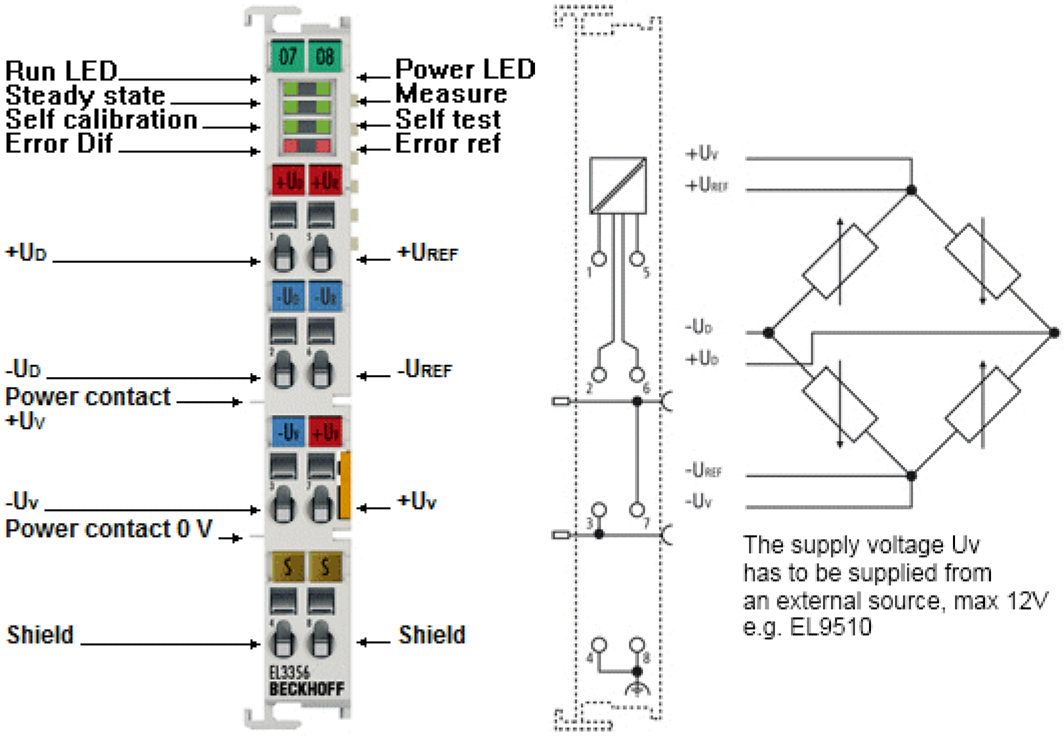
3 Product overview

3.1 EL3356, EL3356-0010 - Introduction



1 channel precise resistor bridge analysis

The EL3356 or EL3356-0010 analog input terminal enables the direct connection of a resistor bridge (strain gauge) or a load cell using a 4 or 6-wire connection technique. The ratio of the bridge voltage U_D to the supply voltage U_{REF} is determined with high precision in the input circuit and the final load value is calculated as a process value on the basis of the settings in the terminal. No further calculations are necessary in the PLC/controller.

The terminal family has the following features in order to meet as many requirements as possible:

- low measuring error of < ±0.01% (see Technical data [▶ 14])
- High resolution: 16-bit (EL3356) or 24-bit (EL3356-0010)
- fast measuring cycles: 10 ms (EL3356) or 100 µs (EL3356-0010)
- automatic self-calibration of the circuit (can be deactivated)
- synchronizable via Distributed Clocks (EL3356-0010 only)
- manual input of the load cell characteristic values according to the load cell certificate (theoretical calibration) or automatic determination by means of calibration procedure
- Tare function
- Special functions for highly dynamic weighing: dynamic filter adaptation, mode change and input freeze

Thus slow weighings can be performed with high precision using the EL3356. The EL3356-0010 is particularly suitable for the fast and precise monitoring of torque or vibration sensors.

The EL3356/EL3356-0010 are not stand-alone scales; they are to be used only in conjunction with a PLC/controller.

Quick links

Basic principles of strain gauge technology [▶ 15]

Basic function principles [▸ 114]

QuickStart [▸ 113]

Object description and parameterization [▸ 148]

3.2 EL3356-00x0 - Technical data

Technical data	EL3356	EL3356-0010
Number of analog inputs	2, for 1 bridge circuit (full bridge)	
Resolution	16 bits, 32 bit display	24 bits, 32 bit display
Conversion rate	100..4 sps (samples per second) (10..250 ms conversion time)	10,000 sps.. 4 sps (0.1...250 ms conversion time)
Distributed Clocks	no	yes
switchable modes	no	yes (2)
Measuring error	< ±0.01% for the calculated load value in relation to the final load value with a 12 V feed and 24 mV bridge voltage (hence nominal strain gauge characteristic value of 2 mV/V), self-calibration active, 50 Hz filter active	
Measuring range U_d	max. -27 mV ... +27 mV typ. (see note on voltage measurement [▸ 137]) recommended: -25 ... +25 mV nominal voltage	
Measuring range U_{ref}	max. -13,8 V ... +13,8 V typ. (see note on voltage measurement [▸ 137]) recommended: -12 ... +12 V nominal voltage recommended supply voltage: 10 V via power supply terminal EL9510 or 12 V via EL9512 Note the information provided by the sensor manufacturer!	
Supported nominal characteristic values	any, resolution of the parameter: 0.01 µV/V recommended: 0.5..4 mV/V	
Min. strain gauge resistance	depending on external supply; parallel operation of strain gauge only recommended with suitable strain gauge	
Filter (hardware)	10 kHz low-pass (-3 dB, see filter notes)	
Filter (software)	preset 50 Hz, configurable: 50/60 Hz FIR notch filter, IIR low-pass 4-fold averager	
Internal resistance	> 200 kΩ (U_{ref}), > 1 MΩ (U_d)	
Special features	auto-calibration	
Power supply for electronics	via the E-bus	
Current consumption via E-bus	typ. 210 mA	typ. 280 mA
Current consumption of power contacts	depending on strain gauge supply, min. 1 mA	
Electrical isolation	500 V (E-bus/signal voltage)	
Configuration	via EtherCAT master/CoE	
Weight	approx. 60 g	
Permissible ambient temperature range during operation	0°C ... + 55°C	
Permissible ambient temperature range during storage	-25°C ... + 85°C	
Permissible relative humidity	95%, no condensation	
Dimensions (W x H x D)	approx. 15 mm x 100 mm x 70 mm (width aligned: 12 mm)	
Mounting [▸ 33]	on 35 mm mounting rail conforms to EN 60715	
Vibration/shock resistance	conforms to EN 60068-2-6/EN 60068-2-27, see also Installation instructions for terminals with increased mechanical load capacity [▸ 35]	
EMC immunity/emission	conforms to EN 61000-6-2 / EN 61000-6-4	
Protection class	IP20	
Installation position	variable	
Approvals	CE cULus [▸ 164]	

3.3 Basic principles of strain gauge technology

Basic information on the technological field of "strain gauges/load cells" as metrological instruments is to be given below. The information is of general nature; it is up to the user to check the extent to which it applies to his application.

- Strain gauges serve either to directly measure the static (0 to a few Hz) or dynamic (up to several KHz) elongations, compressions or torsions of a body by being directly fixed to it, or to measure various forces or movements as part of a sensor (e.g. load cells/force transducers, displacement sensor, vibration sensors).
- In the case of the optical strain gauge (e.g. Bragg grating), an application of force causes a proportional change in the optical characteristics of a fiber used as a sensor. Light with a certain wavelength is fed into the sensor. Depending upon the deformation of the grating, which is laser-cut into the sensor, due to the mechanical load, part of the light is reflected and evaluated using a suitable measuring transducer (interrogator).

The commonest principle in the industrial environment is the electrical strain gauge. There are many common terms for this type of sensor: load cell, weighbridge, etc.

Structure of electrical strain gauges

A strain gauge consists of a carrier material (e.g. stretchable plastic film) with an applied metal film from which a lattice of electrically conductive resistive material is worked in very different geometrical forms, depending on the requirements.

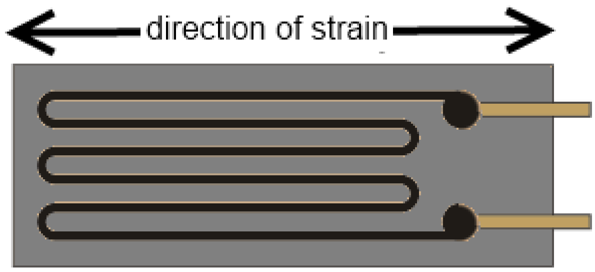


Fig. 8: Strain gauge

This utilizes a behavior whereby, for example in the case of strain, the length of a metallic resistance network increases and its diameter decreases, as a result of which its electrical resistance increases proportionally.

$\Delta R/R = k*\varepsilon$

$\varepsilon = \Delta l/l$ thereby corresponds to the elongation; the strain sensitivity is called the k-factor. This also gives rise to the typical track layout inside the strain gauge: the resistor track or course is laid in a meandering pattern in order to expose the longest possible length to the strain.

Example

The elongation ε = 0.1% of a strain gauge with k-factor 2 causes an increase in the resistance of 0.2%. Typical resistive materials are constantan (k~2) or platinum tungsten (92PT, 8W with k ~4). In the case of semiconductor strain gauges a silicon structure is glued to a carrier material. The conductivity is changed primarily by deformation of the crystal lattice (piezo-resistive effect); k-factors of up to 200 can be achieved.

Measurement of signals

The change in resistance of an individual strain gauge can be determined in principle by resistance measurement (current/voltage measurement) using a 2/3/4-wire measurement technique

Usually 1/2/4 strain gauges are arranged in a Wheatstone bridge (-> quarter/half/full bridge); the nominal resistance/impedance R_0 of all strain gauges (and the auxiliary resistors used if necessary) is usually equivalent to $R1=R2=R3=R4=R_0$. Typical values in the non-loaded state are R_0 = 120 Ω, 350 Ω, 700 Ω and 1 kΩ.

The full bridge possesses the best characteristics such as linearity in the feeding of current/voltage, four times the sensitivity of the quarter-bridge as well as systematic compensation of disturbing influences such as temperature drift and creeping. In order to achieve high sensitivity, the 4 individual strain gauges are arranged on the carrier in such a way that 2 are elongated and 2 are compressed in each case.

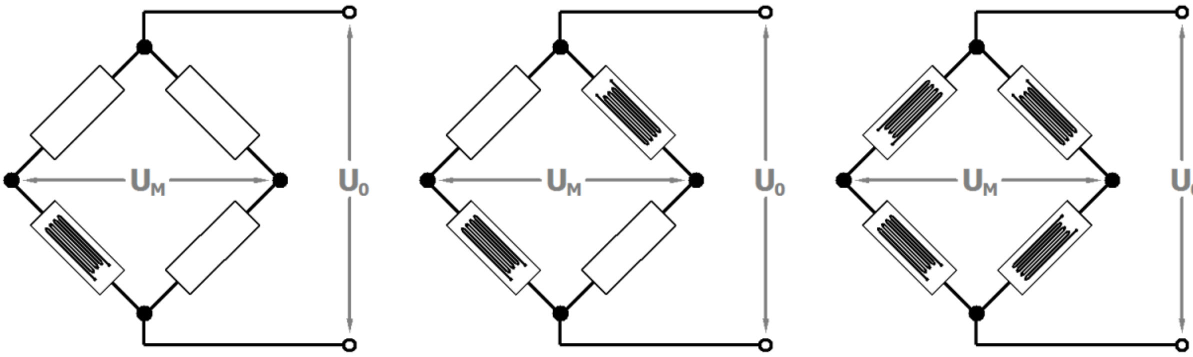


Fig. 9: quarter, half, and full bridge

The measuring bridges can be operated with constant current, constant voltage, or also with AC voltage using the carrier frequency method.

Note	**Measuring procedure** The Beckhoff terminals EL/KL335x and EL37xx only support the constant excitation.

Full bridge strain gauge at constant voltage (ratiometric measurement)

Since the relative resistance change ΔR is low in relation to the nominal resistance R_0, a simplified equation is given for the strain gauge in the Wheatstone bridge arrangement:

$U_D/U_V = \frac{1}{4} * (\Delta R1 - \Delta R2 + \Delta R3 - \Delta R4)/R_0$.

ΔR usually has a positive sign in the case of elongation and a minus sign in the case of compression.

A suitable measuring instrument measures the bridge supply voltage U_V (or U_{Supply}) and the resulting bridge voltage U_D (or U_{Bridge}), and forms the quotients from both voltages, i.e. the ratio. After further calculation and scaling the measured value is output, e.g. in kg. Due to the division of U_D and U_V the measurement is in principle independent of changes in the supply voltage.

If the voltages U_V and U_D are measured simultaneously, i.e. at the same moment, and placed in relation to each other, then this is referred to as a ratiometric measurement.

The advantage of this is that (with simultaneous measurement!) brief changes in the supply voltage (e.g. EMC effects) or a generally inaccurate or unstable supply voltage likewise have no effect on the measurement.

A change in U_V by e.g. 1% creates the same percentage change in U_D according to the above equation. Due to the simultaneous measurement of U_D and U_V the error cancels itself out completely during the division.

4-wire vs. 6-wire connection

With a constant voltage supply, the magnitude of the current can be quite considerable, e.g. 12 V / 350 Ω = 34.3 mA. This leads not only to dissipated heat, wherein the specification of the strain gauge employed must not be exceeded, but possibly also to measuring errors in the case of inadequate wiring due to line losses not being taken into account or compensated.

In principle a full bridge can be operated with a 4-conductor connection (2 conductors for the supply U_V and 2 for the measurement of the bridge voltage U_D).

If, for example, a 25 m copper cable (feed + return = 50 m) with a cross section q of 0.25 mm^2 is used, this results in a line resistance of

R_L= l/ (κ * q) = 50 m / (58 S*m/mm^2* 0.25 mm^2) = 3.5 Ω

If this value remains constant, then the error resulting from it can be calibrated out. However, assuming a realistic temperature change of, for example, 30° the line resistance R_L changes by

ΔR_L =30° * 3.9 * 10^{-4} * 3.5 Ω = 0.41 Ω

In relation to a 350 Ω measuring bridge this means a measuring error of > 0.1%.

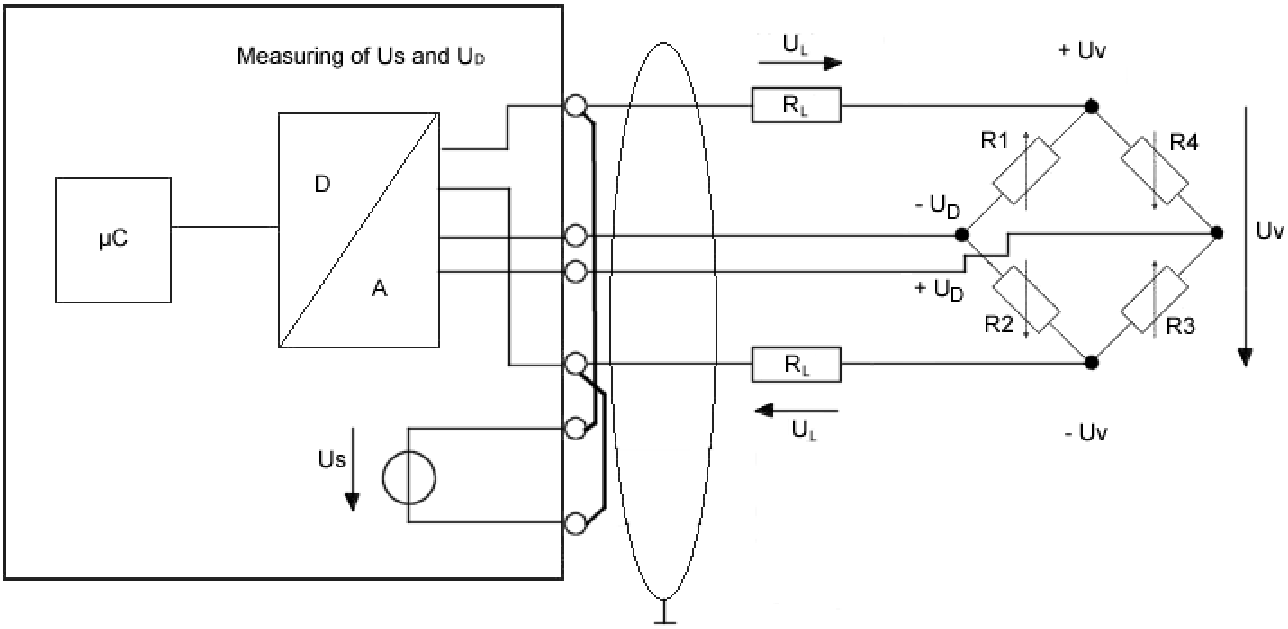


Fig. 10: 4-wire connection

This can be remedied by a 6-wire connection, in particular for precision applications.

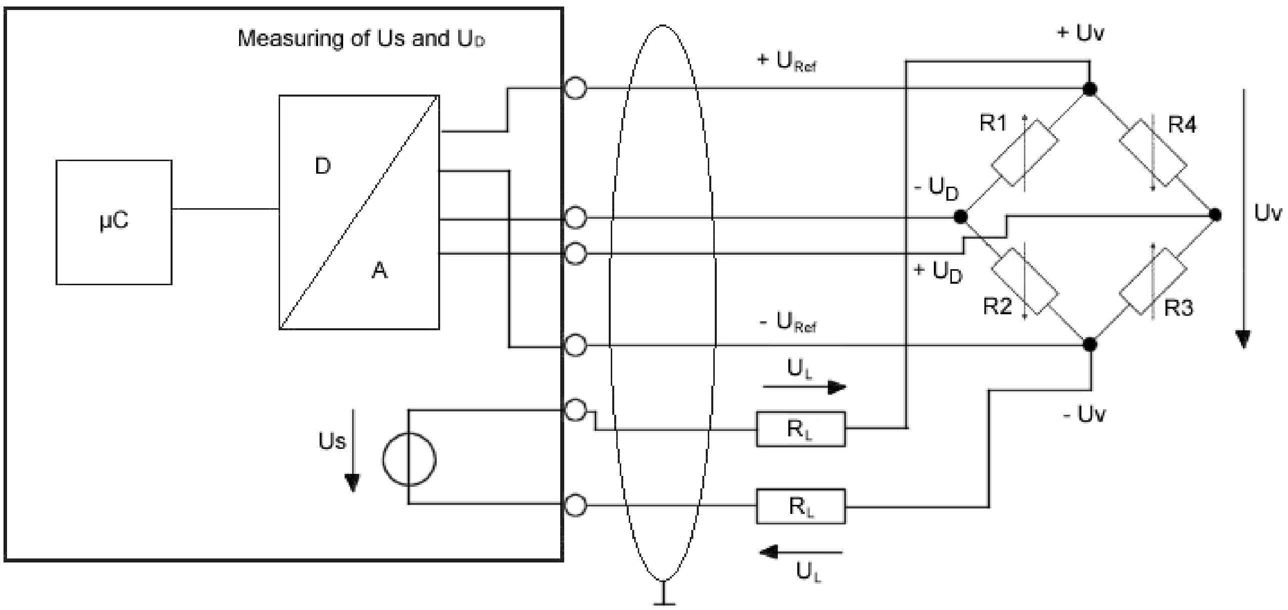


Fig. 11: *6-wire connection*

The supply voltage U_V is thereby fed to the strain gauge (= current carrying conductor). The incoming supply voltage U_{Ref} is only measured with high impedance directly at the measuring bridge in exactly the same way as the bridge voltage U_D with two currentless return conductors in each case. The conductor-related errors are hence omitted.

Since these are very small voltage levels of the order of mV and μV, all conductors should be screened.

Structure of a load cell with a strain gauge

One application of the strain gauge is the construction of load cells.

This involves gluing strain gauges (full bridges as a rule) to an elastic mechanical carrier, e.g. a double-bending beam spring element, and additionally covered to protect against environmental influences.

The individual strain gauges are aligned for maximum output signals according to the load direction (2 strain gauges in the elongation direction and 2 in the compression direction).

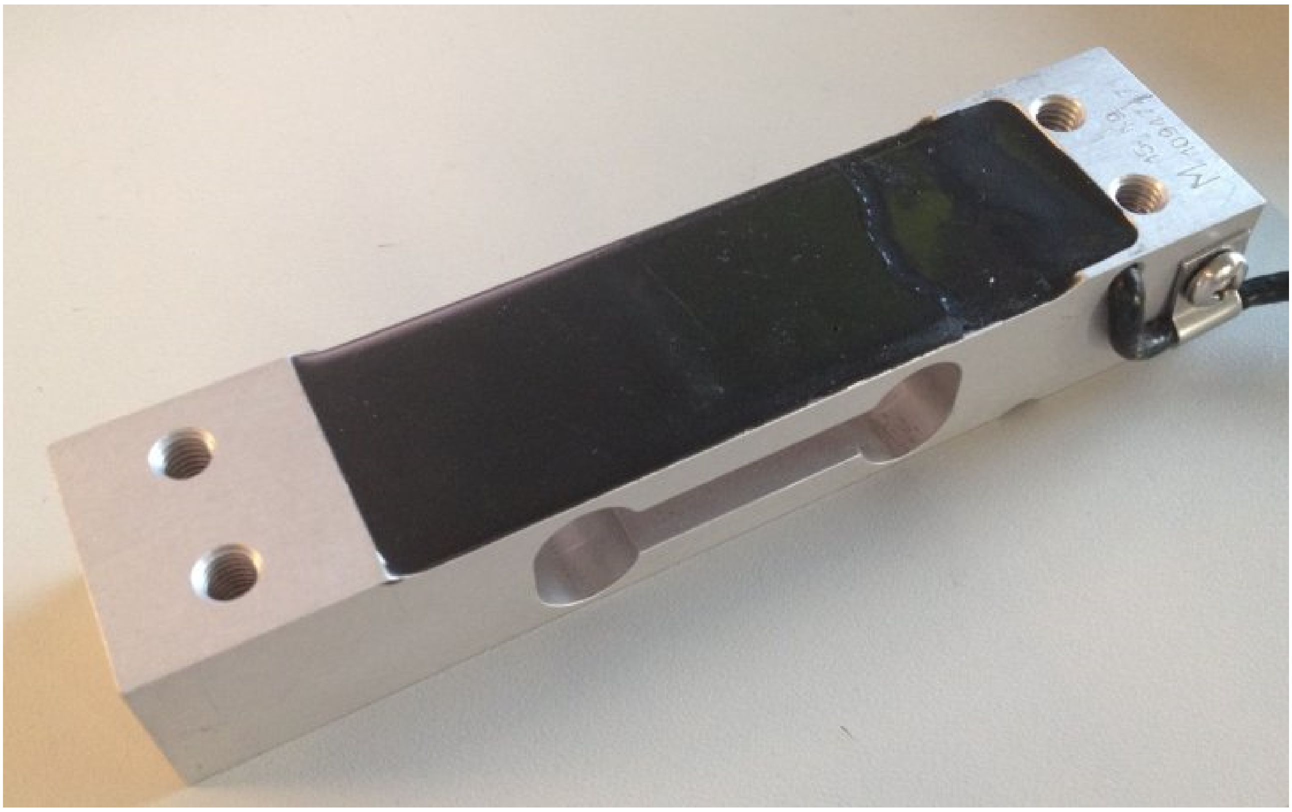


Fig. 12: Example of a load cell

The most important characteristic data of a load cell

Note	**Characteristic data** Please enquire to the sensor manufacturer regarding the exact characteristic data!

Nominal load E_{max}

Maximum permissible load for normal operation, e.g. 10 kg

Nominal characteristic value mV/V

The nominal characteristic value 2mV/V means that, with a supply of U_S =10 V and at the full load E_{max} of the load cell, the maximum output voltage U_D = 10 V * 10 V/V *E = 20 mV. The nominal characteristic value is always a nominal value – a manufacturer’s test report is included with good load cells stating the characteristic value determined for the individual load cell, e.g. 2.0782 mV/V.

Minimum calibration value V_{min}

This indicates the smallest mass that can be measured without the maximum permissible error of the load cell being exceeded [RevT].

This value is represented either by the equation $V_{min} = E_{max} / n$ (where n is an integer, e.g. 10000), or in % of E_{max} (e.g. 0.01).

This means that a load cell with E_{max} = 10 kg has a maximum resolution of

V_{min} = 10 kg / 10000 = 1 g or V_{min} = 10 kg * 0.01% = 1 g.

Accuracy class according to OIML R60

The accuracy class is indicated by a letter (A, B, C or D) and an additional number, which encodes the **scale interval d with a maximum number n_{max}** (*1000); e.g. C4 means Class C with maximally 4000d scale intervals.

The classes specify a maximum and minimum limit for **scale intervals d**:

- A: 50,000 – unlimited
- B: 5000 – 100,000
- C: 500 – 10,000
- D: 500 – 1000,

The scale interval n_{max} = 4000d states that, with a load cell with a resolution of V_{min} = 1 g, a calibratable set of scales can be built that has a maximum measuring range of 4000d * V_{min} = 4 kg. Since V_{min} is thereby a minimum specification, an 8 kg set of scales could be built – if the application allows – with the same load cell, wherein the calibratable resolution would then fall to 8 kg/4000d = 2 g. From another point of view the scale interval n_{max} is a maximum specification; hence, the above load cell could be used to build a set of scales with a measuring range of 4 kg, but a resolution of only 2000 divisions = 2 g, if this is adequate for the respective application. Also the classes differ in certain error limits related to non-repeatability/creep/TC.

Accuracy class according to PTB

The European accuracy classes are defined in an almost identical way (source: PTB).

Class	Calibration value e	Minimum load	Max/e	
			Minimum value	Maximum value
I Fine scales	0.001 g <= e	100 e	50000	-
II Precision scales	0,001 g <= e <= 0,05 g 0,1 g <= e	20 e 50 e	100 5000	100000 100000
III Commercial scales	0.1 g <= e <= 2 g 5 g <= e	20 e 20 e	100 500	10000 10000
IIII Coarse scales	5 g <= e	10 e	100	1000

Minimum application range or minimum measuring range in % of rated load

This is the minimum measuring range/measuring range interval, which a calibratable load cell/set of scales must cover.

Example: above load cell E_{max} = 10 kg; minimum application range e.g. 40% E_{max}

The used measuring range of the load cell must be at least 4 kg. The minimum application range can lie in any range between E_{min} and E_{max}, e.g. between 2 kg and 6 kg if a tare mass of 2 kg already exists for structural reasons. A relationship between n_{max} and V_{min} is thereby likewise apparent: 4000 * 1 g = 4 kg .

There are further important characteristic values, which are for the most part self-explanatory and need not be discussed further here, such as nominal characteristic value tolerance, input/output resistance, recommended supply voltage, nominal temperature range etc.

Parallel connection of strain gauges

It is usual to distribute a load mechanically to several strain gauge load cells at the same time. Hence, for example, the 3-point bearing of a silo container on 3 load cells can be realized. Taking into account wind loads and loading dynamics, the total loading of the silo including the dead weight of the container can thus be measured. The mechanically parallel-connected load cells are usually also electrically connected in parallel and to one measuring transducer, e.g. the EL3356. To this end the following must be observed:

- the load cells must be matched to each other and approved by the manufacturer for this mode of operation
- the impedance of the load cells must be such that the current feed capability of the transducer electronics is not overloaded.

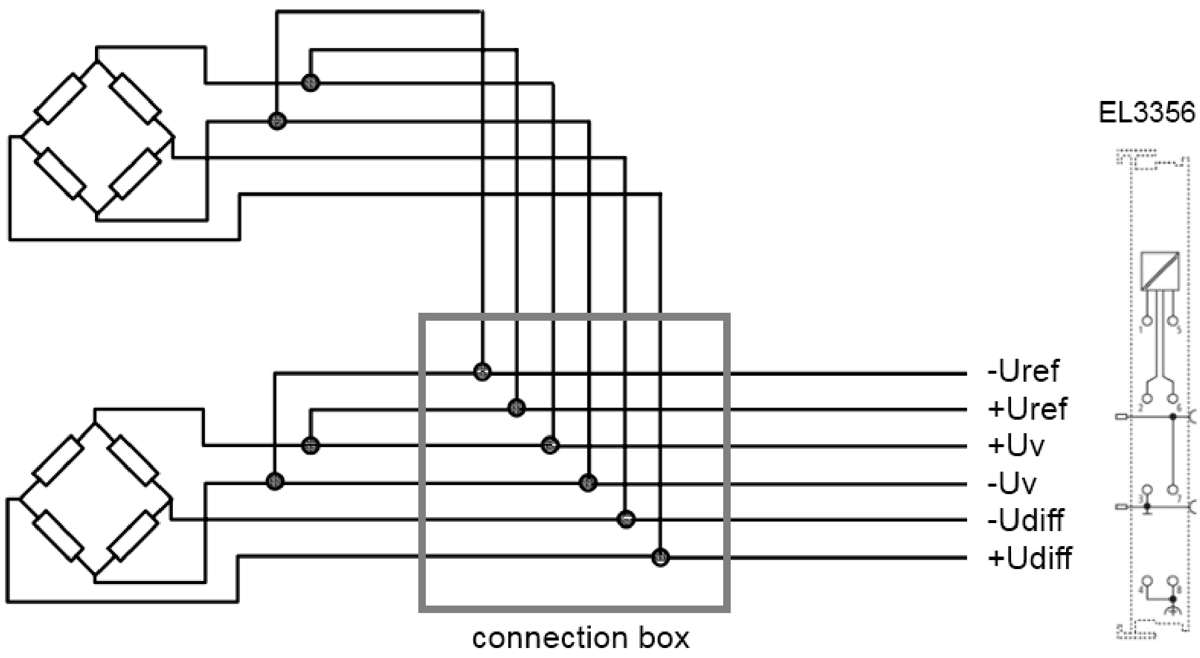


Fig. 13: Parallel strain gauge

Sources of error/disturbance variables

Inherent electrical noise of the load cell

Electrical conductors exhibit so-called thermal noise (thermal/Johnson noise), which is caused by irregular temperature-dependent movements of the electrons in the conductor material. The resolution of the bridge signal is already limited by this physical effect. The rms value e_n of the noise can be calculated by $e_n = \sqrt{4kTRB}$.

In the case of a load cell with R_0 = 350 Ω at an ambient temperature T = 20 °C (= 293K) and a bandwidth of the measuring transducer of 50 Hz (and Boltzmann constant k = 1.38 * 10^{-23} J/K), the rms e_n = 16.8 nV. The peak-peak noise e_{pp} is thus approx. e_{pp}~4* e_n = 67.3 nV.

Example:

In relation to the maximum output voltage U_{out_max} of a bridge with 2 mV/V and U_s = 5 V, this corresponds to U_{out_max} = 5 V * 2 mV/V = 10 mV. (For the nominal load) this results in a maximum resolution of 10 mV/67.3 nV = 148588 digits. Converted into bit resolution: ln(148588)/ln(2) = 17 bits. Interpretation: a higher digital measuring resolution than 17 bits is thus inappropriate for such an analog signal in the first step. If a higher measuring resolution is used, then additional measures may need to be taken in the evaluation chain in order to obtain the higher information content from the signal, e.g. hardware low-pass filter or software algorithms.

This resolution applies alone to the measuring bridge without any further interferences. The resolution of the measuring signal can be increased by reducing the bandwidth of the measuring unit.

If the strain gauge is glued to a carrier (load cell) and wired up, both external electrical disturbances (e.g. thermovoltage at connection points) and mechanical vibrations in the vicinity (machines, drives, transformers (mechanical and audible 50 Hz vibration due to magnetostriction etc.)) can additionally impair the result of measurement.

Creep

Under a constant load, spring materials can further deform in the load direction. This process is reversible, but it generates a slowly changing measured value during the static measurement. In an ideal case the error can be compensated by constructive measures (geometry, adhesives).

Hysteresis

If even elongation and compression of the load cell take place, then the output voltage does not follow exactly the same curve, since the deformation of the strain gauge and the carrier may be different due to the adhesive and its layer thickness.

Temperature drift (inherent heating, ambient temperature)

Relatively large currents can flow in strain gauge applications, e.g. $I = U_s/R_0$ = 10 V / 350 Ω = 26 mA. The power dissipation at the sensor is thus $P_v = U*I$ = 10 V * 26 mA = 260 mW. Depending on application/carrier material (= cooling) and ambient temperature, a not insignificant error can arise that is termed apparent elongation. The sensor manufacturers integrate suitable compensation elements in their strain gauges.

Inadequate circuit technology

As already shown, a full bridge may be able (due to the system) to fully compensate non-linearity, creep and temperature drift. Wiring-related measuring errors are avoided by the 6-conductor connection.

References

Some organizations are listed below that provide the specifications or documents for the technological field of weighing technology:

- **OIML** (ORGANISATION INTERNATIONALE DE MÉTROLOGIE LÉGALE) www.oiml.org
- PTB - Physikalisch-Technischen Bundesanstalt www.ptb.de
- www.eichamt.de
- WELMEC - European cooperation in legal metrology www.welmec.org
- DKD - Deutscher Kalibrierdienst www.dkd.eu
- Fachgemeinschaft Waagen (AWA) im Verband Deutscher Maschinen- und Anlagenbau VDMA www.vdma.org

3.4 Start

For commissioning:

- mount the EL3356 as described in the chapter Mounting and wiring [▶ 33]
- configure the EL3356 in TwinCAT as described in the chapter Commissioning [▶ 113].

For fast commissioning please refer to chapter Commissioning -> Quick start [▶ 113].