Important characteristics of force transducers

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How does a strain gage-based force transducer work?

Strain gage-based force transducers have a so-called spring element or loaded member absorbing the forces to be measured.

The spring element is deformed and strain develops on the surface. The spring element thus has the task of converting the forces to be measured into strains in as repeatable and linear a way as possible. Selecting the material and design of a spring element determines many properties of a force transducer.

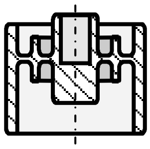
The strain gage (SG) is the actual sensor element. Strain gages consist of an insulating layer, the so-called carrier, onto which a measuring grid is installed. The strain gages are glued in a suitable place on the spring element. Normally, four strain gages are used; two of them are installed such that they are extended by an applied force, while the other two strain gages are shortened.

The four strain gages are connected to a Wheatstone bridge. As shown below, the Wheatstone bridge is supplied with an excitation voltage. An output voltage is produced whenever the four resistors are deformed in different directions, i.e. when two of them are shortened and two extended. This happens when strain is applied to the strain gages. Strain gages arranged opposite from each other need to be uniformly loaded. When the resistance of all strain gages varies in the same direction and amount, no output signal is produced.

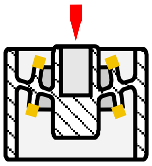
Thus:

$$\frac{U_a}{U_0} = \frac{k}{4}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$

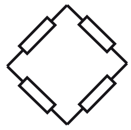
Ua = Output voltage
U0 = Supply voltage
K = Gage factor of SGs (strain gage sensitivity)
ε = Strain on the strain gages



Spring element



The force to be measured results in deformation of the spring element. Strain gages convert strain into a change in resistance.



The Wheatstone bridge enables minute changes in resistance to be measured as voltages.

Operating principle of a strain gage-based force transducer, e.g. a ring torsion transducer (type: C18).

The output signal varies according to the strain gages' change in resistance. Since the strain is proportional to the applied force, and the strain gages' change in resistance is linearly dependent on the applied strain, the relationship between the output signal and the force to be measured is linear as well.

This principle has been tried and tested a million times over and offers many benefits: The main benefits at a glance:

- When the resistances of all strain gages vary in the same direction and amount, no output signal is produced. This enables many parasitic influences, e.g. the temperature dependency of the zero point, effects of the bending moment or lateral forces to be compensated for (see below).
- The measurement principle allows extremely precise force transducers to be produced at relatively moderate costs.
- The transducer's nominal (rated) force is determined by the spring element's stiffness exclusively. HBM offers transducers with nominal (rated) forces ranging between 10 N and 5 MN.

1. General characteristics

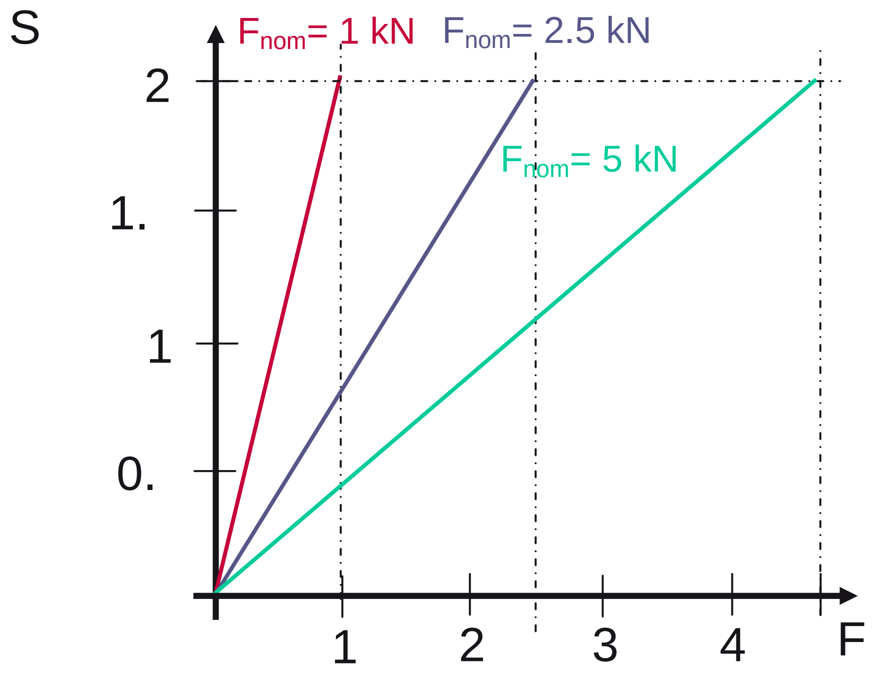
Nominal (rated) force (F_{nom})
The nominal (rated) force is the force at which the transducer is 100 percent loaded. All transducer specifications are met in this force range. Please keep in mind that tare loads resulting, e.g., from the tare weight of mounting parts also need to be taken into account and that they use up part of the nominal (rated) force. With dynamic loading, it is essential to take into consideration the transducers' oscillation width.

Sensitivity (c)
The sensitivity indicates the output signal in mV/V which is produced when the transducer is 100 percent loaded, i.e. loaded with its nominal (rated) force. Any zero signal will be deducted. Example: A transducer shows a zero signal of -0.1 mV/V. The sensitivity is 2 mV/V; in this case, the output signal at nominal (rated) force is 1.9 mV/V.
2 mV/V is a very common output signal for force transducers. As described above, strain gage-based force transducers require a voltage supplied by the amplifiers (excitation voltage). A sensitivity of 2 mV/V means that a force transducer produces an output signal of 2 mV at nominal (rated) force, when supplied with one volt. With 5 V excitation voltage, the corresponding output voltage will be 10 mV.
A force transducer's output voltage can be calculated as follows:

$$U = U_0 \cdot C \cdot \frac{F}{F_{nom}}$$

With U being the output voltage, U_0 the excitation voltage, C the sensitivity, F the applied force and F_{nom} the transducer's nominal (rated) force. This formula assumes that the zero signal is ideally zero.

The transducer's behavior is similar when the force varies, i.e., the transducer from the example is loaded with half its nominal (rated) force to get 1 mV/V at the output. With an excitation voltage of 5 V this corresponds to 5 mV.



The characteristic curves of three different force transducers with a sensitivity of 2 mV/V, however with different nominal (rated) forces. The smaller the nominal (rated) force, the steeper the characteristic curve in the graph; the force transducer is more sensitive.

A nominal (rated) sensitivity is specified in the technical data sheets. This sensitivity is valid for all force transducers of a type and is therefore given with a tolerance, the so-called "sensitivity tolerance". For this reason, every HBM force transducer comes with a manufacturing certificate specifying the exact sensitivity for the respective transducer.

Tip: Always adjust the amplifier as specified in the manufacturing certificate or according to an existing calibration to ensure optimal measurement accuracy. In this case, the sensitivity tolerance does not affect the error computation.

The transducer can also be ordered with so-called TEDS. A small chip containing the manufacturing certificate's exact specifications is installed in the transducer or in the cable. Amplifiers supporting this feature can read these data and use it for automatic setup.

Relative sensitivity error tension/compression (d_c)

Force transducers for tensile and compressive loading often have a small characteristic-curve variation for mechanical reasons, depending on whether they are used with tensile or compressive forces.

This parameter describes the maximum difference.

Zero signal
The zero signal is the force transducer's output signal prior to installation. When you install the force transducer the signal changes due to pre-stress and the masses of mounting accessories.

2. Mechanical characteristics

Nominal (rated) displacement (s_{nom})
The force transducer is deformed when the force to be measured is applied. The nominal (rated) displacement specifies the deformation at nominal (rated) force. It is an important characteristic because, together with the nominal (rated) force, it determines a transducer's stiffness. The force transducer's stiffness is crucial to its resonance frequency. From the physical point of view it is absolutely permissible to compare a force transducer with a very stiff spring.

Stiffness (c_{ax})
A transducer's stiffness is calculated from the nominal (rated) force F_{nom} and the nominal (rated) displacement s_{nom}.

$$c_{ax} = \frac{F_{nom}}{s_{nom}}$$

Stiffness is primarily determined by the transducer's design principle and its nominal (rated) force. In physics it corresponds to a spring constant. Stiffness is crucial to the computation of a transducer's resonance frequency.

Fundamental frequency (f_g)
Like every mass and spring system, force transducers, too, have a resonance frequency. It can be calculated as follows:

$$f_G = \frac{1}{2\pi}\sqrt{\frac{c_{ax}}{m}}$$

With m being the oscillating mass - not to be mixed up with the transducer's mass. The resonance frequency given in the specifications takes into account the force transducer only, not the required loading fittings. Of course the relevant resonance frequency of the whole setup varies with additional masses being installed on the transducer. Therefore, this is only a recommended value. Dynamic design of a test setup always requires the mounting conditions to be taken into account.

3. Characteristics of the forces acting on the force transducer

(Relative) maximal operating force (F_g)
The maximal operating force is specified either as an absolute value in N or relative to the nominal (rated) force F_{nom} in %. The force transducer will not suffer damage up to the maximal operating force, provided that it is not used several times within this range. The relationship between the output signal and the applied force is repeatable, i.e. the measurement error increases, however, the force can still be assessed.

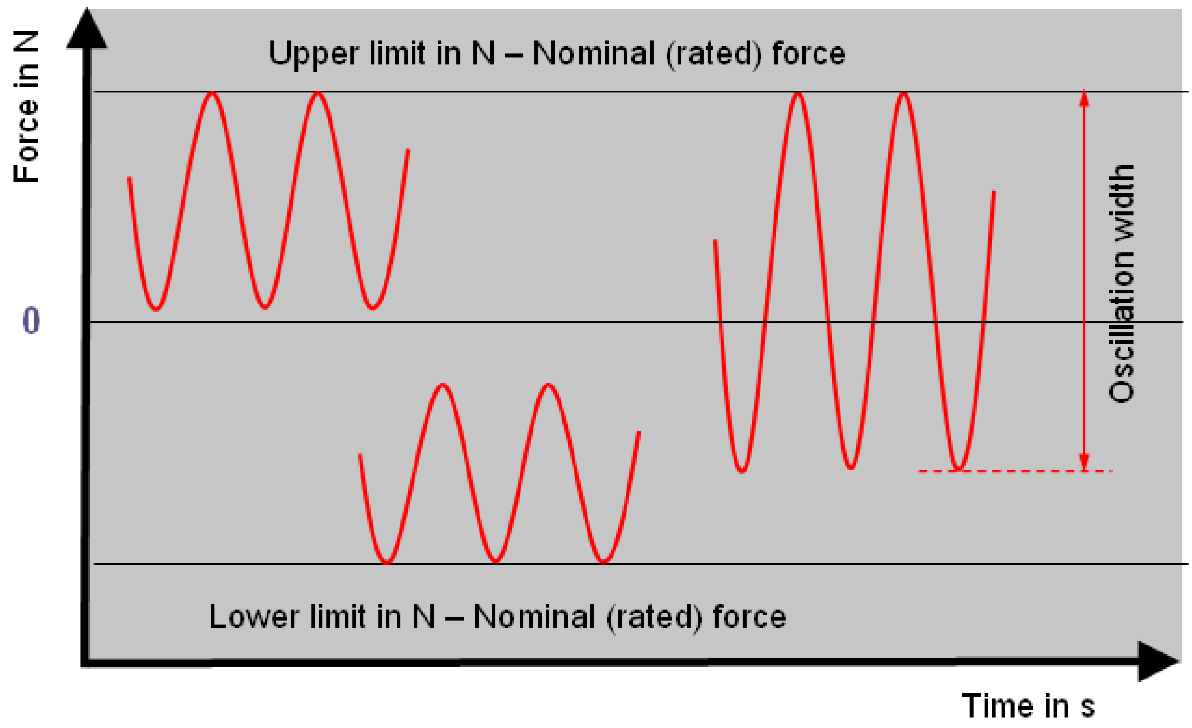
Force transducers need to be dimensioned such that the maximal operating force is not utilized.

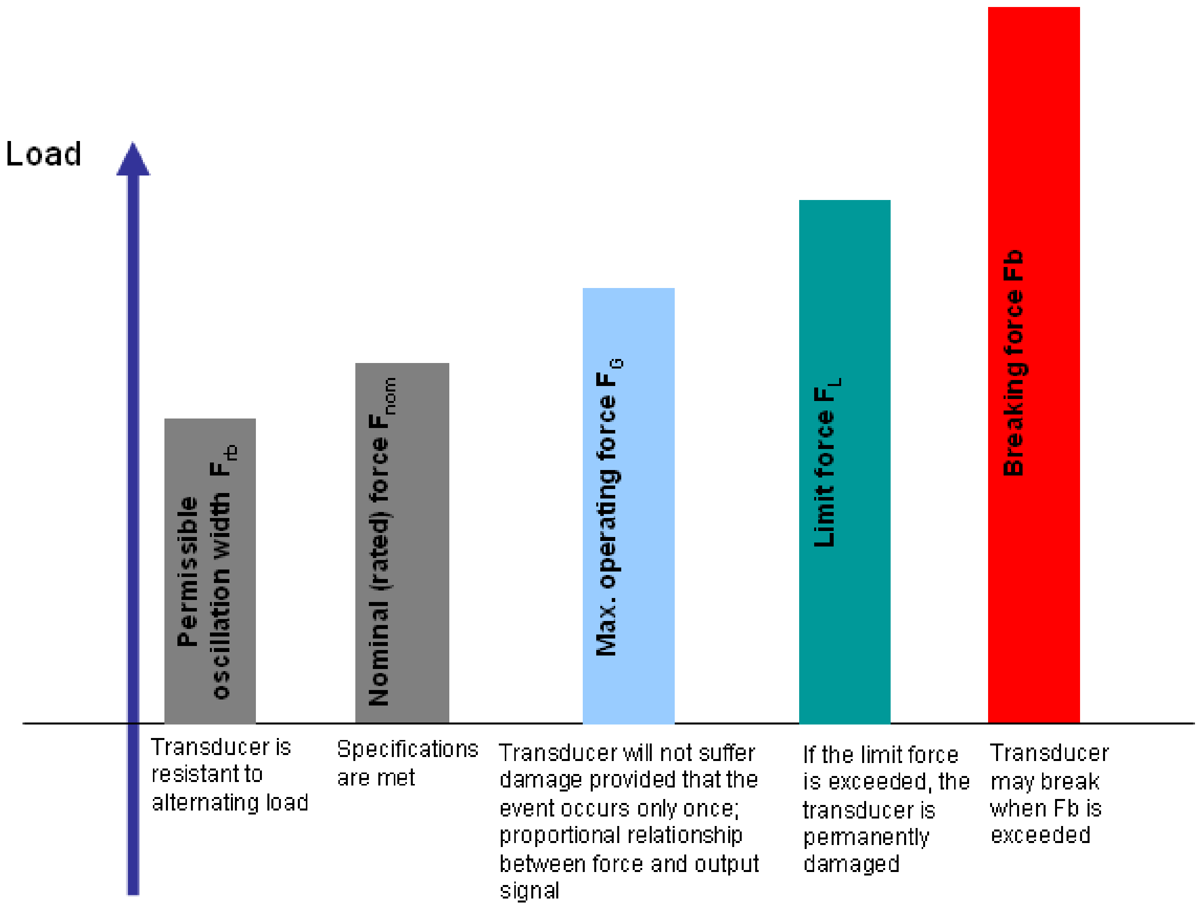
(Relative) limit force (F_L)
As with the operating force, a relative value based on the nominal (rated) force in % or the absolute operating force in N is commonly specified.
If the transducer's limit force is exceeded, the transducer is likely to be no longer suitable for measurement.
Often the force transducer is plastically deformed upon exceeding of the limit force and there is a significant zero point variation. The force transducer may no longer be used and has to be replaced, because the force transducer shows substantially changed specifications. In particular, there is the risk of mechanical limit values such as breaking force and dynamic oscillation width being reduced.

(Relative) breaking force (F_B)
Either an absolute value or a percent value is specified. The name of this characteristic indicates the possibility that the transducer may break.

Tip: Please refer to the safety instructions given in the transducer's mounting instructions.

(Relative) permissible oscillatory stress (F_{rb})
The relative permissible oscillatory stress specifies the stress up to which the transducer is fatigue resistant. This value is usually specified as a relative quantity based on the nominal (rated) force.
In general, the permissible oscillatory stress is given as a peak-to-peak value, i.e. the difference between the maximum and the minimum force. Force transducers may be stressed with this amplitude both dynamically and alternatingly.
Example: A tensile and compressive force transducer has a nominal (rated) force of 200 kN, the permissible oscillation width is 100%. In this case, the transducer may be loaded between 0 and 200 kN as well as between -100 kN and 100 kN.




Load
Permissible oscillation width F_{rb}
Nominal (rated) force F_{nom}
Max. operating force F_G
Limit force F_L
Breaking force Fb
Transducer is resistant to alternating load
Specifications are met
Transducer will not suffer damage provided that the event occurs only once; proportional relationship between force and output signal
If the limit force is exceeded, the transducer is permanently damaged
Transducer may break when Fb is exceeded