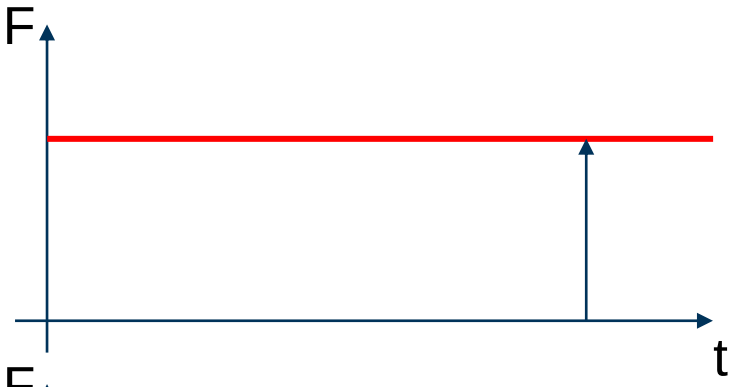
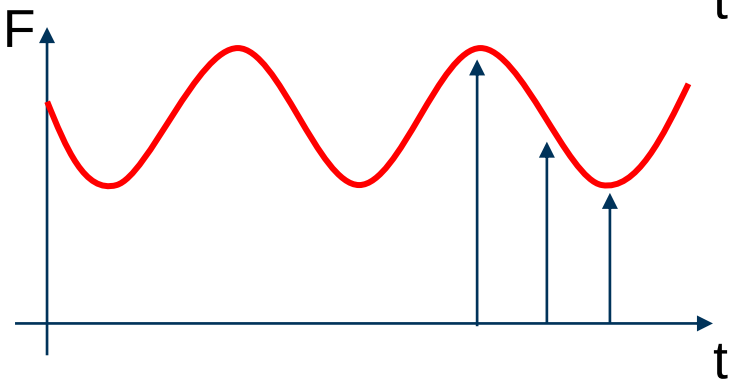
Dynamic or static measurement?

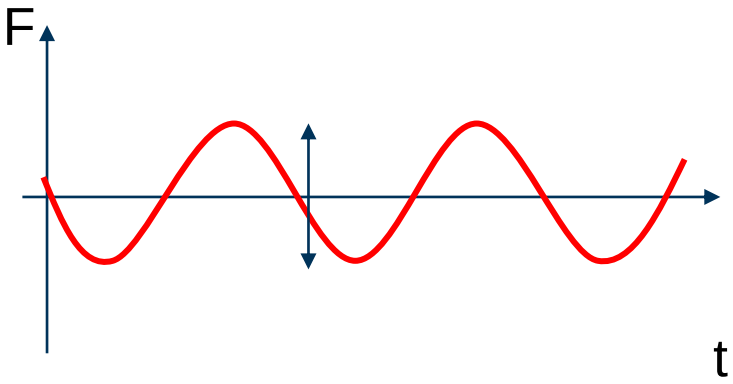




Static load (related to zero point)



Dynamic load (related to zero point)



Dynamic load (not related to zero point)

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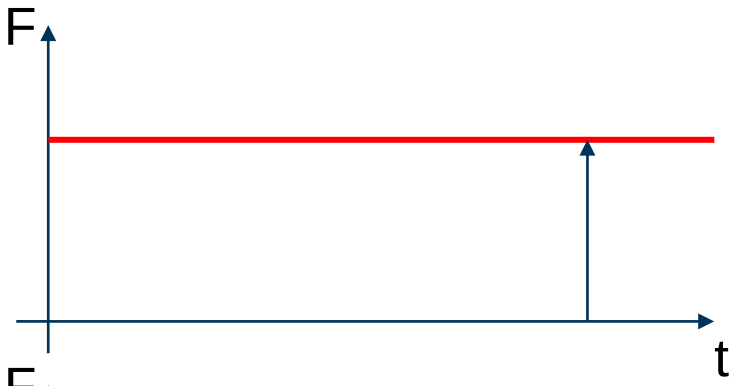
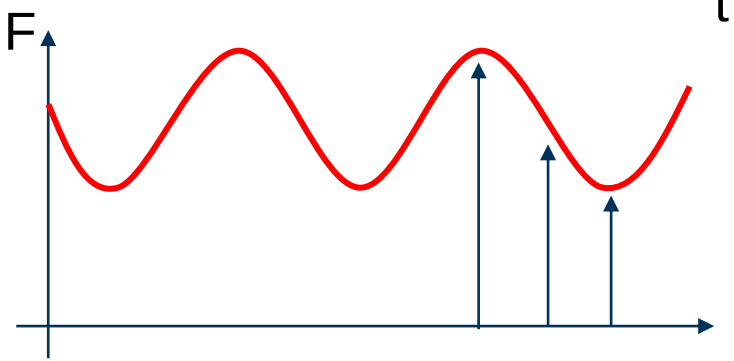
Dynamic or static measurement?

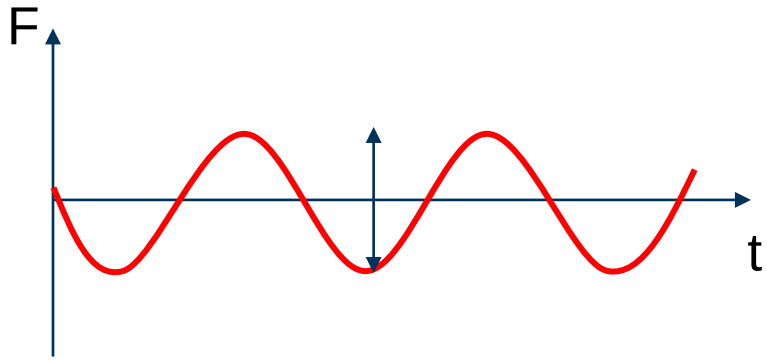


Static load (related to zero point)



Dynamic load (related to zero point)

For longer duration: Only strain gauges are suitable ´. The drift of the piezoelectric sensors does not allow to use them for a longer measurement time.



Dynamic load (not related to zero point)

Piezoelectric sensors or strain gauge based sensors

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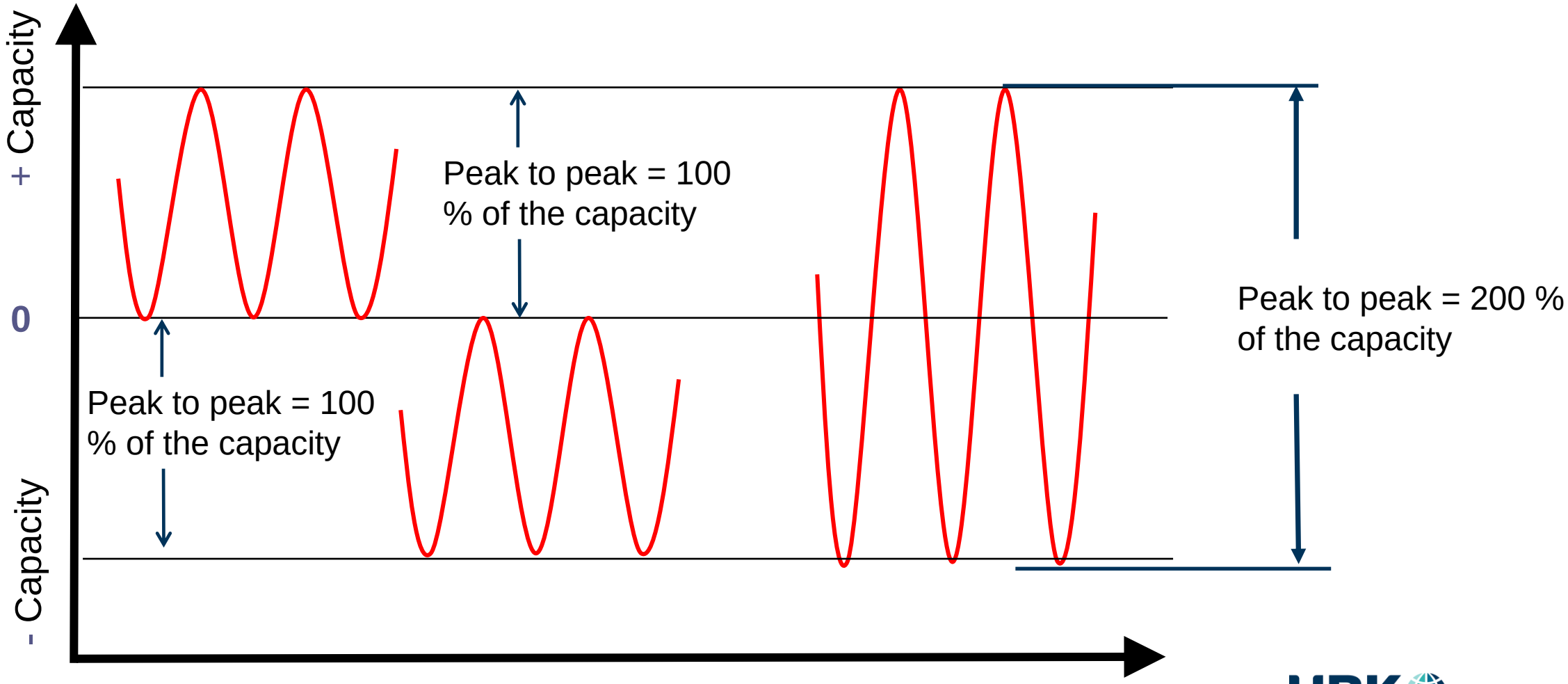
Fatigue tests / dynamic applications



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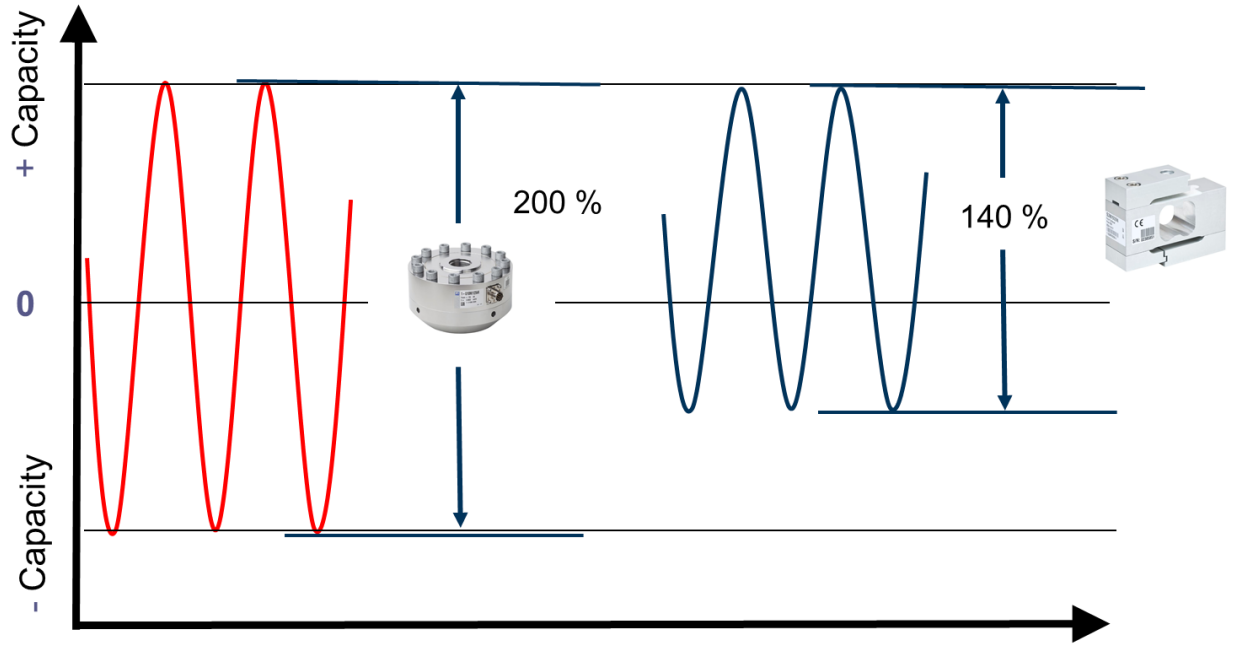
Peak too peak value: Why is it so important?

quency	f_G	kHz	4.5	5.9	9.3	6.6	9.2	6.5	8.1	6.6	6.1	3.8
Relative permissi-ble oscillatory stress	f_{rb}	% of F_{nom}	200									
Rigidity	F/S	10^5 N/mm	0.625	1.25	2.5	4.17	8.33	16.7	31.3	50	83.3	140

Relative permissible oscillatory stress	F_{rb}	% of F_{nom}	140



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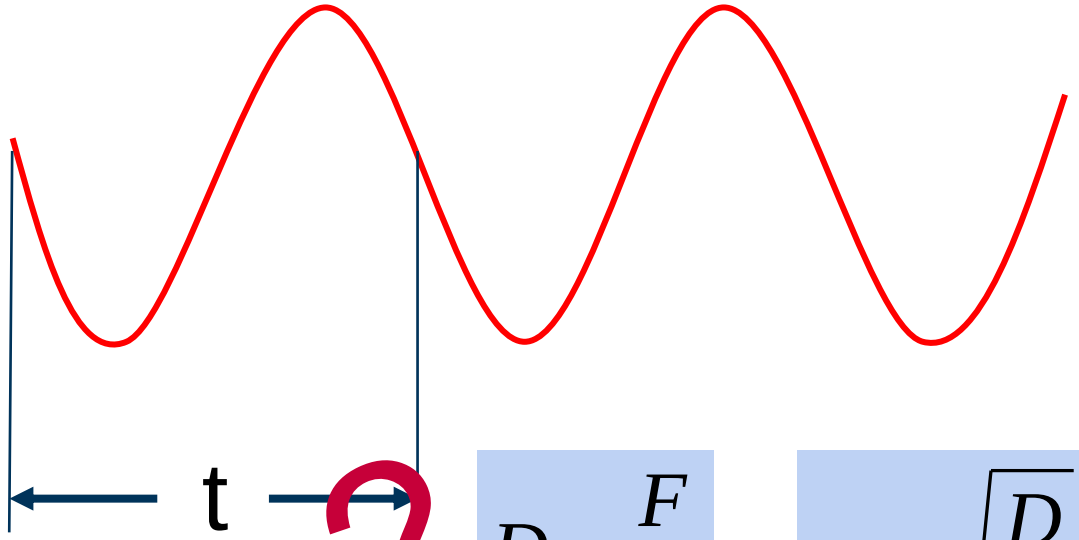
Mechanical bandwidth / natural frequency

- Nominal Force Capacity ***(F)***

- Rated deflection
  The displacement needed to have a suitable strain for the gauges ***(s)***

- Stiffness: Can be calculated
  Can be calculated from rated deflection and capacity ***(D)***

- Natural frequency
  Can be calculated from Stiffness and masses ***(ω)***



Masses?

$$D = \frac{F}{s}$$

$$\omega = \sqrt{\frac{D}{m}}$$

U10m/25kN:
ω = 9,2 kHz

U10m/25kN:
ω = 7,5 kHz

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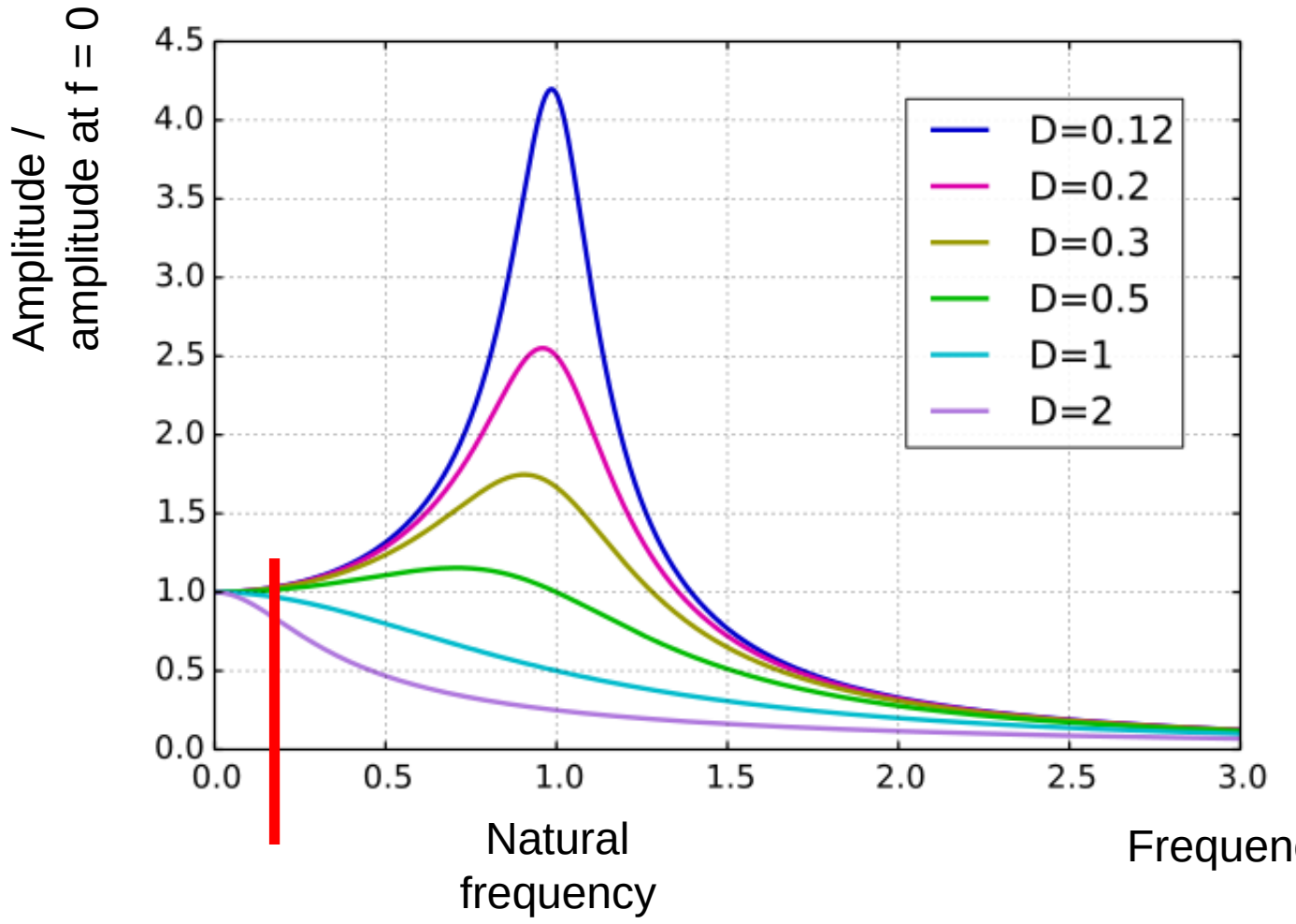
Mechanical bandwidth / natural frequency



Load cells are springs. If the frequency gets > 20 % of resonance frequency => Signal too high

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What is the lowest force to be measured

Highest force: Capacity of the sensor / Relative permissible oscillation bandwidth

Lowest force: Capacity of the sensor / precision of the sensor

Example: Improvement C10

	Linearity error in ppm		
Capacity	**Up to now**	**new**	**Improvement**
2,5 kN	300	200	**33%**
5 kN	300	200	**33%**
10 kN	300	200	**33%**
25 kN	400	250	**38%**
50 kN	400	350	**13%**
100 kN	400	350	**13%**
250 kN	400	350	**13%**
500 kN	400	350	**13%**
1 MN	600	500	**17%**

	Hysteresis in ppm		
Capacity	**Up to now**	**new**	**Verbesserung**
2,5 kN	300	200	**33%**
5 kN	300	200	**33%**
10 kN	300	200	**33%**
25 kN	400	300	**25%**
50 kN	400	400	**0%**
100 kN	500	400	**20%**
250 kN	500	400	**20%**
500 kN	500	400	**20%**
1 MN	600	500	**17%**

	Creep (30 min) in ppm		
Capacity	**Up to now**	**new**	**Verbesserung**
2,5 kN	400	200	**50%**
5 kN	400	200	**50%**
10 kN	400	200	**50%**
25 kN	250	200	**20%**
50 kN	250	200	**20%**
100 kN	250	200	**20%**
250 kN	250	200	**20%**
500 kN	250	200	**20%**
1 MN	250	200	**20%**

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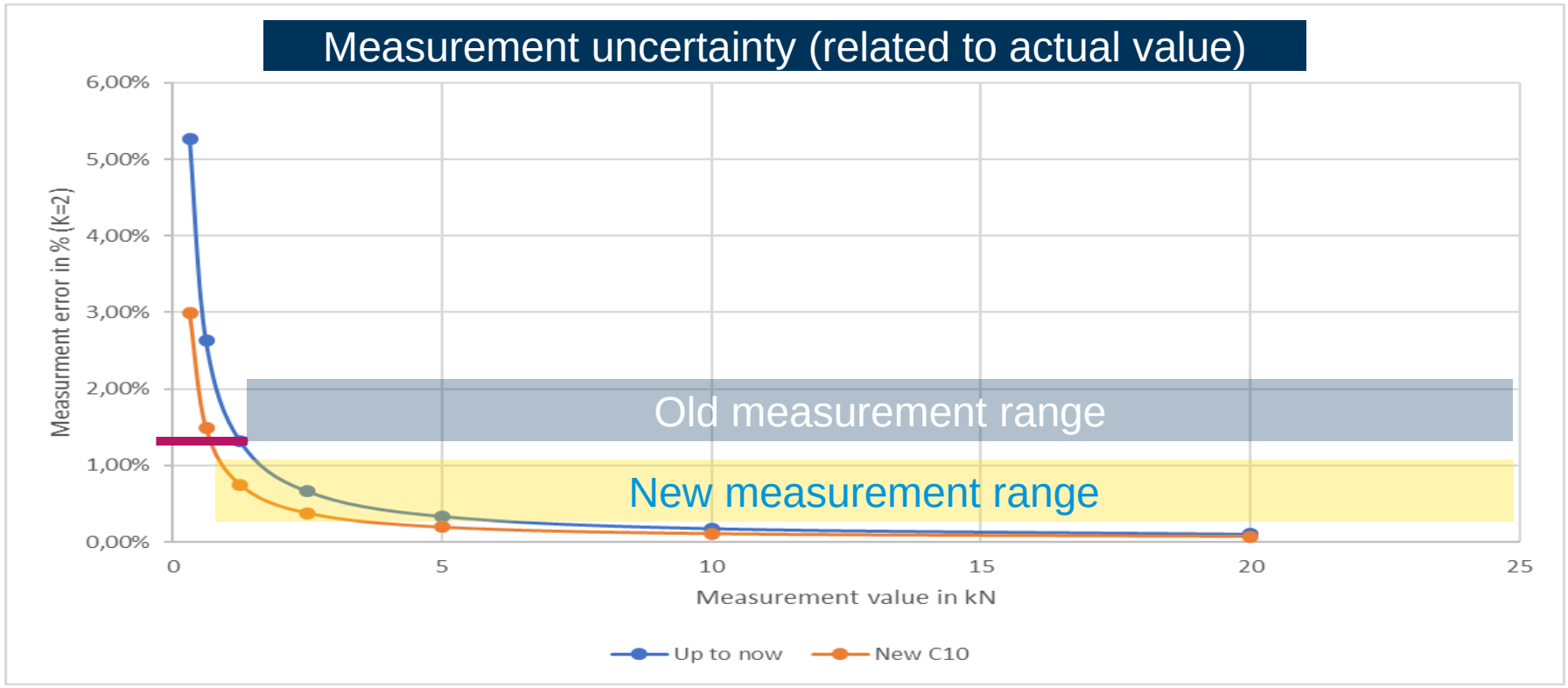
Lowest force to be measured

With the new improved characteristics you can expand your measurement range.

The more precise the sensor, the wider the effective measurement range.

A good decision should be based on a uncertainty calculation



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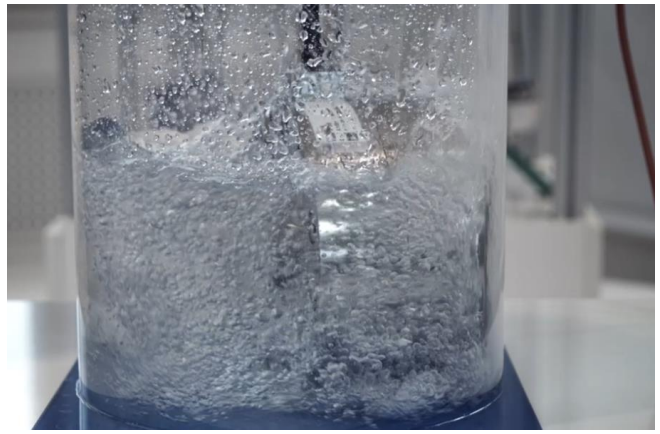
What else? Temperature and Humidity

- - **Temperature:**

  - Nominal temperature range: The sensor works within the specification
  - Operation temperature range: The sensor works with expanded uncertainty

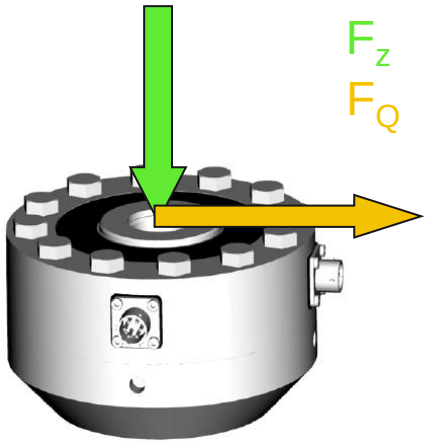
- -**Humidity:**

  - Short term under water: Ip67 => Nearly all sensors
  - Long term use under high humidity (outside) => Hermeitically sealed sensors With HBM: IP68



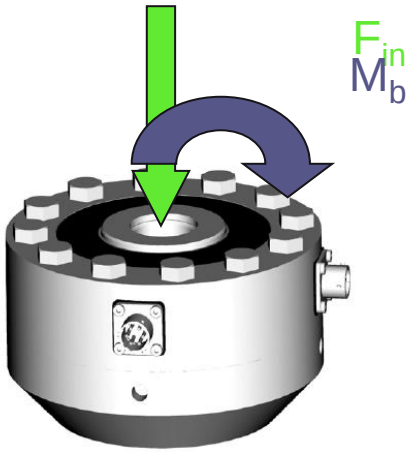
U10 / C10 are available with Option IP68
S9M for lower forces

What else? Lateral forces and bending moments



Lateral forces

- Limited, find maximum in the datasheet
- **Lateral forces may cause bending moments**



Bending moments

- Limited, find maximum in the datasheet
- **Bending moments have an influence on the accuracy of your measurement. (=> Datasheet)**

U10M

U3

U93

Models stable and insensitive against bending and lateral forces

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Thank you!

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