Welcome to the “Understanding Force Sensors and Best Practices” Webinar

The presentation will begin at 1pm EST

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Host: Bernadette Humm
Presenter: Chris Novak

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Chris Novak

- Bachelor’s degree in Electrical Engineering from Cleveland State University
- Field Sales Engineer and Business Development Manager with HBK
- Previously – Global Applications Engineer with Honeywell for Test & Measurement
- Has 25+ years of sensor experience

Understanding Force Sensors and Best Practices

Agenda:

- Sensor overview
- Base design overviews
- Design Characteristics /Features
- Selecting a Sensor
- Best practices with installations

Sensor Principle Technologies

Without Spring Body	Changes of electrical properties: Magneto-resistive, Hall Effect, and piezo electrical
Compensation	Force compensation (Comparator): Compensation of the force to be measurement by an electro-magnetically generated force, magneto-elastic effect
With Spring Body	Strain detection on the surface of materials: Surface acoustic wave (SAW) Strain gauge technology (bonded foil, semi-conductor)

Foil strain gauges (app. 1950)

HBK
HOTTINGER BRÜEL & KJÆR

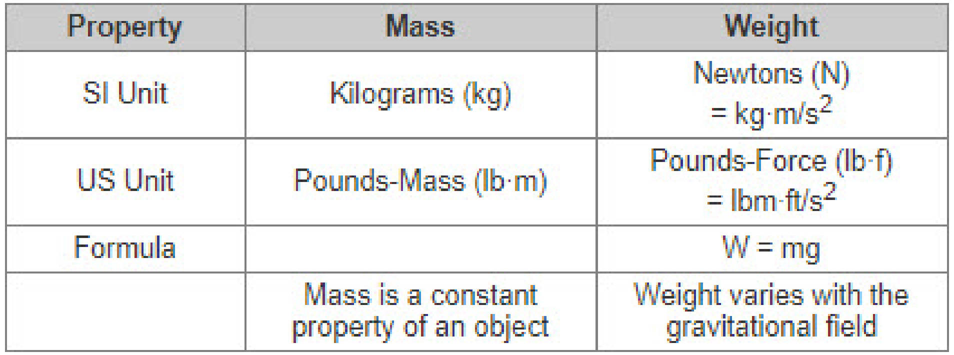
What is Force?

A **force** is a push or pull upon an object resulting from the object's *interaction* with another object. Whenever there is an *interaction* between two objects, there is a force upon each of the objects. Forces only exist as a result of an interaction.

Force = m * Acceleration

English Measurement → lbf
Metric Measurement → N

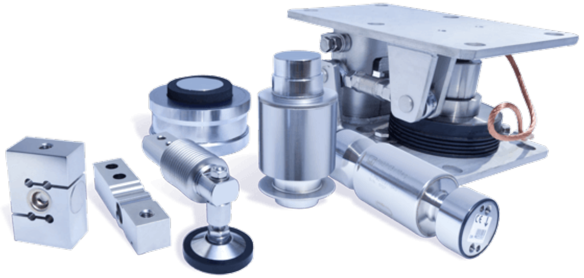
One **Newton** is the amount of force required to give a 1-kg mass an acceleration of 1 m/s/s. Thus, the following unit equivalency can be stated:
1 Newton = 1 kg • m/s2



Property	Mass	Weight
SI Unit	Kilograms (kg)	Newtons (N) = kg·m/s^2
US Unit	Pounds-Mass (lb·m)	Pounds-Force (lb·f) = lbm·ft/s^2
Formula		W = mg
	Mass is a constant property of an object	Weight varies with the gravitational field

Load Cells versus Force Sensors

Load Cells



If an object is placed on the load cell or suspended from it, the object's weight can be determined. The intended load for a load cell is always aligned in the direction of the center of the earth, in other words in the direction of gravity. Only that force component of the load should be acquired.

That is not the case for force sensors, which are similar in design, and are also frequently specified as "load cells": They are usually designed to acquire loads that occur in all directions. The direction of the earth's gravitational force is not relevant to how they are installed.

Force Sensors

Sensors: Weighing or Force Measurement

Weighing: (Load Cells)

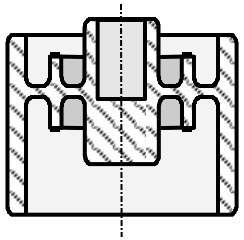
- “Legal for Trade” (OIML)
- Calibration is done after mounting
- Repeatability in unchanged mounting position is important

Force measurements: (Force Sensor)

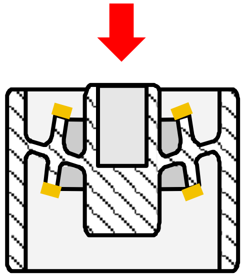
- Calibration is (mostly) performed at manufacturer
- Set up of the measurement chain according to the result of the calibration at manufacturer
- Repeatability in changed and unchanged mounting position is important

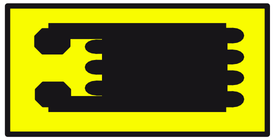
Understanding Sensors Based on Strain Gauges

Sensors based on strain gauges - How do they work?

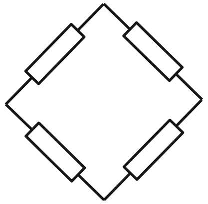


Spring Body





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 Wheatstone bridge converts this change in resistance into a measurable strain.

Understanding Sensors Based on Strain Gauges

Mechanical Input (Force)

Structure ($\Delta L/L$)

Strain Gauge

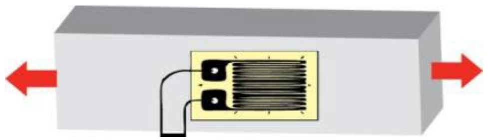
Resistance Change ($\Delta R/R$)

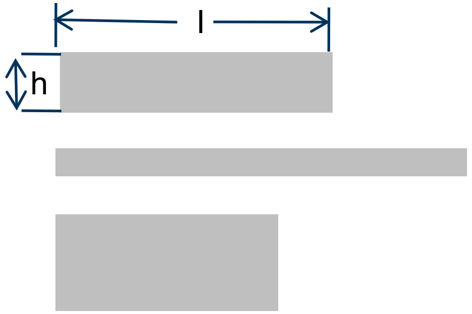
Wheatstone Bridge

Electrical Output (V_{out})

$$V_{out} = V_B - V_D$$

$$Strain = \varepsilon = \frac{\Delta L}{L} \propto \frac{\Delta R}{R}$$



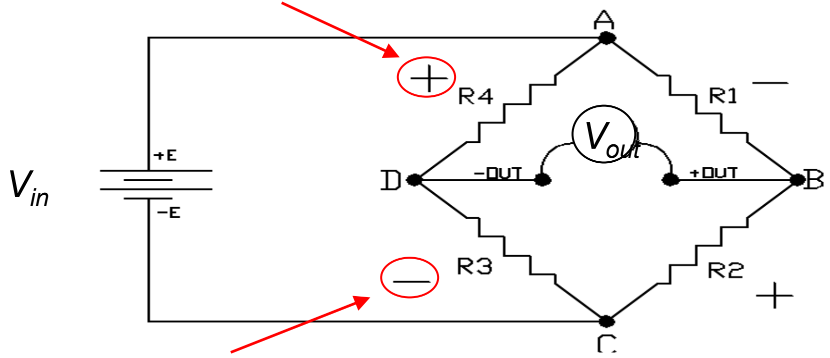


Without strain

Positive strain

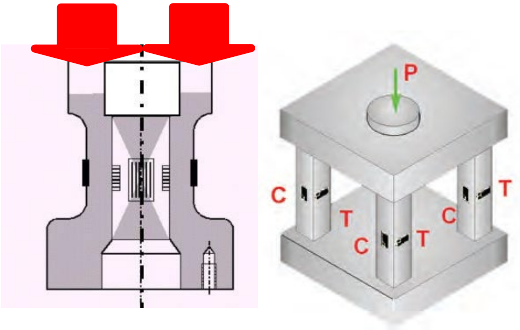
Negative strain

+ increased resistance = increased output

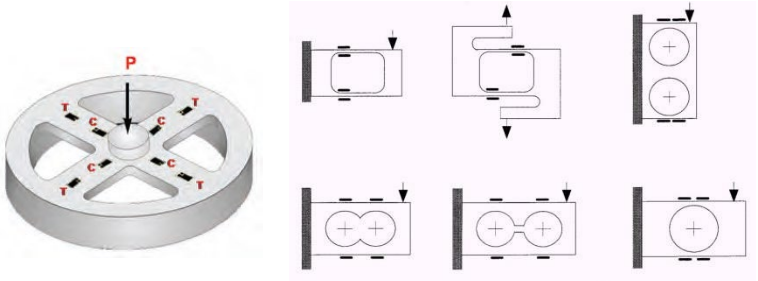


- Decreased resistance = increased output

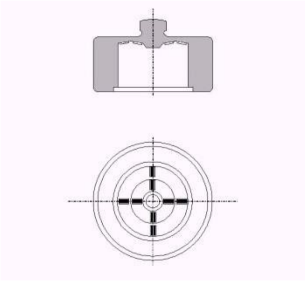
Mechanical Designs Structures – Spring Element



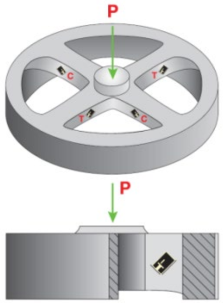
Tension / Compression
Column / bar style



Single or Double bending
beam designs

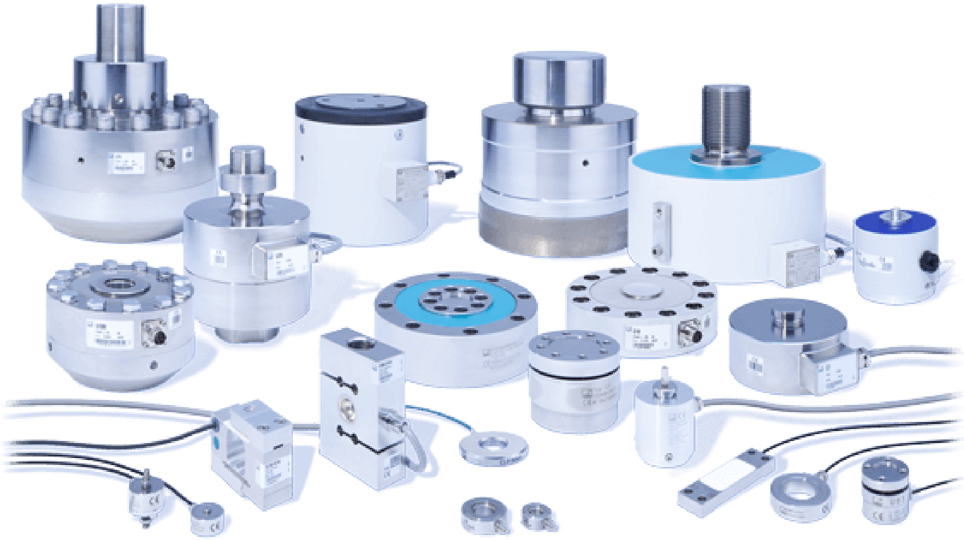


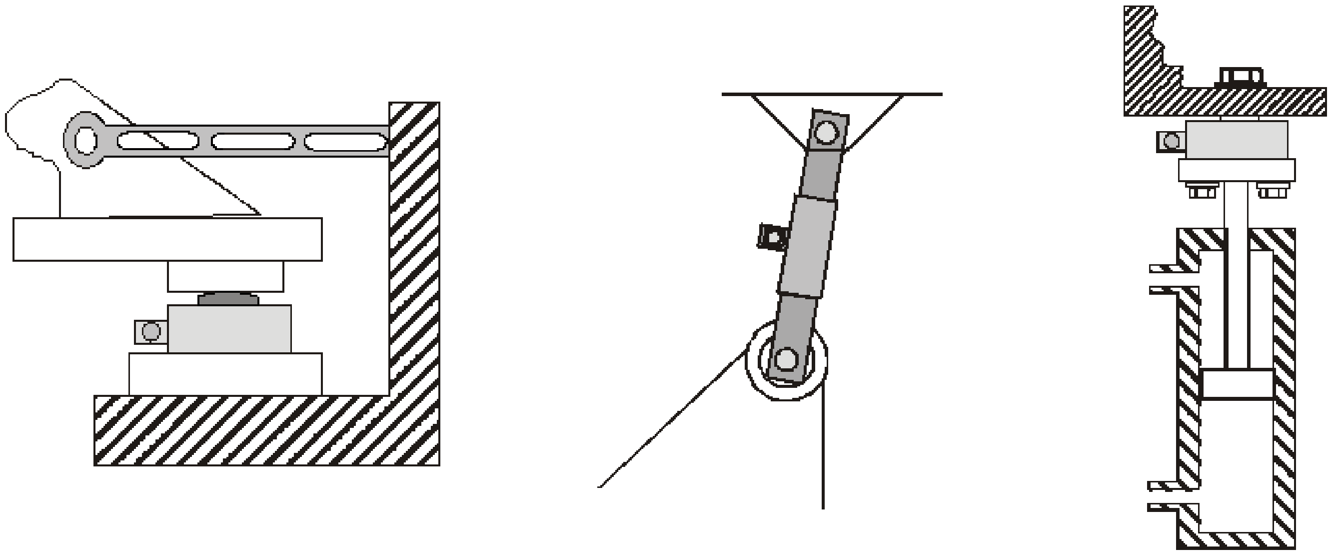
Diaphragm /
Membrane types



Shear web

Force Sensor Configurations





Compression Only

Tension Only

Tension & Compression

Core Designs Can Lead to a Multitude of Configurations / Geometries

Technical Properties of Strain Gauge Sensor

Rated Capacity	The load that leads to the nominal (rated) output
Dynamic Bandwidth Permissible Oscillatory Stress	The amplitude that can be applied for more than 100 million cycles
Nominal Deflection	Displacement under load usually given for nominal (rated) output value
Stiffness	Relation between capacity / Nominal deflection
Natural Frequency	Vibration frequency of the spring body after applying a pulse (unmounted)
Limit Force / Breaking Force	Up to the limit force the relation between force and output signal is proportional / The force transducer may break if you apply more force than the breaking force

Sensor Design Characteristics & Features

Shear Web Design

Advantages:
- Low profile, height
- Low deflection
- Symmetrical output
- Extraneous load capability

Limitations:
- Weight of product, especially at higher ranges
- Larger diameter sizes
- Requires a load base or equivalent
- Not good for lower capacity ranges

Sensor Design Characteristics & Features

Single and Double Bending Beam Designs

Advantages:

- Excellent Linearity
- Good Hysteresis
- Capable of many configurations

Limitations:

- Higher nominal deflections
- Not good for handling extraneous loads
- Double bending beam designs limited to single bridges

Sensor Design Characteristics & Features

Diaphragm or Membrane Style

Advantages:
- Compact sizes
- Design flexibility
- Broad range capability

Limitations:
- Lower performance attributes
- Lower extraneous load capability
- Connector limitations
- Prone to have temperature effect due to compact sizes

Sensor Design Characteristics & Features

Single or Multi-column

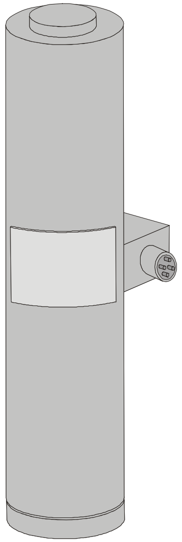
Advantages:

- Excellent for larger capacity ranges
- Lower weight for larger capacity ranges
- Smaller diameter sizes

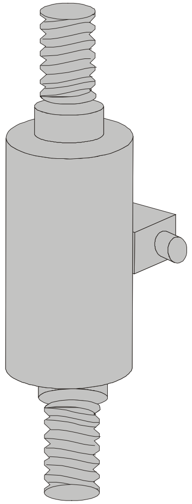
Limitations:

- Larger profile, height
- Not good with extraneous loads
- Larger variations in cal slopes (tension vs compression)

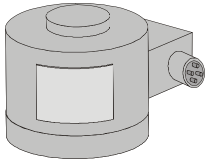
General Hint – Extraneous Loading



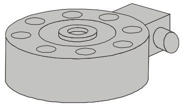
Poor



Better



Good



Best

Generally the larger the width to height ratio the higher the immunity to side load

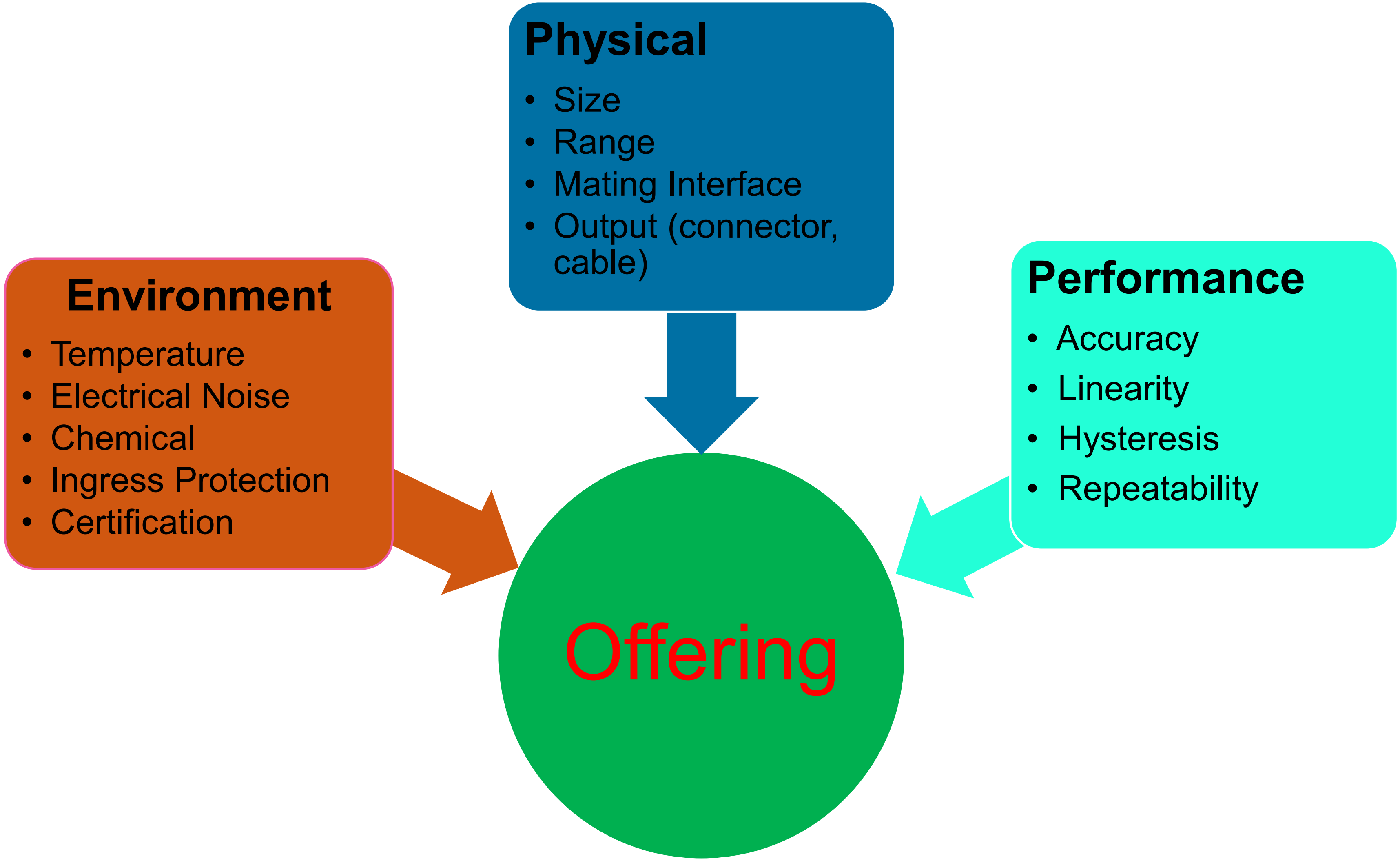
Sensor Design Characteristics & Features - Overview





Mechanical						Options			Accuracy			
NAME	High Capacities	Low Profile	Insensitive against lateral forces, torque	Permissble Oscillation Stress	Weight/ Dimensions	Multi-Bridge Possible?	High Rated Output (4mv/v)	Flange Possible	Influences of Temp. Gradients	Repeatability	Hysteresis	Linearity
Radial Symmetric Shear Beam	Yes	Medium	Yes/ Adjustable	200%	High weight but compact	Yes	Yes	Yes	Excellent	Medium	Limited by mounting	Good
Radial Symmetric Bending Beam	Theorectically	Medium	Yes/ Adjustable	140%	Medium	Yes	No	No	Not Good	Outstanding	Excellent	Excellent
Double Bending Beam	No	Medium	Theorectically	150%	Low	No	No	No	Good	Excellent, but Limited by Symmetry	Excellent	Excellent
Diaphragm/ Membrane Types	Theorectically	Yes	Very limited	160%	Low weight compact	No	No	Yes	Not Good	Medium	Medium	Good
Column or Bar Style (single or mutilple)	Excellent	Impossible	Not good	limited	low wieght not compact	Yes	No	Theorectically Yes	Can be optimized	Medium	Depends on load introduction	Depends on load introduction

General Hint - Specifying a Force Sensor



Physical

- Size
- Range
- Mating Interface
- Output (connector, cable)

Environment

- Temperature
- Electrical Noise
- Chemical
- Ingress Protection
- Certification

Performance

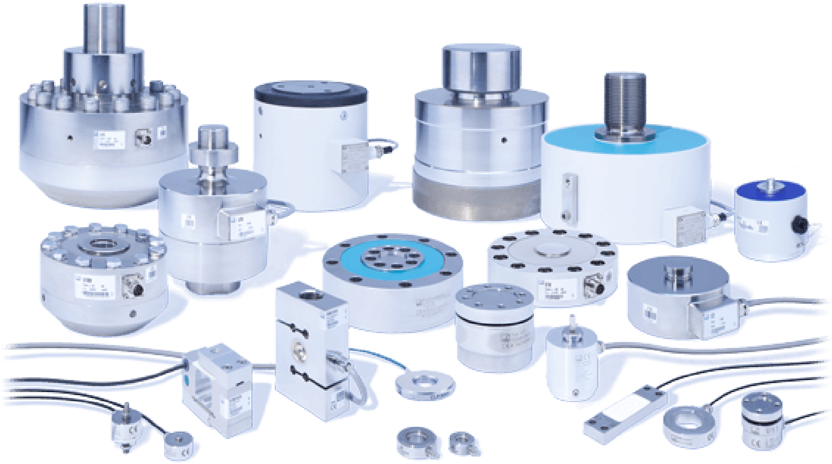
- Accuracy
- Linearity
- Hysteresis
- Repeatability

Offering

General Hint – Choosing a Force Sensor

- Many combinations of specs are mutually exclusive:
  - Specifying a force sensor can lead to trading one performance criteria against another.
    - Example
      - High load capacity
      - Small size
      - High accuracy
      - Immunity to extraneous loads

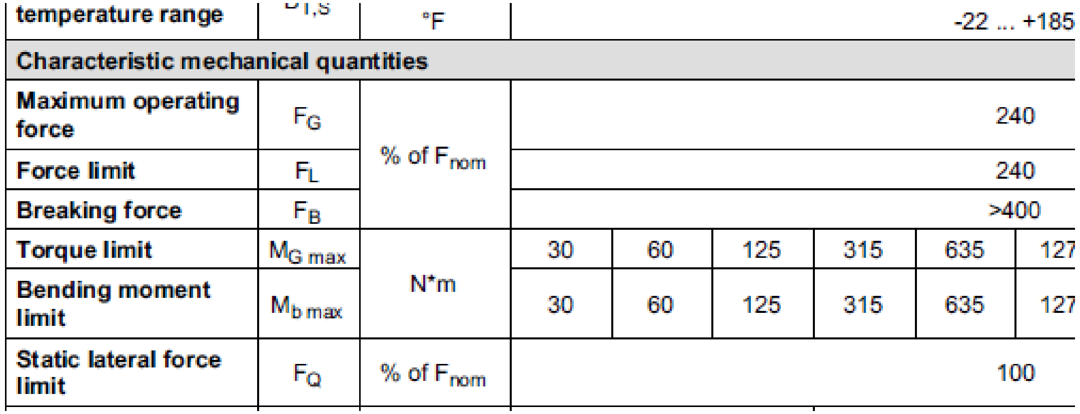
Note: *Pick 3 and you usually compromise the fourth*



General Hints – Before Installation

Before you are going to install your sensor:

- Everything clean?
- Please make sure that you do not exceed the maximum values of:
  - Force in direction of measurement
  - Lateral force
  - Bending
  - Torque
- Caution: Sensors are very stiff components - mechanical shocks can damage them



temperature range	$_{T,S}$	°F	-22 ... +185					
Characteristic mechanical quantities								
Maximum operating force	F_G	% of F_{nom}	240					
Force limit	F_L		240					
Breaking force	F_B		>400					
Torque limit	$M_{G\,max}$	N*m	30	60	125	315	635	127
Bending moment limit	$M_{b\,max}$		30	60	125	315	635	127
Static lateral force limit	F_Q	% of F_{nom}	100					

General Hint – Accuracy Dependency

The accuracy of a force measurement is dependent on:

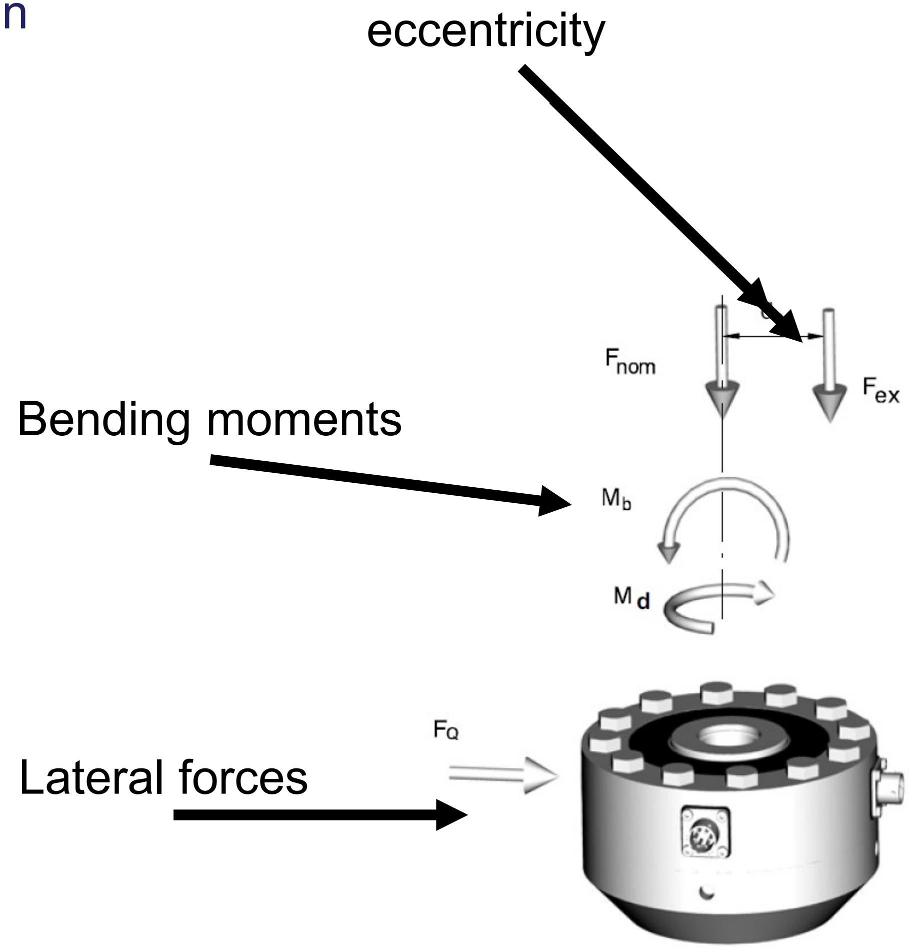
- The uncertainty of the measurement chain
- The environment (temperature, electromagnetic fields,….)
- The uncertainty of the calibration
- The installation process

Ideally, the sensor should be installed in the same way as it was installed for calibration to achieve best results

General Hint – Extraneous Load Effects on Sensor

Lateral forces, bending moments or torque have an negative impact on the accuracy or can damage sensors.

➡ Use Knuckle Eyes / Rod Ends

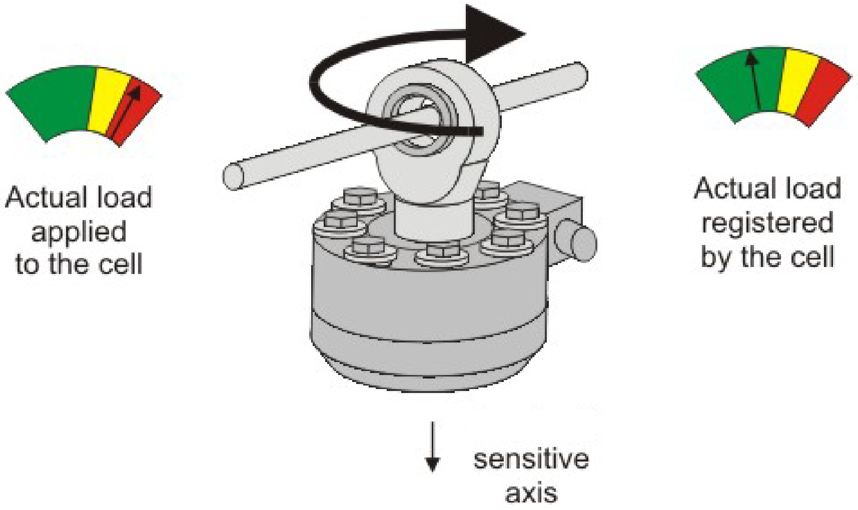


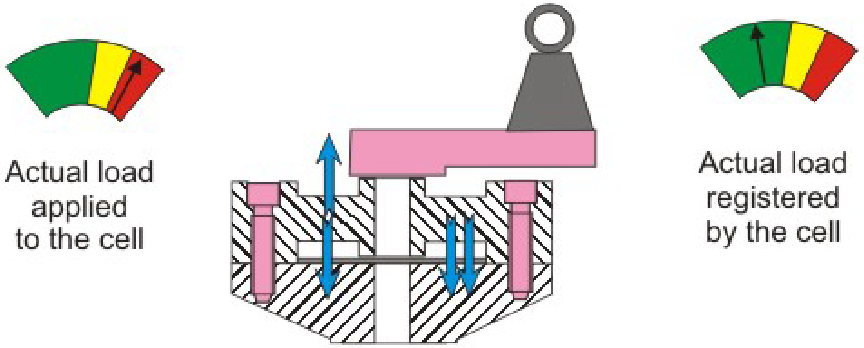
eccentricity

Bending moments

Lateral forces

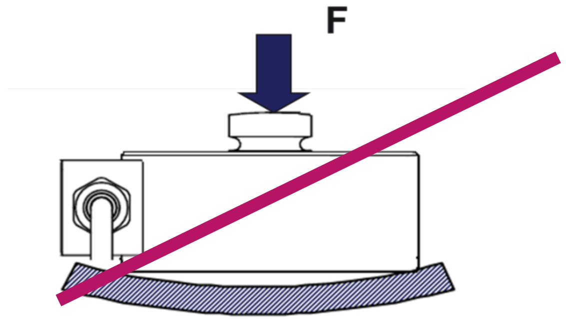
General Hint – Avoiding Damage to Sensors



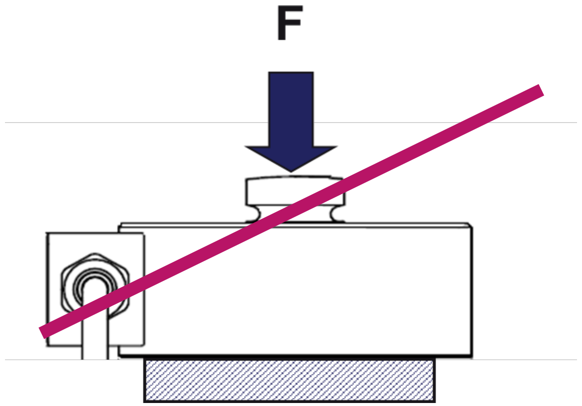


Force sensor does not accurately display damaging overload from load introduction in other than the controlled direction(s)

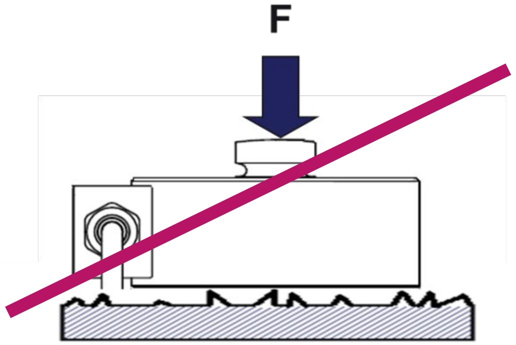
General Hint – Mounting Guidelines



The elements under the sensor should not bend too much under load (=> more stiff than the sensor)



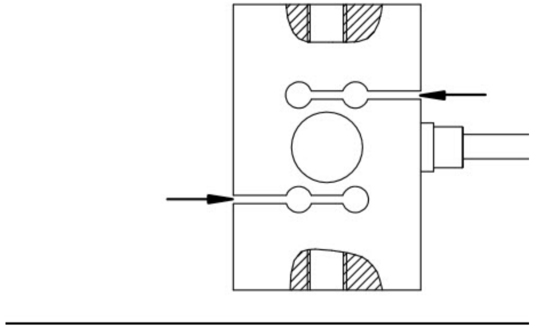
Plates under the sensor must be larger than the load cell



Flatness, Hardness of around 39 HRC

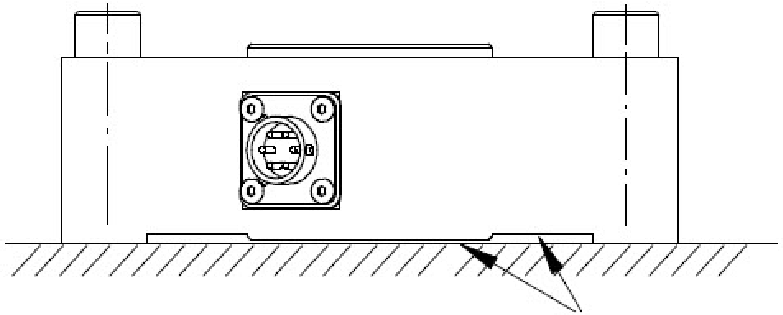
General Hint – Mounting Guideline

Example S9M



Deposits at the marked areas must be avoided

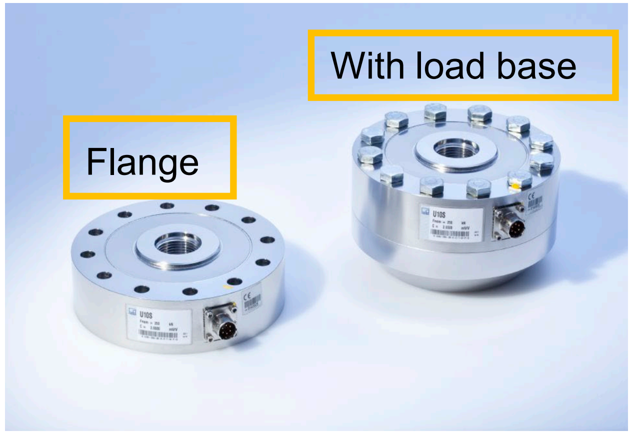
Example U10M

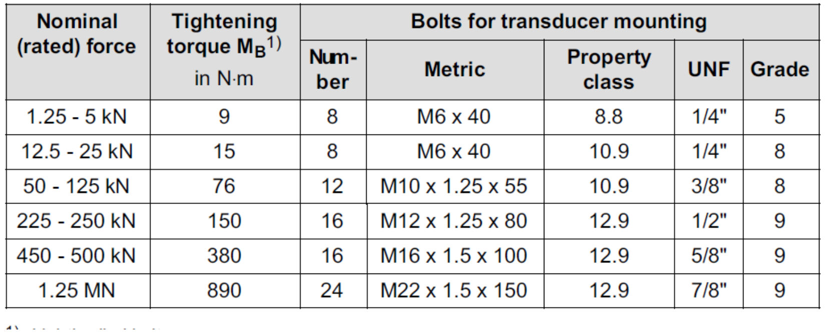


The gap must remain free

Dirt or dust must not be in touch with the sensor so that it prevents the movement of the sensor

General Hint – Installation Guidelines





Nominal (rated) force	Tightening torque M_B[1) in N·m	Bolts for transducer mounting				
		Num-ber	Metric	Property class	UNF	Grade
1.25 - 5 kN	9	8	M6 x 40	8.8	1/4"	5
12.5 - 25 kN	15	8	M6 x 40	10.9	1/4"	8
50 - 125 kN	76	12	M10 x 1.25 x 55	10.9	3/8"	8
225 - 250 kN	150	16	M12 x 1.25 x 80	12.9	1/2"	9
450 - 500 kN	380	16	M16 x 1.5 x 100	12.9	5/8"	9
1.25 MN	890	24	M22 x 1.5 x 150	12.9	7/8"	9

If using a sensor without a base plate is best for your solution please remember:

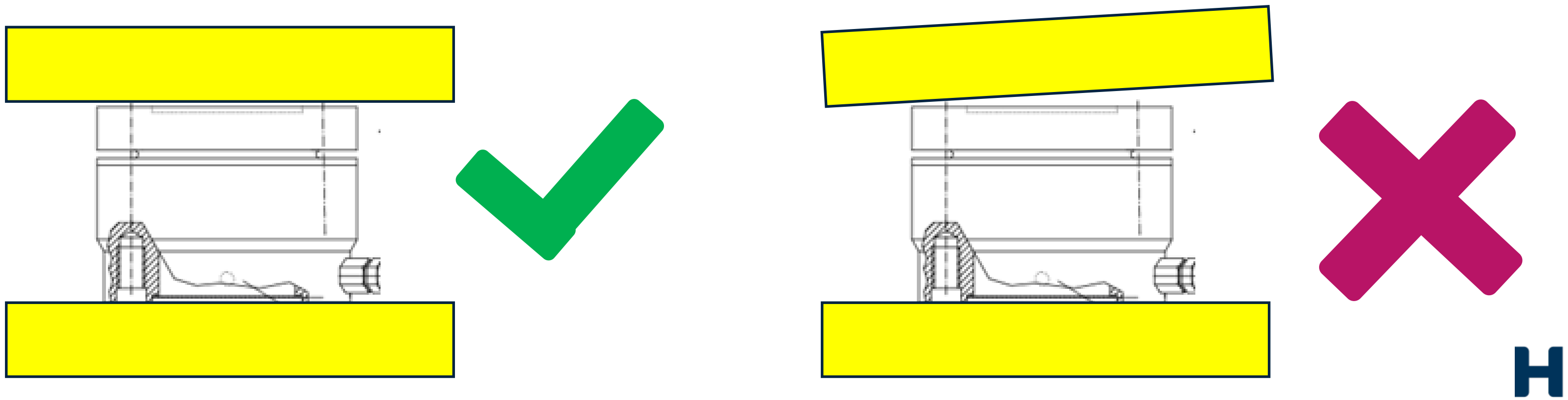
- The sensor needs to be bolted to a very even and flat plate, correct harness
- Free of dirt, debris, non-painted surface
- Refer to the manual to choose the right bolts (size, grade, length, and pitch)
- Please note the correct torque

Too much torque: Risk of breaking under tensile load
Too low of torque: Higher hysteresis, bad zero return, reduced linearity

General Hint – Adapter Fixtures & Uniform Loading

Adapters/Fixtures connected to the force sensor:

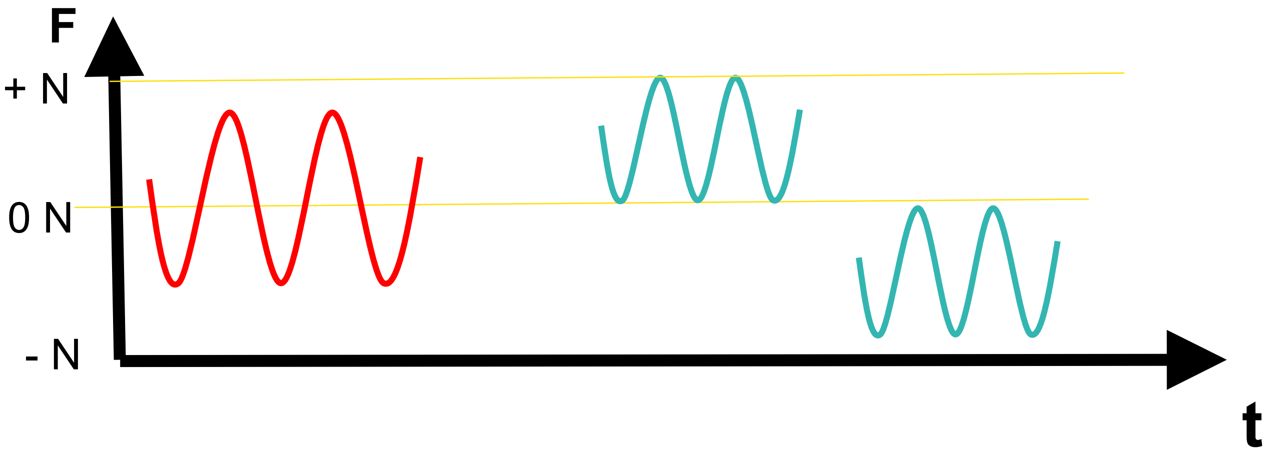
- Minimum Rockwell hardness – usually 39 HRC or higher – comparable to sensor
- Must be flat and even
- Must be clean and free of painting or grease, dirt, debris
- If two plates are used make sure they are parallel to each other



General Hint – Alternating Load Guideline

In case of alternating loads:

Threads must be pre-stressed above the maximum load!



Method one: Applying a suitable torque => Refer to manual

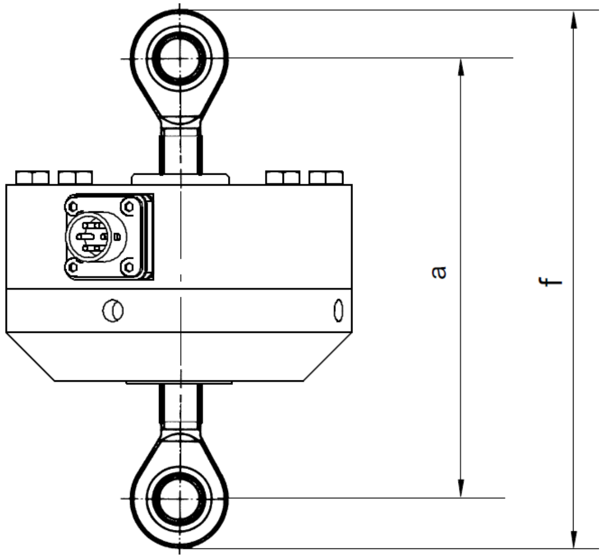
Nominal (rated) force in kN	Thread on transducer	Tightening torque in N·m
0.5 … 1	M8	15
2 … 10	M12	50
20	M24X2	200
50	M24X2	500

Method two: Pre – stressing with tensile forces

- Screw in the element to be connected to the sensor
- Apply a force which is 110 % to 120 % of maximum force to be measured
- Fasten locknut(s)

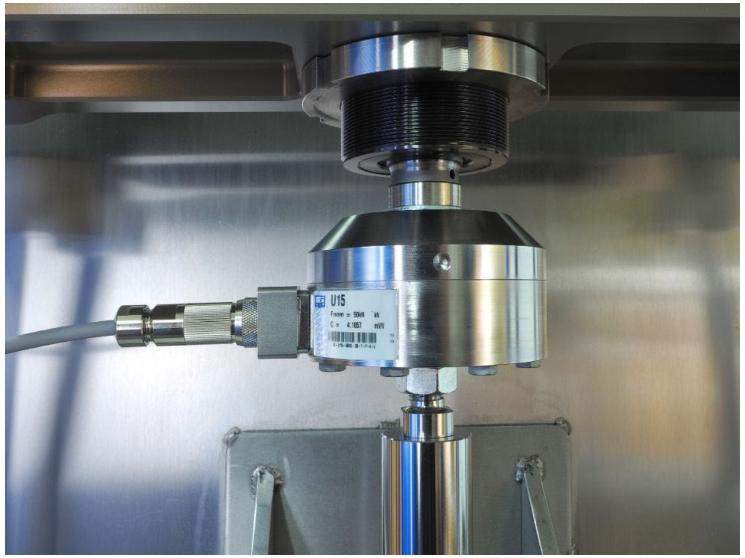
Nominal (rated) force	Tensile force to be applied
50 kN	60 kN
125 kN	150 kN
225 kN	270 kN
250 kN	300 kN
450 kN	540 kN
500 kN	600 kN
1.25 MN	1.5 MN

General Hint – Alternating Load Guideline

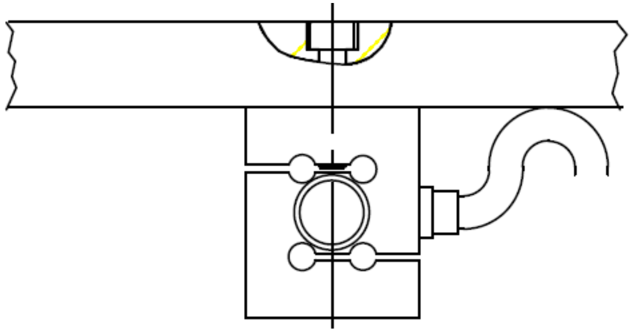


Caution: Limit using with alternating loads, higher frequencies

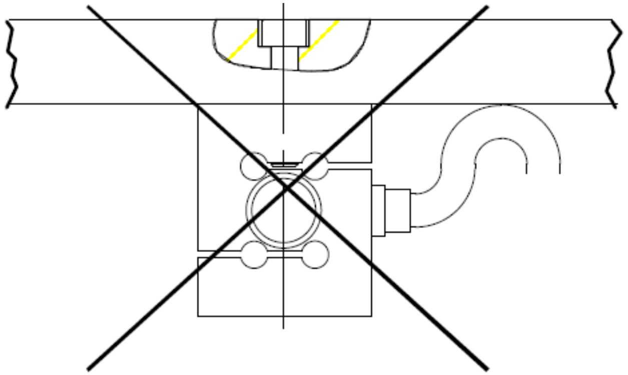
Mounting without knuckle eyes



General Hint – Cable Routing



correct



incorrect

Mount the sensor in a way so that you avoid cable movement => Small forces!

Avoid force shunt error due to cable:

- Relevant for low capacity sensors (< 1 kN or 220 lbs)
- Fix the cable at the side without movement under load
- Possible problem with low temperatures or aging – hardening of cable

Questions?

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Thank You

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