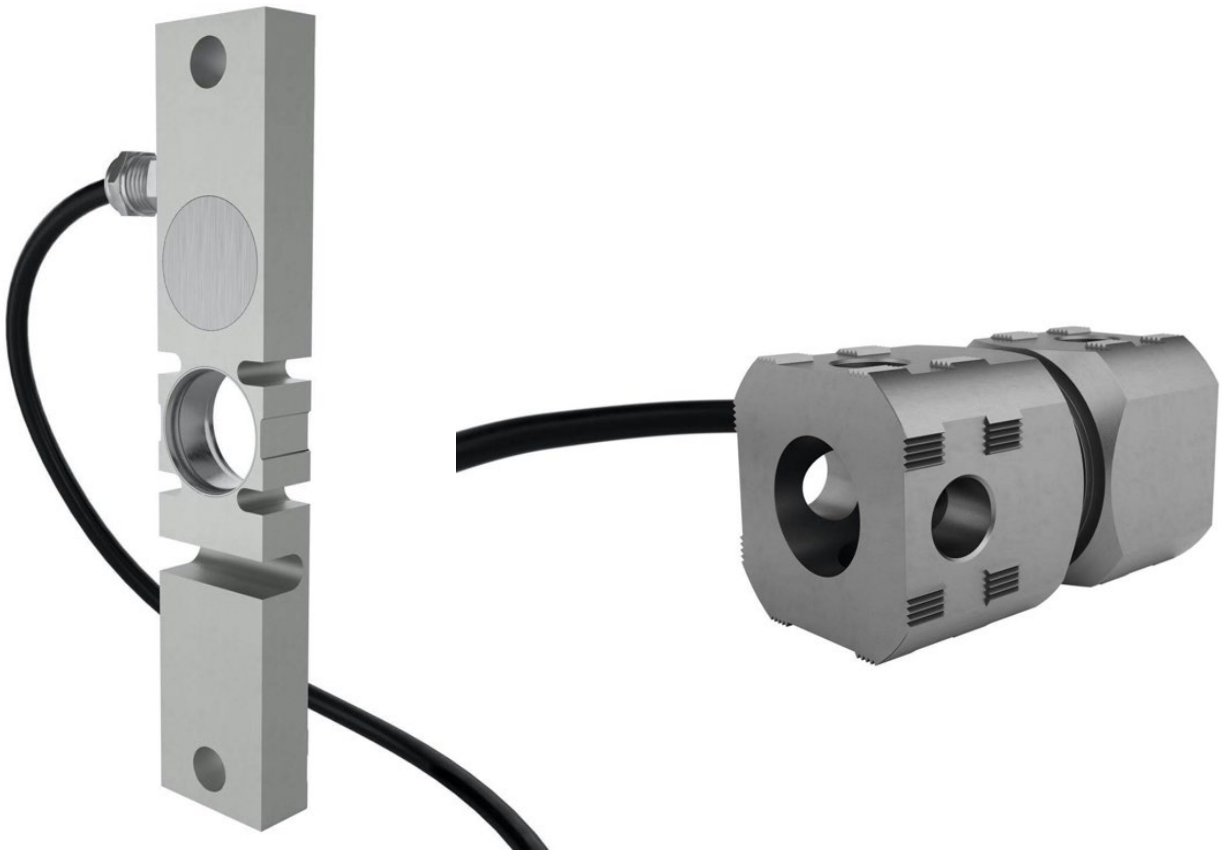
VT1 / XT50

Extensometer

User Manual



1. Revision history

Revision	Description of change	Date	Prepared by
01	First issue	17th Nov 2022	N Jones
1.1	Edits : Greek Letters, Superscripts & Labels	28th May 2024	R Joslin

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2. General instructions and preconditions for installation:

Handle extensometers (EM) with care: Unlike load cells or force sensors, EMs are designed to sense strain on metal structures at minimum activation forces. They are easily damaged by external forces, moments, or impact, e.g., dropping on a hard floor. Do not use their bodies as drilling template or welding template. Their bodies are too flexible and the 10.5mm holes are too large for precise positioning of M10 bolts. Installation areas must be flat and clean bare metal surfaces. Remove scale, rust, or paint (e.g. by a suitable size belt grinder, recommended width 30 to 40 mm) and grease or any other dirt by suitable solvents. Strain transmission teeth of EM must “bite” directly into metal surface without any soft layer in between. Do not use washers or shims between EM and mounting surface of structural parts. Install extensometers only on *empty* silos / tanks / hoppers or unloaded structural parts. Before and after installation, check Zero-signal, resistance – In (black + green) and Out (red + white), check insulation resistance of wires against extensometer body and cable shield. Acceptable change for Zero is +/- 0.5 mV/V. If higher, repeat extensometer mounting and avoid squeezing, bending or distortion during bolting procedure. Recommended test instruments: Flintec load cell tester LCT-11, or, alternatively, 5-digit digital multi meter, GOhm insulation tester, mV/V indicator. Wherever possible, cable entry should point downwards or sidewards in outdoor installations.

Extensometers can be installed indoors / outdoors, for silo, tank, hopper content monitoring, load monitoring on structural steel objects, overload protection on presses, cranes, bridges etc.

Important Disclaimer: *Flintec extensometers are not certified as safety parts of control systems for emergency shut off to protect human life or health! (Functional Safety, SIL, PL etc.)*

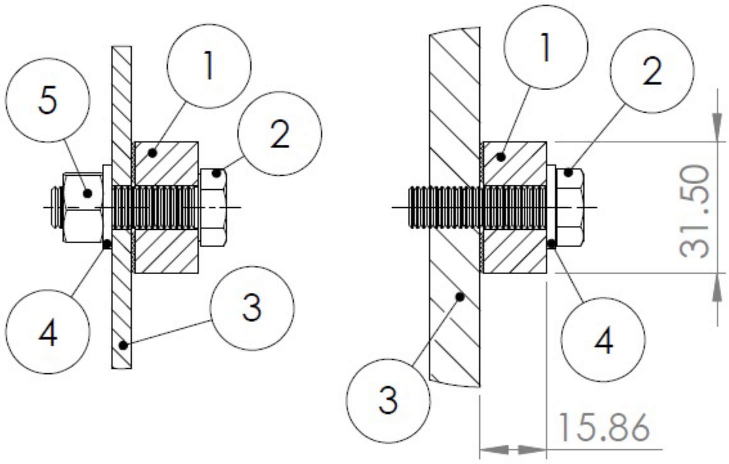
3. Mounting options for extensometers:

There are 2 options for mounting onto structural steel or aluminium parts:

3.1. Bolting:

Mark positions and drill holes for M10 mounting bolts in selected area. Use drilling template (DT) made from hard steel (part of optionally available Flintec installation kit) to guarantee precise hole distance. DT itself can be bolted to selected surface by 2 x M6 bolts if external clamping is not feasible. For thin-walled parts, use through holes and lock nuts with thick washers from rear side. For thick-walled parts (12mm and more) threaded holes are possible if rear side of installation area is not accessible for lock nuts. Apply anti-friction oil or grease on bolt threads before assembly. Use torque wrench with correct set value for M10-A4-80 mounting bolts (50Nm). If A4-80 bolts are not available, M10-8.8 galvanized or hot dip zinc coated structural bolts M10 can be used. Grade 8.8 is a minimum requirement. Approach to final torque value step by step and switch to other mounting bolt after each step, at least use 2 steps per bolt. Check Zero indication change.

Bolted Installation (3.1)

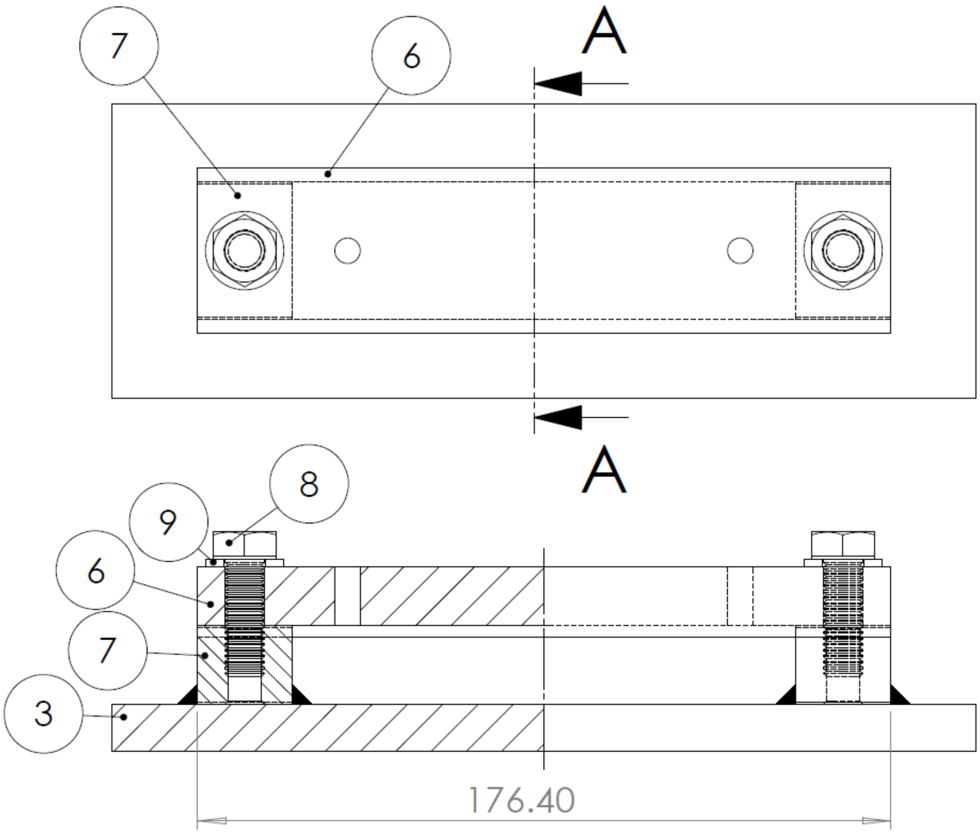


1: Sensor VT-1 **2**: Hex-headed bolt M10 grade 8.8 or higher **3**: Structural part
4: Washer **5**: Lock nut grade 8.8 or higher

3.2. Welding:

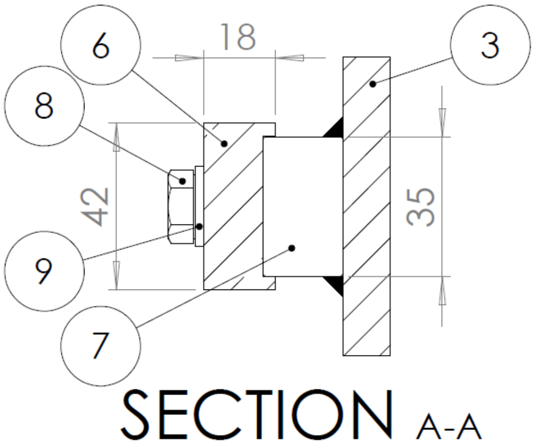
Particularly recommended on structural parts which are accessible from one side only, or which are slightly curved (concave or convex). Welding blocks (WB) M10, designed to fit VT1-drilling template (DT), and VT-1 drilling templates are available upon request within scope of Flintec VT-1 installation kit.
Insert WB M10 into slot of drilling template (DT) on both ends and bolt them with hexagonal head M10 bolt. Make sure no bolt end is protruding from the mounting face of WBs.
If required, use washers between DT and bolt head to compensate excess bolt length. Put alignment marks on desired installation area for VT-1, hold DT with mounted WBs on in desired position and mark welding area around WBs, about 10mm wider on all sides.
Remove DT with WBs M10, grind surface of steel structure in designated welding areas and clean it. Re-position DT with WBs M10, tack weld both WB on 3 sides each, then fusion weld all 3 accessible sides of WBs with fillet weld of min 3mm root height. Unbolt and remove DT and complete welding seam on each WB. Clean and smoothen weld seams with suitable grinder if required. Remove all slag and apply anti-corrosion paint. Install VT-1 using stainless steel A4-80 bolts or hot dip zinc coated structural bolts or galvanized hex head bolts M10 grade 8.8 or higher. Ensure, chosen bolt length (recommended length 30mm, max possible is 34mm) is not bottoming out inside M10 thread holes against structural part. One galvanized steel or stainless-steel washer DIN 125 or one shim washer DIN 988 of higher thickness can be used between bolt head and VT1 to adjust for longer bolts. Apply anti-friction oil or grease on bolt threads before assembly. Use torque wrench set to recommended torque for chosen bolt type. Approach to final torque value step by step and switch to other mounting bolt after each step, at least use 2 steps per bolt.

Welded Installation (3.2)
Drilling Template with Weld Block M10:



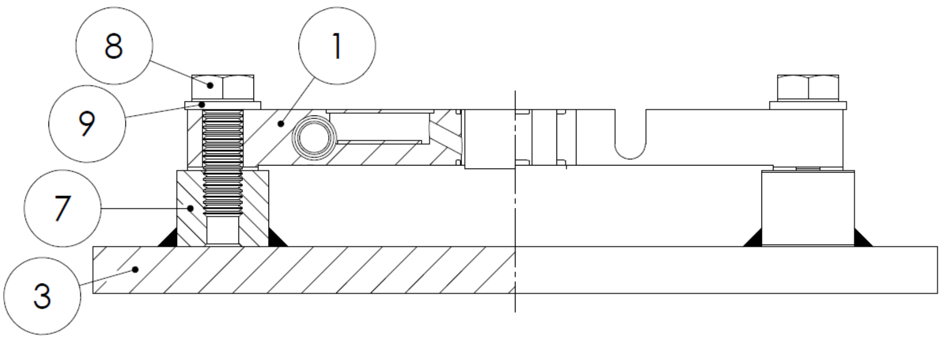
3: Structural part **6**: Drilling template **7**: Weld block M10 **8**: Hex-head-bolt M10
9: Washer

Section view of drilling template with Weld Block M10 (3.2)



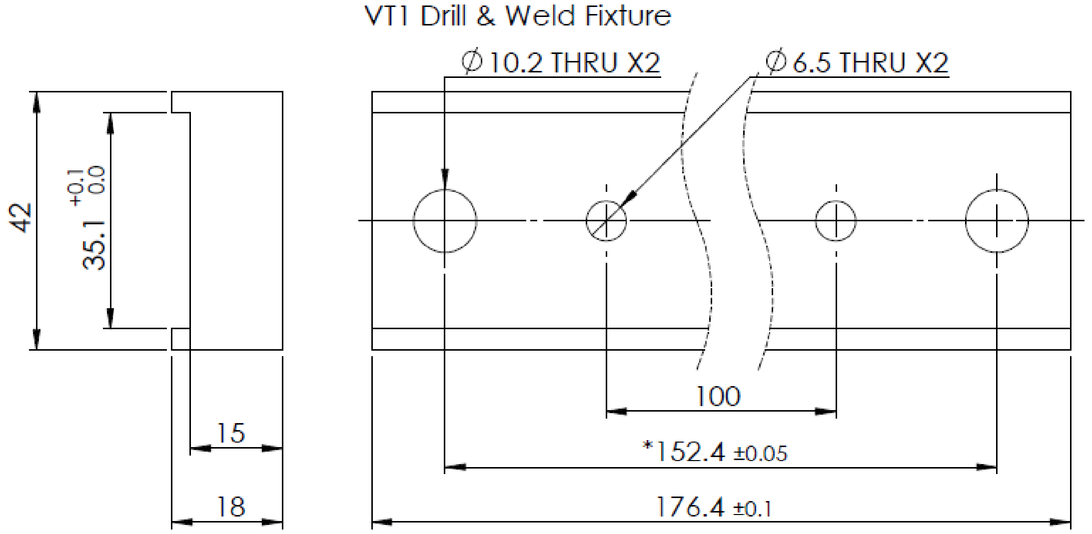
3: Structural part 6: Drilling template 7: Weld block M10 8: Hex-head-bolt M10
9: Washer

VT1 mounted on Weld Blocks (3.2)



1: Sensor VT-1 **3**: Structural part **7**: Weld Block M10 welded to **3**
8: Hex-head-bolt M10 grade 8.8 **9**: Washer

3.3. Optional drilling and welding accessories

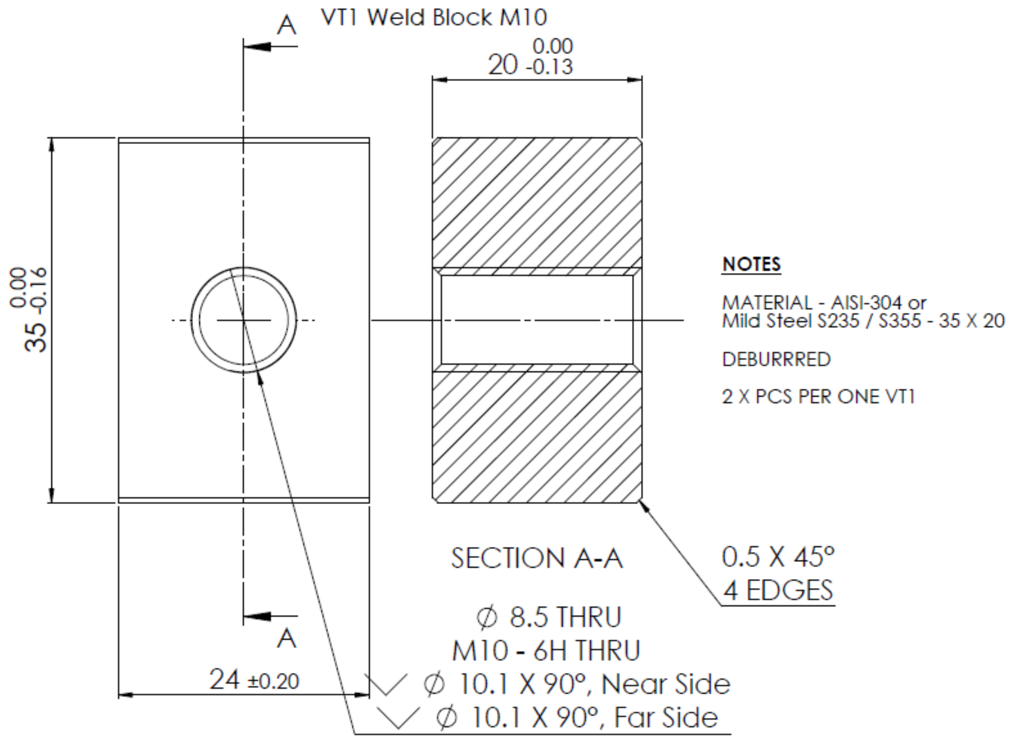


NOTES

MATERIAL - 17-4PH 1.75" X 0.75" X 180mm

HARDNESS - HRC 43~46

* 152.4 +/-0.05 SHOULD BE ACHIEVED AFTER HEAT TREATMENT



Drilling template works also as welding template for square weld blocks or round weld blocks up to 35mm diameter (not depicted). It is designed for high stiffness and has precisely drilled positioning holes for M10 bolts mating exactly VT-1 mounting hole distance. To avoid rotation during pre-assembly of weld blocks M10 onto drilling template, square weld blocks are fitting exactly into the 35mm slot of the template.

4. Principles of strain/stress sensing on beam type structures:

4.1. Compression or Tension

Extensometers (EM) are installed on outer or inner surfaces parallel to longitudinal axis of structural parts, in-line with the expected force applied to it. Common applications: Silos, hoppers or tanks standing on legs or suspended from overhead ceilings, frames etc., overhead crane bridges, road or rail bridges. Less common: Press frame columns, push or pull rods, actuator rods or arms of all kinds of machinery where indirect force measurement is desired to protect equipment against overloading or misuse resulting in serious damage. Expected EM signal output in mV/V is determined by.

- change in load or force Δ F (N) between unloaded / loaded condition divided by
- load bearing cross-sectional area As (mm^2) of related structural part,
- Elastic Modulus (Young´s Modulus) **E** (KN/mm^2) of the material from which the structural part is made.

Values of **E** are:	Alloy and structural steel	210 KN/mm^2
	Stainless steel	200 KN/mm^2
	Aluminium	70 KN/mm^2

Equations for calculation:

Change in material stress Δ Σ (N/mm^2) = Δ F (N) / As (mm^2)

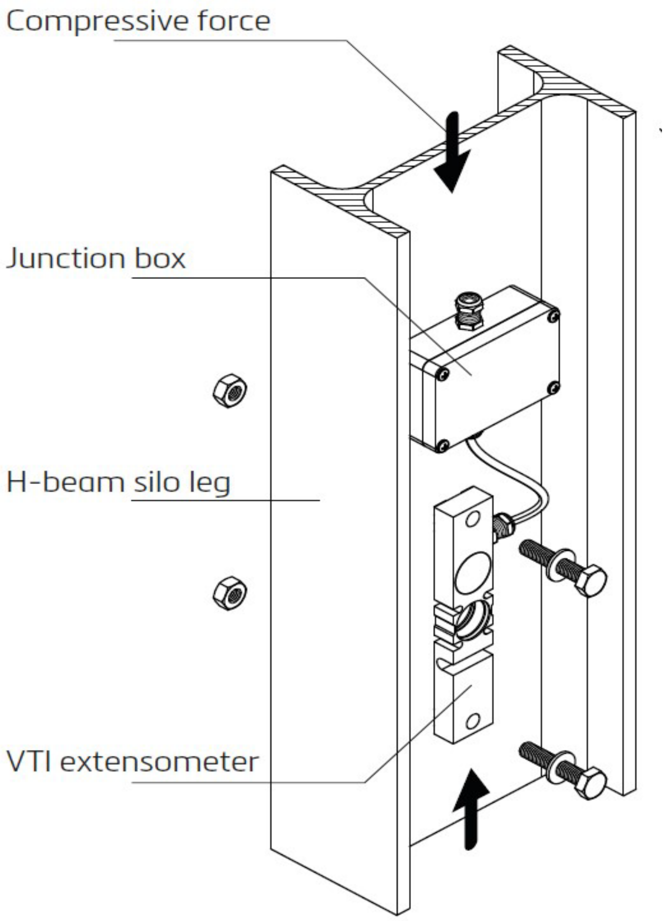
Rated FSO, e.g. VT1 extensometer = 1.7 mV/V at 500 ppm strain (or 500 micro strain)

(See individual extensometer data sheets for Rated FSO values)

Change in surface strain Δ ε (ppm strain) = Δ Σ (stress in N/mm^2) / (**E** in KN/mm^2) x 1000)

Expected signal output in mV/V = FSO x Δ ε / 500 ppm

For Installation example for a Silo Leg, see next page.



Source: VT1-Data sheet page 4.

4.2. Bending on beams, profiles, pipes etc.

Forces or loads in structural parts like beams or masts with various profiles causing bending are sensed by extensometers mounted in the longitudinal direction on outer surfaces of such profiles. Select mounting position in areas where high compression or tension stress can be expected. Best results are achieved when extensometers are mounted in pairs in longitudinal direction on opposite outer surfaces of profiles with symmetric cross-section, providing similar magnitudes of stress or strain in tension and compression along their centre lines.

Benefits of this installation method using “anti-parallel” connected pairs are explained under 3.

Equations for calculation:

Bending stress Σ -b (N/mm^2) = Mb / Wb with

Bending moment Mb (Nmm) = F (N) x L (mm),

F = Force perpendicular to centre line of beam,

L = Length of lever arm from fixed or supported end of beam to position of F, and with

Wb = second moment of area (mm^3) (related to same cross-sectional axis as Mb).

Wb values for all standardised structural steel and aluminium profiles can be found on engineering web sites. As this value is purely related to geometry and not to material properties, tables for steel profiles or aluminium profiles can be used regardless of the exact alloy.

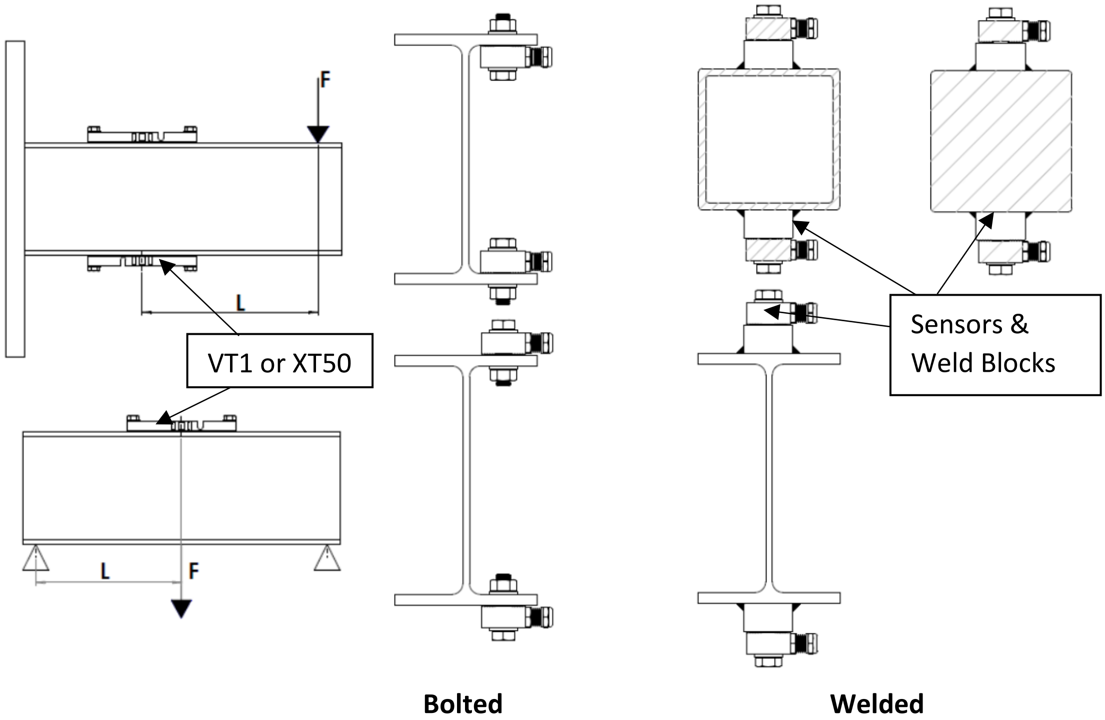
Rated extensometer FSO , e.g. VT1 = 1.7 mV/V at 500 ppm strain (or 500 micro strain)

(See individual extensometer data sheets for Rated FSO values)

Δ ε (ppm strain) = Δ Σ (stress in N/mm^2) / (**E** in KN/mm^2) x 1000)

Expected signal output in mV/V = FSO (mV/V) x Δ ε (ppm strain) / 500 (ppm strain)

Bending on Beams (4.2)
Positioning of Extensometers (examples)



Installation as anti-parallel connected pair on cantilever beam and as single sensor on bending beam.

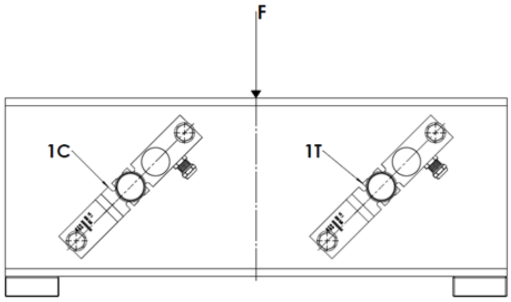
4.3. Shear

Forces or loads on horizontal structural parts like girders or yokes with various profiles which are supported on both ends and loaded in the centre area are also sensed by pairs of extensometers, connected in parallel. Best results are achieved when both extensometers are mounted at 45° angle in places of shear stresses with opposite direction and connected in anti-parallel mode as described under **4.3.** Shear stress sensing installation is especially recommended on short H-beams or box-girders or yokes, where only little length and room is left between supported and loaded area. For round profiles special custom-made welding blocks fitting to the outer diameter are required to enable 45° mounting position and good quality fillet weld seams.

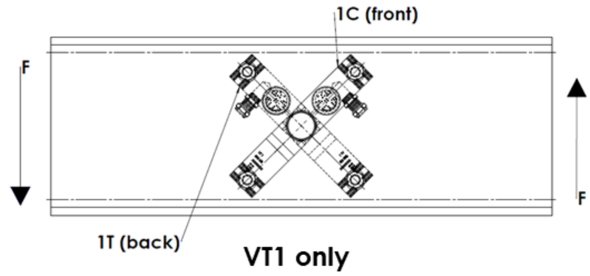
Benefits of this installation method using “anti-parallel” connected pairs are the same as under **4.2** for bending installation. To enable best temperature compensation, extensometers for positive and negative strain or stress sensing should be mounted as close to one another as possible. Each pair of anti-parallel connected Extensometers is considered as “one measuring point”.

Schematic installation examples and Extensometer orientation:

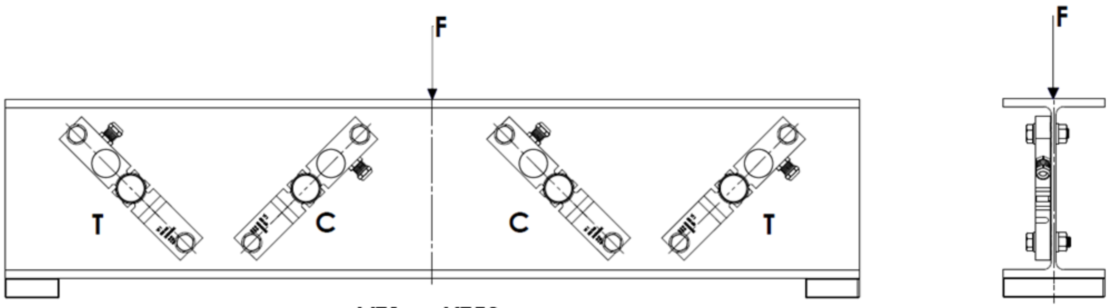
Shear Sensing Installations (4.3)
Positioning of Extensometers (examples)



VT1 or XT50



VT1 only



VT1 or XT50

1 T: Sensor for tensional strain **1 C**: Sensor for compressive strain

Front-to-backside mounting in X–arrangement is not possible with XT-50 due to its short length.

Equations for calculation:

Instead of Young´s Modulus or Modulus of Elasticity **E**, the lower Shear-Modulus or Modulus of Rigidity **G** for steel and aluminium is used. **G** can be calculated from E and Poisson´s Ratio $\boldsymbol{\mu}$:

$$\boldsymbol{G} = \boldsymbol{E}/2(1 + \mu)$$

Or found on the web, e.g. engineeringtoolbox.com: (GPa = KN/mm^2)

	Shear Modulus G	Poisson´s Ratio μ	Young´s Modulus E
Aluminum	27 GPa	0,334	69 GPa
Aluminum 2024 T4:	28 GPa	0,32	70 GPa
Carbon Steel	77 GPa	0,295	200 GPa
Mild Steel	64 GPa	0,303	210 GPa
Cold rolled Steel	75 GPa	0,287	200 GPa
Stainless steel	77 GPa	0,305	180 GPa

Table 1

For official structural static calculations, values from material supplier should be requested, e.g. mill certificate 3.1 etc. Alternatively use minimum mechanical properties according to applicable standards for desired structural profile and metal alloy.

To distinguish shear stress form bending or compression / tension stress “Σ”, shear stress is denoted as “τ-s”.

Shear Stress τ-s (N/mm^2) = Shear Force Fs (N) / cross-sectional Area As (mm^2)*

With cross-sectional area As taken perpendicular to the longitudinal centre line of the structural profile. If the geometry of the structural element is changing over the profile length in the area between load application area and support area, the smallest cross section has to be considered for As. This is usually at the position of minimal height of profile.

* Note: As flanges of I-beams / H-beams do not contribute much to shear resistance, As can be calculated as total height H of I-beam x thickness t of vertical web: As = H x t

With known shear-stress change Δ τ-s between loaded and unloaded condition, corresponding strain change Δ ε-s can be calculated as:

Δ ε-s (ppm strain) = Δ τ-s (shear-stress in N/mm2) / (**G** in KN/mm2) x 1000)

With rated FSO extensometer, e.g. VT1 = 1.7 (mV/V) at 500 ppm strain (or 500 micro strain)

(See individual extensometer data sheets for Rated FSO values)

we can calculate

Expected signal output in (mV/V) = FSO (mV/V) x Δ ε-s (ppm strain) / 500 (ppm strain)

4.4. Torsion

For sensing torque in stationary or rotating shafts, extensometers are installed in opposite positions under 45° angle to the centre line of the shaft to sense torsional shear stress. Regardless if shafts are solid or hollow (round or square thick-walled pipes), it is recommended to use weld blocks M10 and Drilling-/ Welding Template as described under 3.2, because drilling thread holes into such structural parts will create stress risers and reduce fatigue resistance of such parts drastically. In addition, creating 2 flat mounting faces for extensometers will be very difficult without welding on round shafts.

It is important to keep symmetry (especially on rotating shafts where dynamic mass balance matters) with respect to the centre line of the shaft by careful placement in opposite positions. To get the same benefits from anti-parallel connection as described under **4.4**, it is important to orientate extensometers under 45° angle, one pointing to left side of the shaft axis and the opposite one pointing to the right side of the shaft axis. See sketches further below. For non-rotating shafts single side installation can be considered, but double-sided installation compensates overlaid bending moments in addition to temperature compensation of the Zero signal.

To distinguish torsional shear stress from shear stress “τ-s” , torsional shear stress is denoted as “τ-t”.

Equations for calculation:

Instead of Young´s Modulus or Modulus of Elasticity **E**, the lower Shear-Modulus or Modulus of Rigidity **G** for steel or aluminium is used as explained under 4.3.

Torsional stress τ-t (N/mm^2) = Mt / Wt

Torsional moment or Torque Mt (Nmm or Nm or KNm) = Usually provided by the customer application.

Wt = Second polar moment of area (mm^3) (related to the cross-sectional area centre point = longitudinal axis of the shaft under torque Mt).

Wt values for all standardised structural steel and aluminium profiles can be found on engineering web sites. As this value is purely related to geometry and not to material properties, tables for steel profiles or aluminium profiles can be used regardless of the exact alloy.

For simple profiles like solid rod or solid square bar, Wt can be calculated as

Wt-rod (mm^3) = Pi x r^3 / 2 with r = D/2 and Pi=3,1415 for round shafts and rods with diameter D (mm)

Wt-bar (mm^3) = 0,208 x a^3 for square bars with a = thickness of bar in (mm)

With known torsional shear-stress change Δ τ-t between loaded and unloaded condition,

corresponding strain change Δ ε-t can be calculated as:

Δ ε-t (ppm strain) = Δ ττ-t (stress in N/mm^2) / (**G** in KN/mm^2) x 1000)

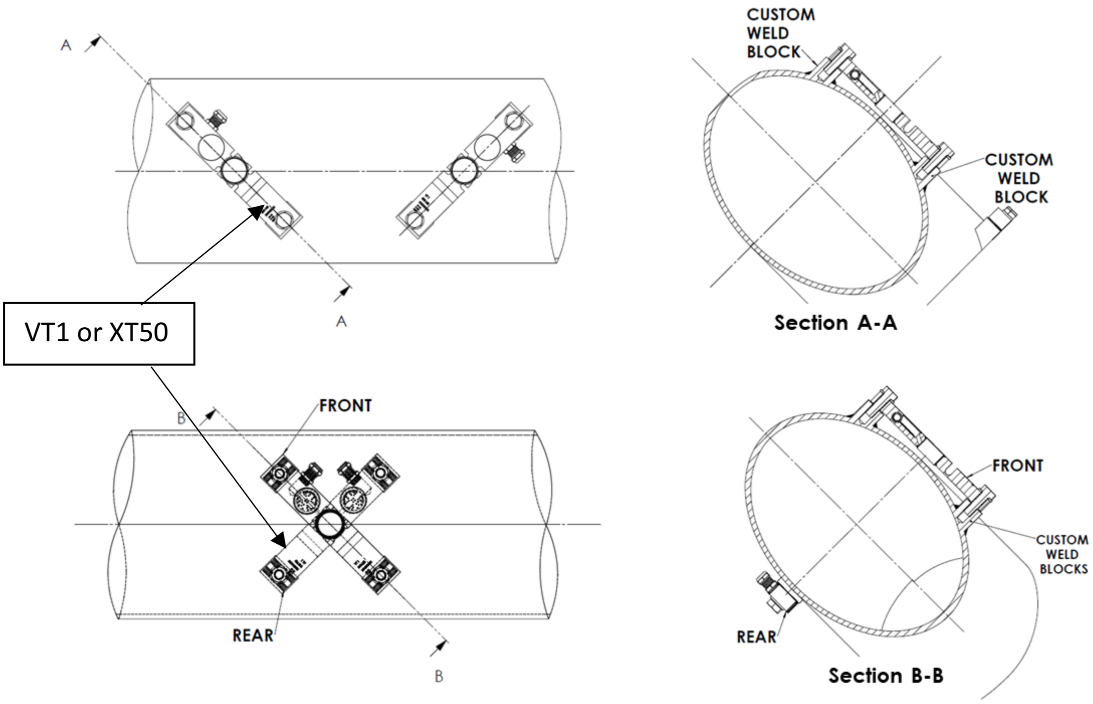
With rated FSO extensometer, e.g. VT1 = 1.7 mV/V at 500 ppm strain (or 500 micro strain)

(See individual extensometer data sheets for Rated FSO values)

we can calculate

Expected signal output in (mV/V) = FSO (mV/V) x Δ ε-t (ppm strain) / 500 (ppm strain)

Sensing Torsional Stress (4.4)



Such installation requires customized weld blocks M10 with inclined mounting face to match the radius of the structural part, i.e. shaft or round beam.

For square shafts or beams, standard Flintec weld blocks will fit.

5. Installation and wiring in pairs

Benefits of this installation method using "anti-parallel" connected pairs are:

- Cancellation of signal drift caused by thermal expansion due to temperature changes in the structural parts or ambient temperature changes
- Up to twice as much signal for the same amount of surface strain compared to single extensometer installation on each "measuring point"

5.1. Compensation of thermal expansion effects

Especially in outdoor installations, structural steel or aluminium parts are subject to temperature changes. On larger structures, this change is different for various locations of sensor installation due to orientation in relation to sunlight or shade, exposure to wind and rain, ice and snow. Even with approximate knowledge of thermal expansion coefficients of the structural alloys, general compensation is not easily possible as every structural part with an extensometer installation has its individual expansion versus temperature characteristics due to design effects as well as hinderances to free thermal expansion or contraction. By installation in pairs at each desired location of strain measurement, individual compensation of thermal expansion at this particular measurement location is possible, if extensometers are connected in "anti-parallel" mode. As thermal expansion is equal in all directions of a metal structure, thermally induced Zero-Drift is cancelled for each pair of anti-parallel connected extensometers, independent of their orientation on the structure. For this to work well those two extensometers should be installed close to each other to ensure they see the same temperature changes.

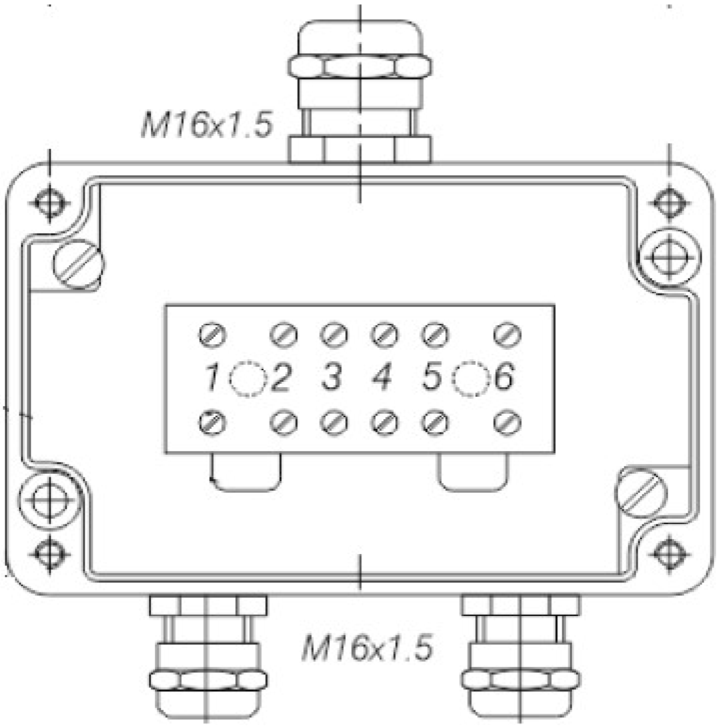
This principle of thermal Zero-Drift compensation works also if only one sensor is subjected to force or load induced strain.

To enable this thermal Zero-drift compensation and to avoid signal cancellation when “tension” extensometer A is connected in parallel to “compression” extensometer B, output signal wires of one extensometer need to be connected in reversed polarity or “anti-parallel-connection”. For sensor cables with Flintec colour code: Extensometer A *white* with Extensometer B *red*, Extensometer A *red* with Extensometer B *white*. Green and black wires are connected as usual by colour.

Recommended for this “2 in 1 cable connections” are Flintec KA-2 junction boxes. From this KA-2 onwards, each pair of extensometers is connected either with a junction box (KAK-x, KPF-x, KPK-x with x≥ number of pairs) or directly to an mV/V indicator.

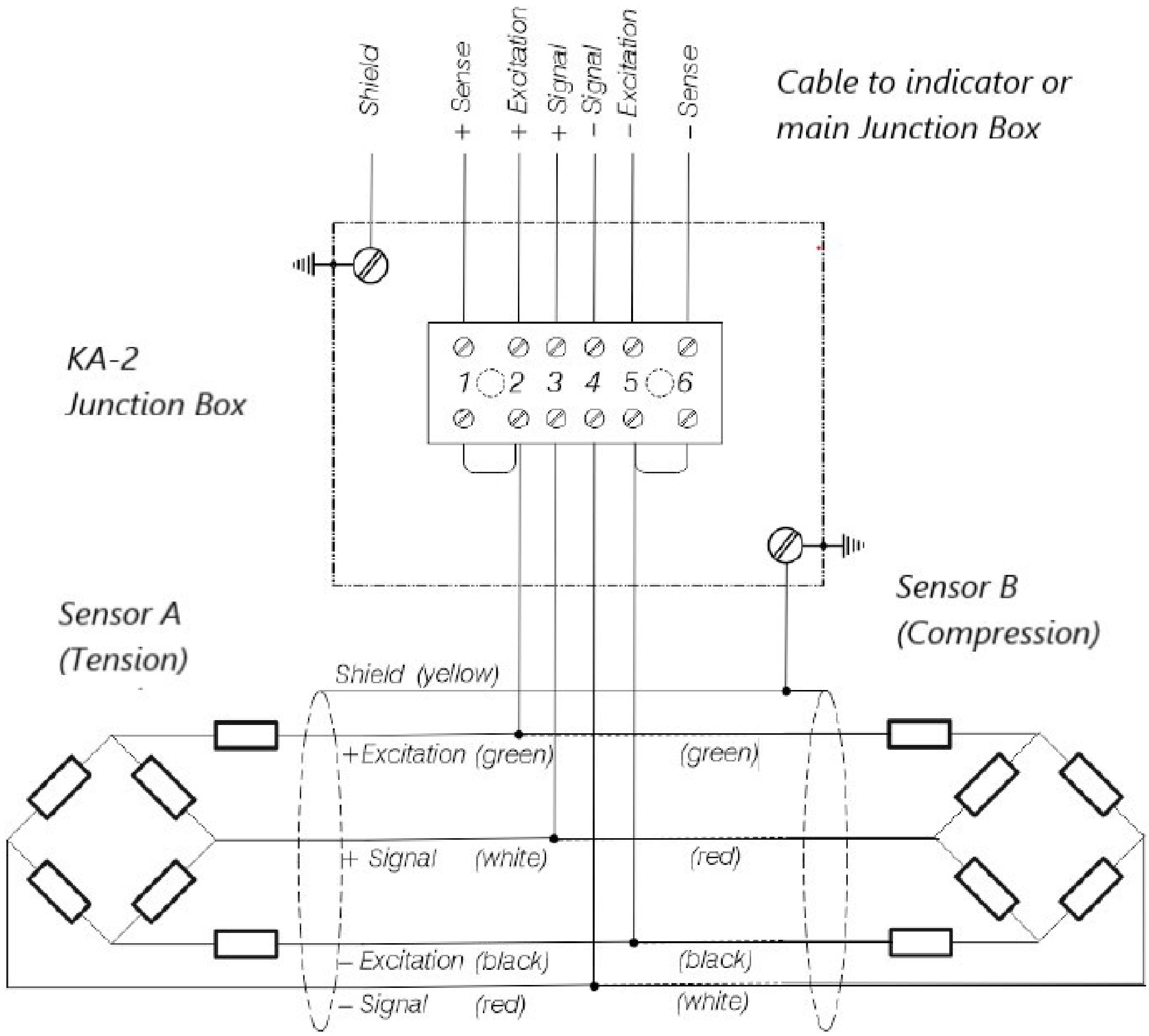
See next page for wiring instructions on KA-2.

KA-2 junction Box with 6-wire screw terminals, without lid (5.1)



~~Wiring scheme on next page~~.

Wiring instructions on KA-2 (5.1)



5.2. Maximising signal output combined with 5.1

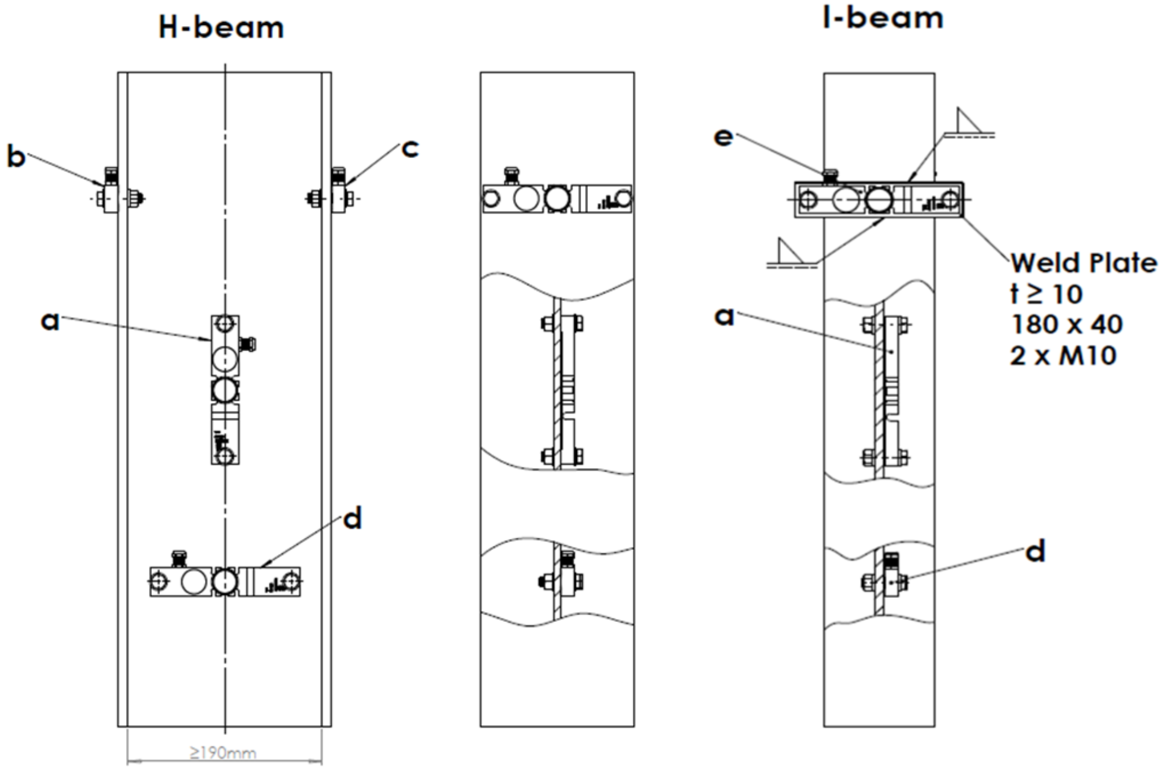
Highest signal output can be expected in all installations where equal amount of strain, but in opposite direction, can be utilized for anti-parallel connection of pairs. Like bending, shear and torsion.

Sufficient output signal level can be expected even at low sensor utilization of ca. 100ppm (20% of 500ppm rated strain) as difference between fully loaded and unloaded condition of relevant structural part.

For column type structures and profiles under compression or tension, there is only limited strain in the opposite direction, determined by Poisson´s ratio, which is about 0.3 for most metals as mentioned in Table 1 under **4**.3. Mounting extensometers in a T-shaped configuration utilizes this 30% lateral strain with opposite sign in relation to the longitudinal direction. For example, on H-beams under compression, extensometer A is mounted along the longitudinal centre line of the web, extensometer B is mounted on the outside of one of the flanges in the lateral direction, i.e. perpendicular to centre line of the H-beam, which means horizontal direction on vertical H-beams. Even though the signal increase will be only about 30% compared to a single extensometer installation, temperature compensation of Zero Drift works as perfect as described under **5**.1.

This T-shaped configuration can be used on single side bending beam installation as well where a symmetric, double-sided installation is not possible or practical, like on vehicle axles where any sensor on the underside, facing the road, would be prone to damage.

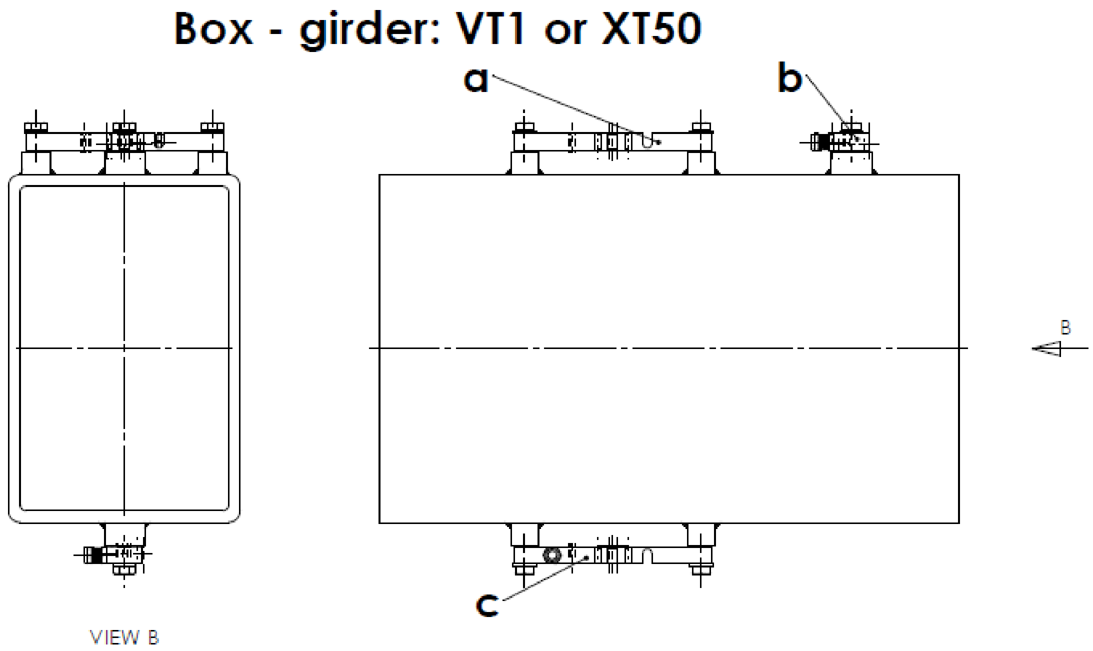
Arrangements of anti-parallel Pairs (5.2)



Position a + b; a + c; a + d; a + e for anti-parallel connection of pairs

Position a + e for I-beam spacing < 190mm for VT-1 or < 90mm for XT-50.

Arrangement of sensors for box girder (5.2)



Position a + b for longitudinal tension or compression or for single side bending installation.

Position a + c for bending with double side installation (tension and compression) only.

Output signal of anti-parallel connected pairs:

a + b = 1.3 x single sensor;   a + c = 2 x single sensor.

6. Suitable indicators / instruments and adjustment

As extensometers are used for content monitoring in silos, tanks or hoppers with an expected accuracy much lower than for weighing instruments (0.5 to 5% compared to 0.03% or less), indicators without fixed weighing ranges and scale intervals are preferred. If not available, indicators suitable for Class IIII weighing instruments for scale intervals from 100e to 1000e with e-min= 50kg or more might work as well. It is recommended to use an instrument with its own display to be able to check the installation independently from customer´s control and IT systems.

Instruments with eCal–function, virtual zero and extrapolated capacity are very useful in adjusting the system. Additional precise adjustment / calibration with known load or known amount of material should be performed after at least one full loading and unloading cycle of the related silo. Extensometers need to see such conditioning cycles to settle after installation to achieve repeatable zero return. If repeatability is not satisfactory, mounting bolts of all extensometers need to be retightened.

Adjustment of outdoor silo content monitoring installation delivers best results over the year when it is done at average weather conditions in spring or autumn. Cloudy sky, no frost, no heat. Best accuracy in content monitoring is achieved when readings for actual silo content are taken early morning before sunrise. Relative weight measurements like loss-in-weight for dosing / filling operations are much more accurate than absolute silo content weighing, since short-term accuracy is higher.

Whenever a known amount (at least 30% of total silo capacity) of material, ideally verified on an approved weighbridge, is added to silo content, it is an opportunity to compare and to calibrate or to re-adjust silo level monitoring installations.

7. Sun shield installation to reduce thermal effects on signal

As extensometers are thermally connected to structural parts by their “teeth” only or sitting on welding blocks about 15mm away from structural part surface, they don´t see necessarily the same temperature as the material of the structural part. Additionally, their thermal mass is extremely small compared to thermal mass of the structural part they are mounted to, which adds a time dependant gradient problem to the system. Any temperature deviation between structural part and extensometer, whether it is stationary or a gradient, disturbs the internal temperature compensation of each individual extensometer as well as the external temperature compensation by anti-parallel installation.

Therefore, it is recommended to protect extensometers installed outdoor from direct sunshine.

Sheet metal aluminium or polished stainless steel covering the areas of extensometer installations, folded in U-shape and fitted to customers structural parts like H-beams are an easy, well proven solution. They can be fixed with double-sided tape and held in place by cable ties or stainless-steel straps without damaging corrosion protection coatings of the structural steel part.

See installation proposal on next page.

H-beam silo leg with sun shield for single side or double side sensor installation (7)