Operation Manual for Force Sensors

Imprint

Manufacturer, Place	Lorenz Messtechnik GmbH, D-73553 Alfdorf
Valid for...	Force Sensors
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References in this Text

1.6 Warning Notes; Page 4

Attention must be paid to the accident prevention regulations of the trade associations. During operation, the safety precautions must be operative.

5.1 General Requirements; Page 7

Caution: During the assembly inadmissibly large forces may not act on the sensor. At small nominal forces (< 100 N) connect the sensor electrically during the assembly and observe the signal, the measurement signal may not exceed the limit values.

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The assembly without balancing elements is problematic for the operating safety!

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The warming-up period of the force sensor is approx. 5 min.

7.3.2 Natural Resonances; Page 11

An operation of the device in natural resonance can lead to permanent damages.

Contents

1 Read First

1.1 Safety and Caution Symbols

Caution:
Injury Risk for Persons
Damage of the Device is possible

Note:
Important points to be considered

1.2 Intended Use

Force sensors are intended for the measurement of forces in test benches, assembly-force appliances, presses and testing machines. This measurand is suitable for control and regulation tasks. The valid safety regulations must be absolutely respected. The force sensors are not safety components in the sense of the intended use. The sensors need to be transported and stored appropriately. The assembly, commissioning and disassembling must take place professionally.

1.3 Dangers

The force sensor is fail-safe and corresponds to the state of technology.

1.3.1 Neglecting of Safety Notes

At inappropriate use, remaining dangers can emerge (e.g. by untrained personnel). The operation manual must be read and understood by each person entrusted with the assembly, maintenance, repair, operation and disassembly of the force sensor.

1.3.2 Remaining Dangers

The plant designer, the supplier, as well as the operator must plan, realize and take responsibility of safety-related interests for the sensor. Remaining dangers must be minimized. Remaining dangers of the force measurement technique must be pointed out.

1.4 Reconstructions and Modifications

Each modification of the sensors without our written approval excludes liability on our part.

1.5 Personnel

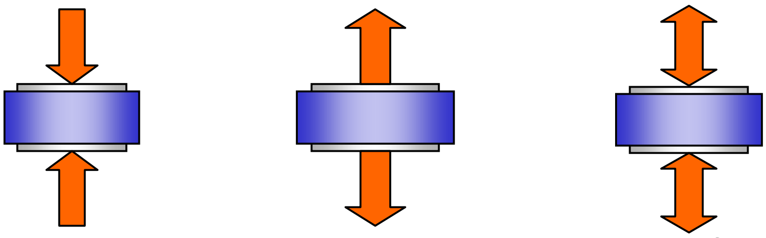
The installation, assembly, commissioning, operation and the disassembly must be carried out by qualified personnel only. The personnel must have the knowledge and make use of the legal regulations and safety instructions.

1.6 Warning Notes

Attention must be paid to the accident prevention regulations of the trade associations.
During operation, the safety precautions must be operative.

2 Term Definitions

2.1 Direction of Force

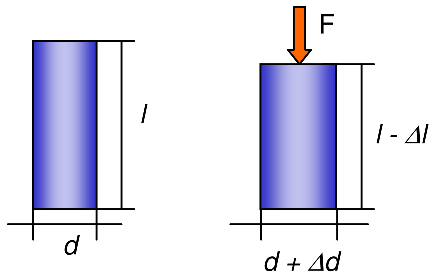


Compression Force   Tension Force   Tension and Compression Force

Compression Force Sensor	→	Compression Force	≙	Positive Output Signal
Tension Force Sensor	→	Tension Force	≙	Positive Output Signal
Tension and Compression Force Sensor	→	Tension Force	≙	Positive Output Signal
Compression and Tension Force Sensor	→	Compression Force	≙	Positive Output Signal

2.2 Spring Constant

Under compression force F the measuring body is jolted by the amount Δl.
The spring constant is calculated according:



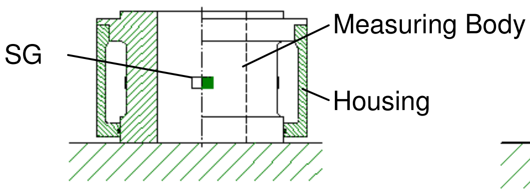
Spring constant c of a sensor $$c = \frac{F}{\Delta l}$$

3 Product Description

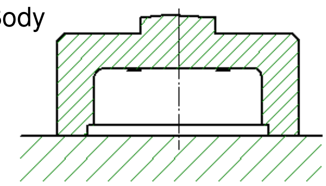
The sensor measures static and dynamic forces. The mounting position of the force sensor is horizontal or vertical.

3.1 Mechanical Setup

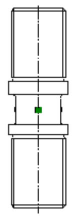
The force sensor consists of a measuring body and a housing. By the introduced force, mechanical tensions occur in the measuring body which are measured by strain gauges (SG). Since the obtained measuring signal is very small, the SG are interconnected to a full bridge. By the bridge connection, the temperature compensation is obtained as well.
There are following types of force sensors:



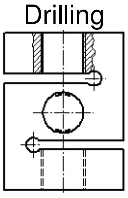
Compression Cylinder with Drilling



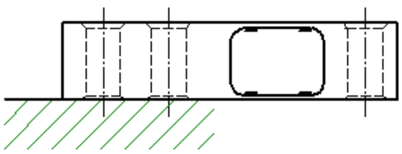
Membrane Force



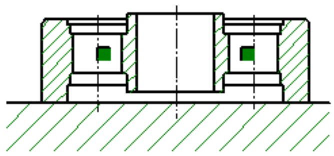
Tension Rod



Bending Beam



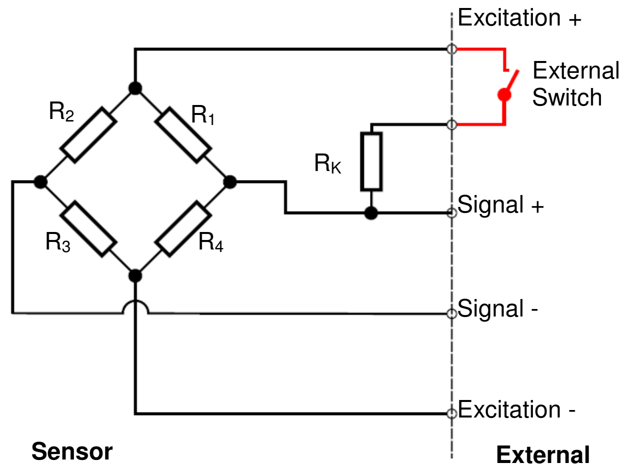
Bending Beam



Shear Force

3.2 Electrical Setup

The SG-Full Bridge is led-out directly to the connector or the cable.
Optionally a control was inserted. For this, the SG-Full Bridge gets detuned in such a way that at the output a measuring signal can be measured which corresponds to the nominal force.



4 Construction and Design

Please clarify following points at the beginning of the construction:

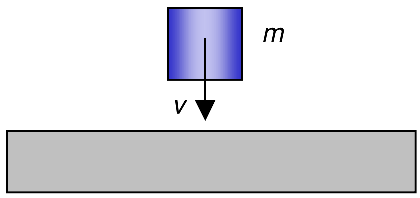
- Required space for the connection cable.
- For equipment monitoring (calibration), the sensor must be easily demountable.
- If necessary, provide a dummy for assembly and test runs.
- Consider required space for overload protection.
- Consider requirements of the force introduction faces.
- Determine maximum load (accelerated masses generate forces as well).
- Dynamic characteristics of the setup.
- Ambient conditions.
- Temperature gradients.
- Impact of temperature changes to the setup

For further indications see chapter Assembly.

- Consider electrical measuring devices (for test and trouble-shooting as well).

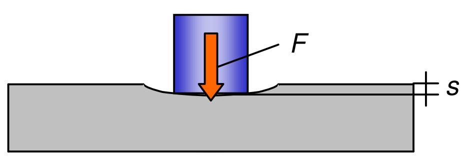
4.1 Calculation Example for an Accelerated Mass

Example Mass *m* falls on a plate with celerity *v;* by this, force peaks emerge (acceleration, deceleration).



Demonstration shortly before the collision

Kinetic energy of the mass $E_v = ½\, m \cdot v^2$

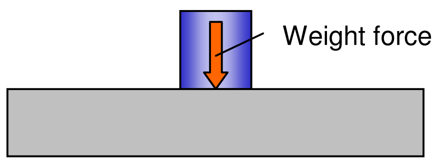


Demonstration of max. brake force

Brake energy $E_B = F \cdot s$
The brake distance *s* must be estimated.

Example
v = 1 m/s = 3,6 km/h; m = 1 kg → E_v = 0,5 kg·m²/s²
braking
s = 0,1 mm → $E_B = F \cdot s = E_v$
→ $F = E_v / s$ = 0,5 kg·m²/s²/0,0001m = 5000 kg·m/s² = 5000 N

Weight force = $m \cdot g$ with g = local acceleration of fall



Demonstration in resting state

5 Mechanical Assembly

5.1 General Requirements

Requirements of the bearing surface and the force introduction faces:
Surfaces hardened to HRC 50, grinded and/or lapped, roughness Rz 4, evenness 0,02 mm.
At possible overload, an overload protection should be considered.
For calibration, the sensor must be easily demountable.

Assembly:

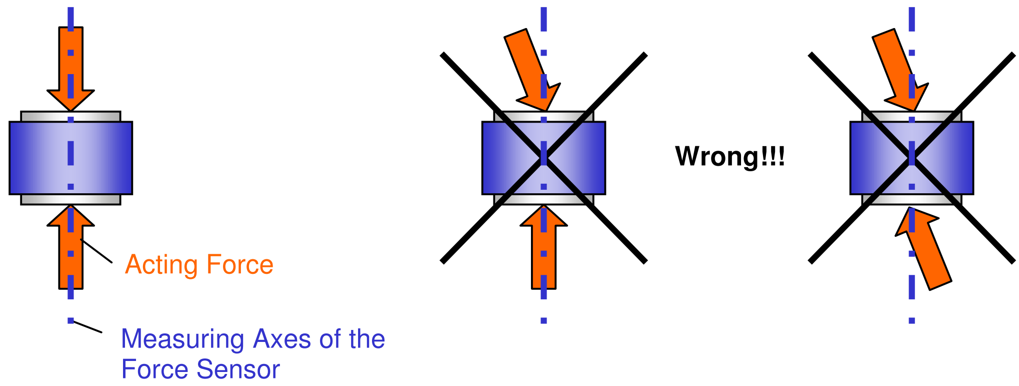
- The base frame of the force sensor must show a preferably plane mounting surface (evenness 0,02 mm).
- The base frame must be free from dirt, grease and dust.
- Do not overload the sensor during the assembly. (Even a short term overload can damage the sensor)
- Preferably use dummies for the alignment of the mechanic introduction parts.
- The force introduction must be carried out punctiform.
- The load conduct, the force introduction components and the force sensor must be connected to each other rigidly and free from backlash.
- The lead-in forces should always act on the force sensor in the sensor specific direction of measurement (see data sheet). By this, the applied load and the force sensor form a continuous line of action.
- Loading the sensor with shearing forces, lateral forces and torque must be absolutely avoided, even small shearing forces can generate larger uncertainties of measurement. In addition, the spring body (depending on the measuring range) can be plastically deformed.
- At flexible mounting positions, especially pendulous assembly in tension direction, we recommend the joint balls listed on the data sheet for the force introduction.
- Force shunts (cables, hoses, pipes etc.) must be avoided.

Caution: During the assembly inadmissibly large forces may not act on the sensor. At small nominal forces (< 100 N) connect the sensor electrically during the assembly and observe the signal, the measurement signal may not exceed the limit values.

Force Direction = Measuring Direction of the Sensor (Geometric Axis)
Always treat the sensor with care.

5.2 Further Notes

5.2.1 Face - Face



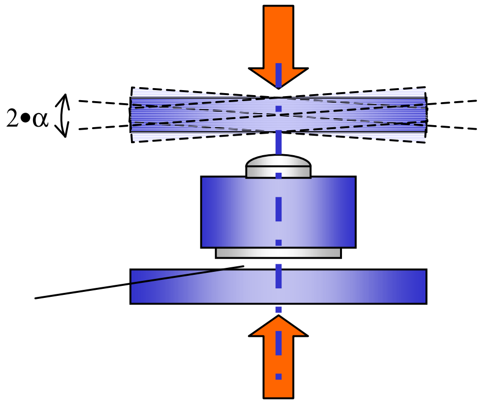
⇒ Faces always plane (preferably grinded)
⇒ Faces always parallel to each other
⇒ Force introduction always measuring axis

5.2.2 Face - Convex

The convex introduction balances small angular deviations of the introduction levels.
Error ~ (1 – cos(α))
e.g. a = 1,8° → Error related to the final value 0,05%

⇒ Faces always plane (preferably grinded)
⇒ Minimize angular errors

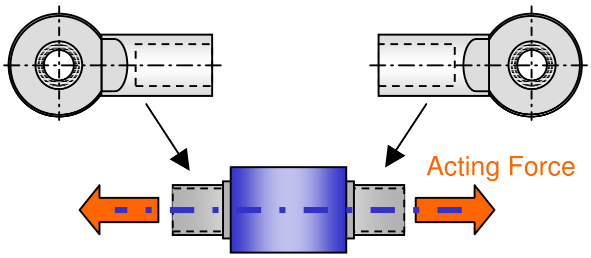
Sensor must bear on the complete face



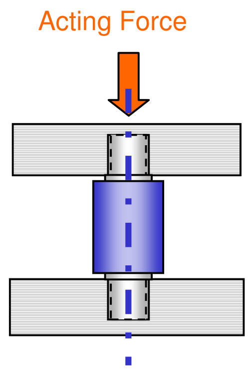
5.2.3 Joint Eyes

Avoid lateral forces at tension force sensors

⇒ Balance of axial offset
⇒ Force introduction in axial direction
⇒ **Not suitable for compression forces!!!**



5.2.4 Fix Assembly



☞	**The assembly without balancing elements is problematic for the operating safety!**

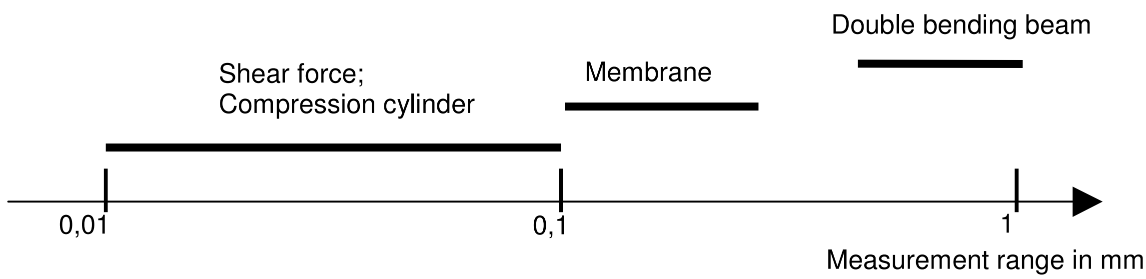
⇒ The introduction must occur free of lateral forces
⇒ Torque may not arise in the sensor
⇒ The introduction faces must be parallel to each other (axial force introduction)

The temperature elongation of the parts must be considered!
The effect can not be planned.

5.3 Overload Protection

5.3.1 Measuring Path

Estimate of the measuring path of the sensor



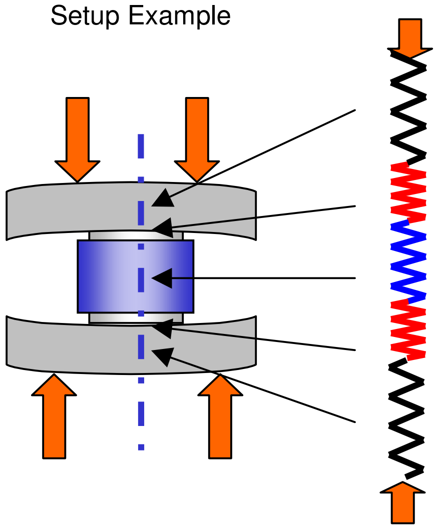
Typical values of the measuring path at force sensors.

Further must be considered:
Contact stiffness (stiffness of the transit of the introduction part to the sensor) Stiffness of the introduction parts etc.

Example for the estimate of the complete spring stiffness of a force measurement layout

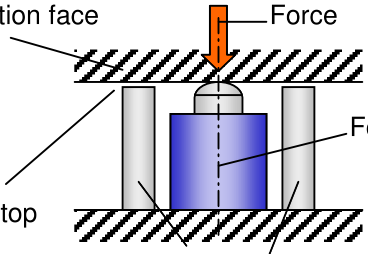
at minimum, these spring constants must be considered:

- ⇒ of the sensor
- ⇒ of the contact faces
- ⇒ of the introduction parts

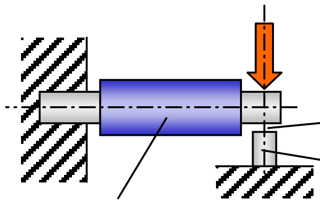


5.3.2 Simple Overload Protection

Caution! Normally the measuring path is very small.
For a simple overload protection, a dead stop, grinded to the corresponding dimension, can be manufactured.
All parts must be grinded and hardened. Accurate alignment of the faces is necessary.



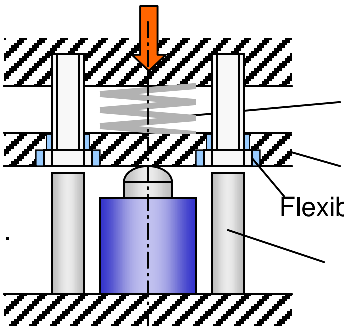
Path for dead stop = Measuring path at nominal force·1,1

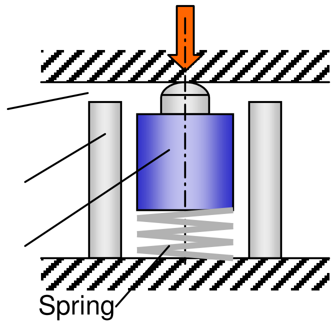


Overload protection for bending beam (large measuring path)

5.3.3 Measuring Path Magnification

The path for the dead stop gets magnified by a spring





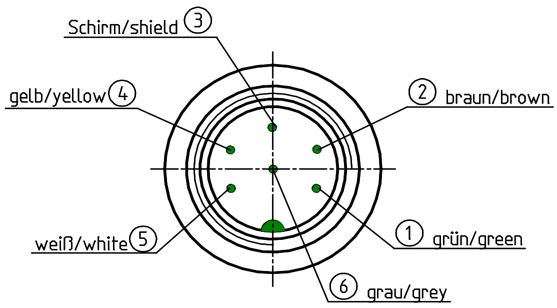
The path for dead stop is determined by the spring.
Disadvantage: large measuring path and the sensor must be lead axially.

By the spring being pre-stressed to nominal force (plate washer package) a higher stiffness is achieved in the nominal range. Above the preload, the spring gets soft and a larger measuring path is achieved.

6 Electrical Connection

6.1 Pin Connection

6-pin	Function
1	Excitation (-)
2	Excitation (+)
3	Shield
4	Signal +
5	Signal -
6	100% Calibration Control (Option)



6.2 Free Cable Ends

Wire	Function
green	Excitation (-)
brown	Excitation (+)
yellow	Signal (+)
white	Signal (-)
grey	100% Calibration Control (Option)
netting	Shield

6.3 Cables

Only use a shielded cables with preferably small capacity. We recommend measuring cables from our product range. They have been tested in combination with our sensors and meet the metrological requirements.

6.4 Shielding Connection

In combination with the sensor and the external electronics, the shield forms a Faraday Cage. By this, electro-magnetic disturbances do not have any influence on the measurement signal. At potential difference problems we recommend to ground the sensor.

6.5 Extension Cables

Caution: depending on bridge resistance and wire cross section, the measuring cable length enters into the characteristic value of the sensor. Therefore order the sensor together with the extension cable and the calibration at Lorenz Messtechnik GmbH.
Dependence of the characteristic value from the cable length:

Wire-cross section	Cable resistance per m	Deviation per m cable length at bridge resistance **350 Ω**	Deviation per m cable length at bridge resistance **700 Ω**	Deviation per m cable length at bridge resistance **1000 Ω**
0,14 mm²	0,28 Ω	0,08 %	0,04 %	0,028 %
0,25 mm²	0,16 Ω	0,046 %	0,023 %	0,016 %
0,34 mm²	0,12 Ω	0,034 %	0,017 %	0,012 %

Cable resistance = 2 x resistance of the cable length (both feeder lines of the sensor).
The sensors with the ordered cable length are calibrated at Lorenz Messtechnik GmbH. Therefore the cable length does not need to be considered in this case.

6.6 Running of Measuring Cables

Do not run measuring cables together with control or heavy-current cables. Always assure that a large distance is kept to engines, transformers and contactors, because their stray fields can lead to interferences of the measuring signals.
If troubles occur through the measuring cable, we recommend to run the cable in a grounded steel conduit.
The space requirement for the connection cable must be considered during the mechnical design.
The connection cable may not be lead-out stiffly.

7 Measuring

7.1 Engaging

The warming-up period of the torque sensor is approx. 5 min. Afterwards the measurement can be started.

The warming-up period of the torque sensor is approx. 5 min.

7.2 Static / Quasi-Static Forces

Static and/or quasi-static force is a slowly changing force.
The calibration of the sensors occurs statically on a calibration device.
The applied force may accept any value up to the nominal force.

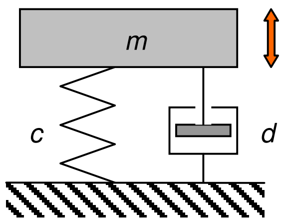
7.3 Dynamic Forces

7.3.1 General

The static calibration procedure of force sensors is also valid for dynamic applications.
Note: The frequency of force must be smaller than the natural frequency of the mechanical measurement setup.
The band width must be limited to 70 % of the nominal force.

7.3.2 Natural Resonances

The force sensor with its assembly parts forms a mechanical oscillator.
The resulting natural resonance of the layout can be estimated according following formula:



$$f = \frac{1}{2\pi}\sqrt{\frac{1000 \cdot c}{m}}$$

f = natural resonance
c = spring constant in N/mm
m = mass in kg

estimated spring constant c from nominal force/measured path
(see 5.3.1 Measuring Path)

The damping *d* of the oscillator can be ignored for a simple estimate.

Operation of the device in natural resonance can lead to permanent damages.

7.4 Disturbance Variables

7.4.1 Temperature

Radiant heat → Higher temperatures than expected (shielding)
Temperature gradient → Error in temperature compensation
Fast temperature changes often lead to temperature gradients.

7.4.2 Humidity

- Normal air humidity up to 90% rel. air humidity has no influence on material
- The sensors are not sea-water resistant.

7.4.3 Gases

Aggressive Gases can damage cables, materials and strain-gauge bridges.

7.4.4 Radioactivity

Influence on material and strain-gauges has not been tested by us and can therefore not be recommended.

7.4.5 Vacuum

At force sensors normally no problems are to be expected at:
Rough vacuum of 10^{3} mbar up to 1 mbar, e.g. for the vacuum packaging
Fine vacuum of 1 mbar up 10^{-3} mbar, e.g. for coating

Problems due to outgassing of the force sensor materials have to be cleared from case to case at:
High vacuum of 10^{-3} mbar up to 10^{-7} mbar, e.g. for scientific research
Ultra-high vacuum of 10^{-7} mbar up to 10^{-12} mbar, e.g. for scientific research

7.4.6 Mechanical Disturbances

Measured values falsifications can occur by following disturbance variables:

- Torsion
- Bending
- Radial load

} Minimize and/or avoid disturbance variables

- Vibrations → Minimize by decoupling of oscillation

7.4.7 EMC

- Electrical disturbances,
- Magnetic disturbances,
- EMC (electro-magnetic disturbances, welding equipment etc.)

Avoid these disturbance variables by covers, shieldings etc.

7.5 Calibration Control (Option)

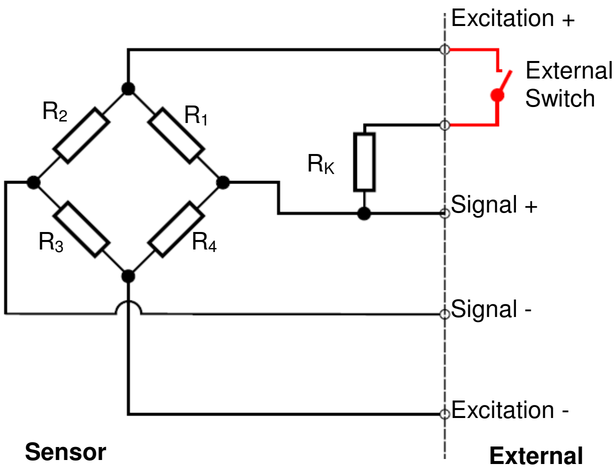
By a control resistance, a signal is generated in the sensor which corresponds to the nominal value of the sensor.

Advantages:

Re-Calibrations are reduced. Before each measurement the zero point and the nominal value can be checked.

Function:

By applying positive SG supply, the measuring bridge is electrically detuned, so that at the output a measuring signal of 100% of the nominal value is available. Optionally 50%, 80% possible.



⇒ Only use calibration control at unloaded condition of the force sensor.

8 Maintenance

8.1 Maintenance Schedule

Action	Frequency	Date	Date	Date
Control of cables and connectors	1x p.a.			
Calibration	< 26 months			
Control of fixation (flanges, shafts)	1x p.a.			

8.2 Trouble Shooting

This chart is used for searching for the most frequent errors and their elimination

Problem	Possible Cause	Trouble Shooting
No signal	No sensor supply	• Outside of permissible range • Connect supply • Cable defect • No mains supply
	Signal output connected wrong	• Connect output correctly • Evaluation electronics defect
Sensor does not react to force	Sensor not mounted properly	• Mount properly
	No power supply	• Outside of permissible range • Connect supply • Cable defect • No mains supply
	Cable defect	• Repair cable
	Connector connected wrong	• Connect properly
	Force shunt	• Eliminate shunt
Signal has dropouts	Cable defect	• Repair cable
Zero point outside of tolerance	Cable defect	• Repair cable
	Sensor mounted distorted	• Mount correctly
	Strong lateral forces	• Minimize shearing forces
	Sensor overloaded	• Send sensor to manufacturer
Wrong display indication	Calibration not correct	• Re-calibrate
	Sensor defect	• Repair by manufacturer
	Force shunt	• Eliminate shunt

9 Decommission

All sensors must be dismantled professionally. Do not strike sensor housings with tools. Do not apply bending moments on the sensor, e.g. through levers.

10 Transportation and Storage

The transportation of the sensors must occur in suitable packing.
For smaller sensors, stable cartons which are well padded are sufficient (e.g., air cushion film, epoxy crisps, paper shavings). The sensor should be tidily packed into film so that no packing material can reach into the sensor (ball bearings).
Larger sensors should be packed in cases.

10.1 Transportation

Only release well packed sensors for transportation. The sensor should not be able to move back and forth in the packing. The sensors must be protected from moisture.

⇒ Only use suitable means of transportation.

10.2 Storage

The storage of the sensors must occur in dry, dust-free rooms, only.
Slightly lubricate rust-sensitive parts with oil before storing.

11 Disposal

The force sensors must be disposed according to the valid provisions of law.
For this, see our "General Terms and Conditions" www.lorenz-sensors.com

12 Calibration

At the time of delivery, force sensors have been adjusted and tested with traceable calibrated measuring equipment at factory side. Optionally, a calibration of the sensors can be carried out.

12.1 Proprietary Calibration

Acquisition of measurement points and issuing a calibration protocol. Traceable calibrated measuring equipment is being used for the calibration. The sensor data are being checked during this calibration.

12.2 DKD-Calibration

The calibration of the sensor is carried out according to the guidelines of the DKD. At this calibration, the uncertainty of measurement of the force measuring instrument is determined. Further information can be obtained from the Deutscher Kalibrierdienst: http://www.dkd.eu/

12.3 Re-Calibration

The recalibration of the force sensor should be carried out after 26 months at the latest.
Shorter intervals are appropriate at:

- Overload of the sensor
- After repair
- After inappropriate handling
- Demand of high-quality standards
- Special traceability requirements

13 Data Sheet

See www.lorenz-sensors.com

14 Literature

Dubbel, Taschenbuch für den Maschinenbau, Springer Verlag.