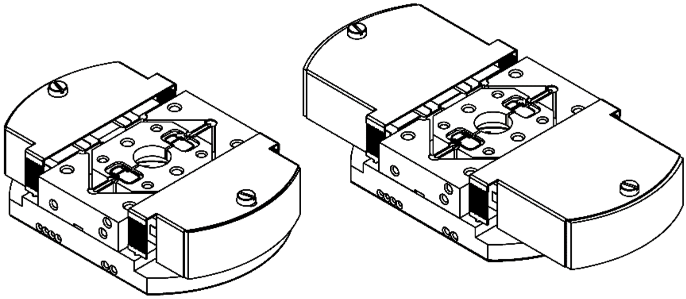
RAZORBILL INSTRUMENTS

DATASHEET



CS2x0T: Transmission Strain Cell

This Datasheet covers the CS2x0T series cells (CS200T, CS220T). These cells are piezoelectric, temperature-compensated apparatus for applying tunable uniaxial strain to test samples while providing access to both sides of the sample for transmission experiments. They are designed for use at low temperature, high magnetic field and within a constrained sample space. Both cells are sized to fit axially in a 2 inch (51 mm) diameter sample space, and the CS200T will also fit transversely.

The sample is mounted between two moving blocks that are driven apart or together in a symmetric fashion. The upper surface is flat, to provide a precision surface for users to mount their samples and any additional measurement components. A pair of capacitive position sensors are integrated into the apparatus. To enhance sensitivity, the shielding of these sensors is electrically isolated from the chassis. Spare tapped holes are incorporated in both moving and static locations, for attachment of, e.g., measurement apparatus or thermometers.

SPECIFICATIONS

		CS200T	CS220T		
Dimensions[1]					
Height		14.2		± 0.1	mm
Width		33		± 0.1	mm
Length		48.8	67.8	± 0.2	mm
Weight	inc. cables	55	65	typ.	g
Performance					
Displacement	at 300K at 4K	± 19 ± 11	± 36 ± 21	± 10% ± 10%	µm
Typ. sample	Length	3.0		note[2]	mm
	Width	0.25			mm
	Thickness	0.2			mm
	Stiffness	5	2	max[3]	N/µm
Operating Environment					
Temperature	Operating	< 0.3 to 325		range	K
	Bakeout	375		max	K
Magn. Field	Operating	0 to > 30		range	T
Atmosphere	Operating	High vacuum. Contact Razorbill for UHV or low pressure helium.			
Drive Electronics					
Drive Voltage	At 300K	- 20 to + 120		range	V
	At 4K	- 200 to + 200		range	V
Capacitance at 290K	Compression Tension	1.2 2.4	3.0 6.0	typ	µF

[1] Width excludes cables, which exit on the side. See also technical drawings.
[2] A wide range of different sample sizes and geometries are possible, see text
[3] All cells can accept 5 N/µm with limited travel range, see text.

		CS200T	CS220T		
Capacitance Sensor					
Area	total for pair	9.0		typ	mm^2
Initial gap		80		typ	µm
Initial value	total for pair	1.0		typ	pF
Response		12		typ	fF/µm
Cell Mechanical Parameters					
Stiffness		12	8.8	typ	N/um
Electrical Connectors[4]					
Drive Wires	two	Lemo FGG.0S.302.ZLAT			
Sense Cables	two	MMCX Female (Molex 73415-341x)			
Construction Materials					
Chassis		Titanium, unalloyed (Grades 2 and 4)			
Piezos		PZT Ceramic			
Drive Wires[5]	four	⌀ 0.8 mm PTFE insulated stranded copper			
Sense Cables[5]	two	⌀ 1 mm coaxial, copper/FEP			
Solder		Cryo-compatible Sn/Pb (non RoHS)			
Epoxy		Cyro-compatible low outgassing			

[4] Mating connectors are provided with every order
[5] Cables and wires 200 mm long. Other lengths are available on request.

PRINCIPLE OF OPERATION

Piezoelectric stacks typically have large negative thermal expansion coefficients, which makes it hard to match them to a sample. The CS2x0T cells have a symmetric arrangement of piezoelectric stacks that cancel out their thermal expansion, allowing the sample to remain near zero strain across a wide temperature range. The stacks drive a flexure-constrained mechanism which prevents any unwanted shear or pillowing of the piezos from being transmitted to the sample.

The strain cell also has piezoelectric stacks much longer than the sample, allowing large sample strains to be achieved. As the strain depends on the sample length, and with care very short samples can be mounted, the maximum achievable strain is very large.

The test sample may still be strained by the differential thermal expansion between it and the titanium of the cell. If the sample mounting plates are titanium, the sample will in principle see only the differential thermal expansion between itself and the titanium of the apparatus and plates. If the sample plates are, e.g., made from a copper-based alloy, then they will contract more than the apparatus during cooling, placing the sample under tension. Similarly, molybdenum or tungsten plates will place the sample under compression. Careful selection of sample plate material and dimensions can be used to cancel out the relative thermal contraction of the sample. Alternatively, the apparatus may be operated during temperature changes to counteract these thermal effects.

The compensation mechanism cancels out thermal expansion of the piezos, so little or no displacement occurs as a function of temperature when the voltage is zero, and it is possible to reach zero displacement at any temperature, which is not always possible if samples are directly attached to piezos. It does not compensate for the reduced stroke at low temperature, so changes will occur as a function of temperature if the stacks are held at constant nonzero voltage. The compensation mechanism and the remaining thermal expansion is described in more detail in Application Note AP001.

SAMPLE SIZE AND OPERATING RANGE

WARNING! Operating the cell at large displacements and stiff samples could cause damage or reduce the lifetime of the cell. This is particularly the case with the more powerful CS220 version and at room temperature where both cells have longer strokes. Read and understand the following section before mounting large samples.

The achievable strain depends on the model of cell, applied voltage, temperature and the spring constant of the sample and sample mounts. The applied voltage and temperature effects are easy to understand, the stroke of the piezo, and therefore the strain, varies nearly linearly with voltage, and approximately linearly with temperature between the values given in the specification table.

The effect of the sample is more complex. The system can be modelled as two springs in series with the applied displacement, one for the sample and sample mounts, and one for the cell. With no sample, the cell will provide the displacement listed in the specification table, and no force. With an infinitely stiff sample, the cell will in principle provide a force equal to the cell spring constant multiplied by the available displacement. But to limit unwanted transverse movements and rotations which will cause strain inhomogeneities and potentially break the sample, the force should be limited to 45 N. The recommended operating limits for the various cells in the CS2x0T series are shown graphically in Figure 1.

To take an example, a typical sample might be 2 mm long (between sample plates), 0.25 mm wide and 0.2 mm thick. Assuming a Young's modulus of 100 GPa, this sample would have a spring constant of approximately 2.5 N/µm. By comparing this with the spring constant for the CS200T cell, we can see that four fifths of the displacement would be transferred to the sample, giving a 4 K displacement of 8 um and a force of about 20 N. This corresponds to a strain of 0.4% and a stress of 400 MPa (which is likely to break the sample). Stiffer samples will see a higher maximum force, but lower displacement, stress and strain. Sample size is a trade-off between achievable stress/strain, and ease of handling.

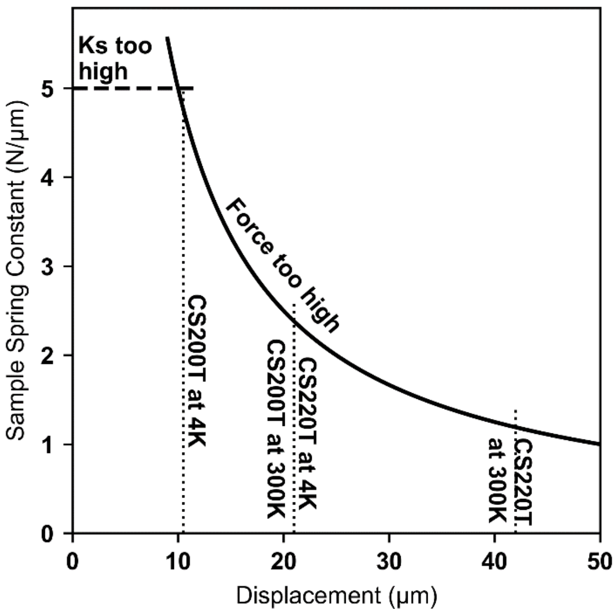


Figure 1. Recommended operating envelope for CS2x0 series cells. Sample spring constant (Ks) should be limited to about 5 N/µm, and force to about 50 N to avoid unwanted twisting of the cell. In other words, the sample spring constant and displacement should be chosen to lie below the solid line. Maximum displacements of the cells are marked for convenience. There is no problem using either cell at e.g. 9 µm and 4.5 N/µm.

The larger CS220T has a lower spring constant but larger displacement. Generally speaking, the larger cell can do anything a smaller cell can do, so it is usually best to choose the larger if it will fit in the space available in the cryostat.

SAMPLE MOUNTING

The method of sample mounting is fundamentally the responsibility of the user, and may be adapted to suit the users' purposes. Here we provide a few suggestions, and more information, including a guide to mounting small metal or ceramic matchstick shaped samples is available as application note AP005.

The most important parameter to bear in mind when specifying a sample mounting method is the sample spring constant. This means the spring constant for compressing/tensioning everything that the user mounts between the two moving blocks, using the two taps provided (See technical drawings at the back of this folder) 5×10^6 N/m is an approximate upper limit, at which the stiffness of the sample starts substantially limiting the displacement that the CS2x0T series cells can apply. Typically, the sample + mount combination will consist of two rigid mounts that are bolted to the CS2x0T, and a sample between them sized to keep its spring constant acceptably low.

The simplest method to mount a sample is to simply glue it to two sample plates, as illustrated in Figure 2a). This mounting method is asymmetric: the sample is secured primarily through its lower surface, and in consequence when the sample is compressed (or tensioned) it will bow upwards (or downwards), imposing a strain gradient across the thickness of the sample. However, for applications such as surface probes, where high homogeneity is not required, or for preliminary measurements, this is a practical mounting method.

A more robust method is illustrated in Figure 2b). This method limits bowing, and so gives more homogeneous strain, and, by reducing strain concentrations, higher strains before sample failure. Here, the sample is secured between lower and upper sample plates. A spacer foil may be included to protect the sample when the screws are tightened. By sanding or grinding the spacer carefully, epoxy thicknesses in the range of ~10 µm are achievable. A more complete overview of the considerations behind this sample mounting method is given in *Review of Scientific Instruments* 85, 065003 (2014).

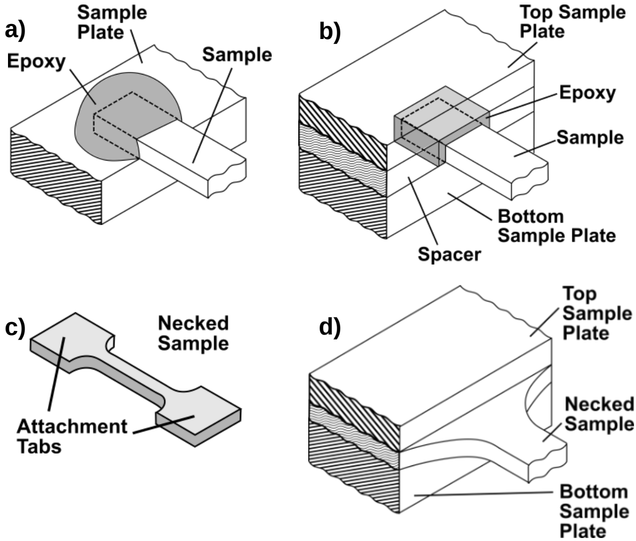


Figure 2. a) It is possible to simply glue the sample to sample plates with a drop of epoxy. b) A better mounting method achieves higher strain homogeneity. c) A necked sample. d) A Necked sample mounted between sample plates.

In some situations it may be possible machine or etch the sample so that it is significantly narrower in the middle than it is at the attachment points. This may be done in silicon, for example, by Deep Reactive Ion Etching (DRIE). A sample which has been 'necked' in this way will experience high, uniform strains in the necked area, and the two tabs may be epoxied to or between sample plates.

Sample Access

Access to the bottom of the sample for transmission experiments is provided by an opening through the centre of the cell. The opening is conical with an included angle of 90 degrees. The apex of the cone is 1 mm above the top surface of the sample mounting area. The exact intersection of the cone with the sample will depend on how the sample is mounted, but the sample will typically be less than 1 mm above the cell.

Access to the top of the sample depends substantially on how it is mounted. Excluding sample mountings, a sample placed at the top surface of the moving blocks is exposed to a complete access cone of 155 degrees, increasing to 180 degrees in the transverse direction.

OPERATING ENVIRONMENT

WARNING! The cell is designed to be used in a cryostat. Observe the usual precautions to avoid cold burns and other injuries. If in doubt, contact the manufacturer of your cryostat for further advice.

WARNING! Do not operate the cell or start cooling if it has condensation or frost on it. Allow the cell to warm up naturally or use desiccant to speed up the drying process. Even quite small quantities of water can cause shorts or damage the cell.

Refer to the specification table for maximum temperatures. The maximum operating temperature is set by the epoxies used in the cell. If the cell is operated above these temperatures, the epoxy will be weaker, and the cell may be damaged. The maximum bakeout temperature is set by the same epoxy, heating above this temperature may cause damage even if the cell is not operating.

The maximum temperature values assumes that the apparatus is operated quasi-statically, so that negligible power is dissipated in the piezoelectric stacks. If this is not the case, care must be taken that the stacks do not exceed the stated temperature. The bakeout temperature given in the specification table applies for infrequent bakeouts of one or two days each, and assumes that the device is not operated and the drive wires are shorted or connected to a RP100 power supply.

For DC operation, the leakage in the piezoelectric stacks is essentially zero at ultralow temperatures; no heating is expected and we do not anticipate any lower temperature limit on operation. CS1x0 series cells have been operated successfully below 200 mK. The body of the strain cell may become superconducting below 400mK, but only at very low magnetic fields, $B_c < 6$ mT. This will not affect the operation of the cell, but may affect the measurement being carried out on the sample, and the thermal conductivity of the cell.

The temperature compensation of the CS200T presumes that the apparatus is at uniform temperature. During rapid temperature changes this may not be the case, and in consequence large thermal displacements may be applied to the sample. If moderately rapid temperature changes are desired, the displacement sensor may be monitored and the CS2x0T operated to minimize displacement applied to the sample. We recommend avoiding very rapid temperature changes, and under no circumstances should the heating or cooling rate exceed 10 K/minute.

The CS2x0T cells are designed to be operated in a vacuum. It is also safe to operate in air at atmospheric pressure. Low pressure helium, which is often used as an exchange gas in low temperature systems, is not suitable, due to the risk of dielectric breakdown of the gas. If operation in helium is desired, contact Razorbill Instruments. Corrosive or explosive atmospheres must be strictly avoided.

The apparatus contains no ferromagnetic components or materials. As such it is suitable for use in both in high magnetic field and environments where stray magnetic fields must be minimised.

MOUNTING THE CELL

The CS2x0T series cells are designed to apply precise deformations to a sample across a wide temperature range. It is important that the cell itself not come under excessive thermal stresses. We recommend that the CS2x0T be mounted using the threaded holes in the bottom, as indicated in the technical drawing. Alternate mounting is possible using the holes in the sides. There should be nothing in contact with the “bridges”, i.e. the curved parts that protrude from both ends of the cell, as they need to be free to move during operation. Razorbill Instruments can provide advice, design assistance, or custom parts to assist with mounting.

With larger sample spaces, it is possible to mount the cell on a rotator or goniometer. However, the PTFE insulated drive wires and micro-coax are not flexible at cryogenic temperatures, so any such rotator must be equipped with suitable flexible wire. This is particularly the case with the drive wires, as an insulation failure on these wires could pose a hazard to the operator.

DRIVE ELECTRONICS

DANGER! The voltages required to operate the cell are high enough to cause serious injury or death. Use a current limited supply – 10 mA is sufficient. Use suitable cables and wiring. Only operate the cell above 50 V in a grounded metal or completely insulating cryostat, or other suitable container. Ensure piezos in the cell are discharged before removing it from the cryostat/container.

The cell requires a two channel ± 200 V source and sink (also called four-quadrant) power supply to access the full strain range at all temperatures. The Razorbill Instruments RP100 power supply is suitable, and also builds in in additional safety features to reduce the risk of shock to operators and the risk of equipment damage. It is of course possible to use other power supplies too, and there is more information available in Application Note AP002.

The four drive wires can be identified by colour, as indicated in the table below:

Connection	Colour	Connector	Pin
Compression stacks positive	Brown	C	1
Compression stacks negative	Blue	C	2
Tension stacks positive	Red	T	1
Tension stacks negative	White	T	2

The drive wires will be terminated with the connector shown in Figure 3. Mating connectors are supplied with each order, along with a short piece of cryogenic heatshrink to make it easy to encapsulate the solder joins. Connectors are also available directly from LEMO (subject to minimum order) or from Razorbill Instruments.

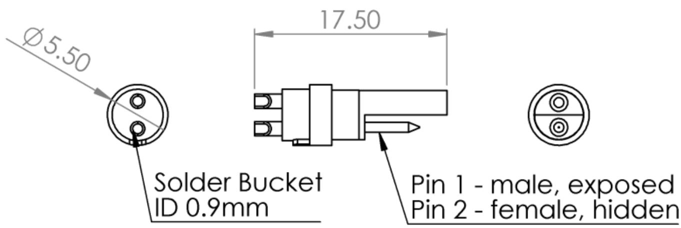


Figure 3. Lemo FGG.0S.302.ZLAT connector. This connector is hermaphroditic, i.e. it mates with another copy of itself. Pin 1 mates with pin 2 and vice versa.

When the cell is in a cryostat but not in use, each pair of drive wires should be connected together, ideally via a resistor of 10-100 kΩ, to dissipate any charge that may be produced by temperature changes in the stacks. If an RP100 power supply is used, it connects a suitable resistor whenever the outputs are disabled, even if the power supply is turned off. Making shorting caps which fit customer-built wiring is recommended.

A positive voltage applied to the compression stacks compresses the sample, and a negative one tensions it. For the tension stacks positive tensions and negative compresses. In general, it is preferable to apply small voltage to both rather than a larger voltage to one. The maximum and minimum voltage which can be applied to the stacks changes as a function of temperature. The limits for room temperature and 4 K are given in the specifications table and for intermediate temperatures refer to Figure 4.

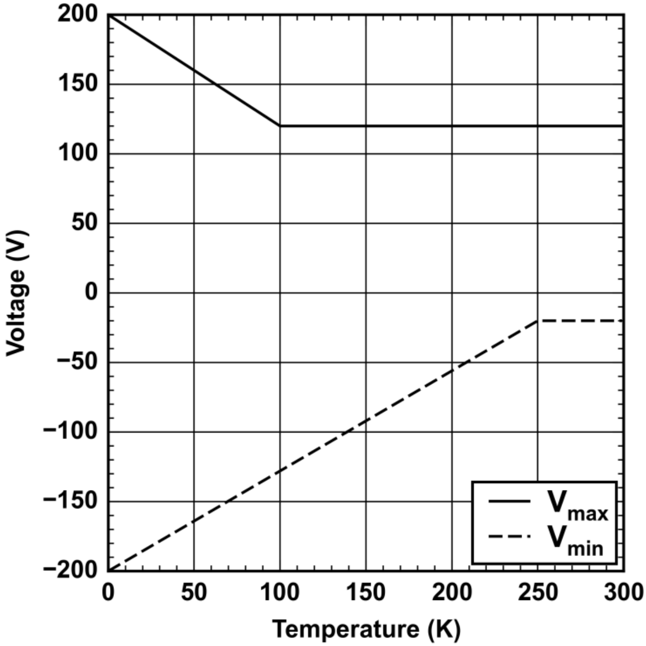


Figure 4. Recommended voltage limits for various temperatures.

POSITION FEEDBACK

Position feedback is provided by a pair of parallel plate capacitors positioned one each side of sample. They are wired in parallel and measured as one. The capacitance of this sensor is small, smaller even than the capacitance of a few meters of typical coaxial cable. A precision capacitance bridge or capacitance meter is required to obtain an accurate measurement, contact Razorbill Instruments if you need help selecting a suitable instrument or cryogenic cable. The excitation used by the capacitance bridge should not exceed 40 Vptp, in most cases much smaller voltages will be adequate.

The coax cables will be terminated with standard female MMCX connectors. The specific part used is given in the specifications table. Any standard MMCX male connector should mate with this part, and two connectors suitable for use on cables of about 1 mm outer diameter are included with each cell.

The cores of the coaxial cables are connected to the capacitor plates. To obtain the lowest possible noise on the capacitance measurement, the “high” or “drive” output of your capacitance bridge should be connected to the high plate, indicated with a yellow band at the connector. The “low” or “sense” output should be connected to the low plate, indicated by the black band at the connector. Unlike some Razorbill instruments products, there is no significant difference between high and low plates, but we recommend connecting as described above for maximum repeatability between measurements.

The braids of the coaxial cables are connected to a two-part titanium shield which encloses the capacitor and is not electrically connected to the chassis of the strain cell. To obtain the best possible measurement, the braids should be connected to the ground terminal on your capacitance bridge/meter, and nothing else. The chassis of the strain cell should be separately connected to ground both to lower noise and for electrical safety reasons.

Capacitance measurement is discussed in more detail in Application Note AP003.

Capacitor Temperature Compensation

The capacitance of the position sensor is somewhat temperature dependent. The capacitor is designed so that several different sources of thermal expansion cancel out, and in theory there should be no temperature dependence, but in practice the cancellation is imperfect and there could be some temperature dependence in either direction (though usually lower temperature means lower capacitance).

It should be appreciated that even if the temperature dependence is known, it would still be difficult to accurately identify the point of zero strain, as it would be difficult to accurately know the thermal expansion of the sample and epoxy relative to the titanium of the cell. This is discussed in more detail in application note AP001.

For users who wish to measure the temperature dependence of the capacitor to use as a calibration, the following method is recommended:

- At room temperature, with no sample mounted (no screws in the top face of the cell), apply 120V to all the stacks, hold for a few seconds and then bring the voltage slowly back to zero. This ensures the stacks have the same voltage history will keep their thermal expansion as similar as possible.
- Fit a titanium calibration sample. This is a titanium bar which can be screwed onto the cell in place of a normal sample and prevents any actual movement during calibration.
- Cool the cell and measure the capacitance as a function of temperature.

WARNING! Do not drive the cell to high voltages with the calibration sample mounted. The calibration sample is much stiffer than the samples the cell is designed to work with. Excessive forces will be generated, and the cell may be damaged.

The cell, sample, and capacitor are all titanium, and all expand together. To make use of this calibration to estimate the zero strain point of the sample, it is necessary to know the thermal expansion of the sample *relative to titanium* and the length of the sample between (titanium) sample plates. The thermal expansion of titanium is given in application note AP001.

RECOMMENDED ACCESSORIES

Razorbill Instruments can provide the following accessories for use with the CS2x0T series strain cells.

- RP100 Power Supply. The RP100 is a two channel power supply designed to power any of the CS or FC series stress and strain cells, and has extra features built in to help protect the cells from damage and to reduce the risk of dangerous electric shocks.
- SP200 Sample plate. Additional sample plates, the same design as the ones supplied with the cell.
- SP210 Sample plate. Sample plates with thin slots cut into them, for mounting matchstick or plate like samples at 90 degrees to the usual orientation.
- SP220 Sample plate. Two sample plates joined together by flexures with a narrow gap in between, this sample plate is designed for use with very small membrane samples.
- TB100 Work table and stand. The stand provides a convenient way of holding the cell while mounting samples etc. and also fits into the work table, which has a pattern of tapped holes designed to accept a wide variety of XYZ stages, positioners and manipulators which might be useful for sample preparation.

RELATED DOCUMENTS

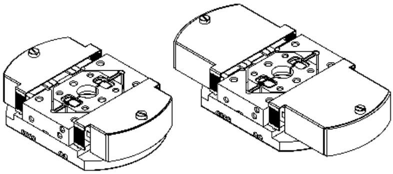
The following application notes and other documents may be useful to users of the CS2x0T series cells. They are available on the Razorbill Instruments website, and new documents are also added from time to time.

- AP001 Thermal Expansion. More detail on the compensation mechanism used in the CS2x0 series cells, its strengths and limitations, and matching the thermal expansion of samples to the cell. It also explains how best to calibrate the temperature dependence of the capacitive position sensor.
- AP002 Drive electronics. Essential information for customers who plan to use their own power supplies, and useful for selecting cryogenic wiring.
- AP003 Measuring Capacitance. More information about capacitance measurement best practice and information about wiring and feedthroughs.
- AP004 Cables and Heat Load. Short worked examples of heat load calculations for customers who are fitting their own cables in cryostats.
- AP005 Sample mounting guide. A photo guide showing how to mount a matchstick shaped sample on a CS1x0 series cell. The CS2x0T series is similar, though slightly larger.

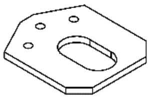
Technical drawings are also available. If this is the paper copy of this datasheet delivered with a cell, they should be included at the back of the folder.

PARTS LIST

As standard, the packing case contains:

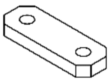


CS200T or CS220T strain cell

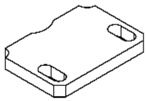


8 Sample mounting plates (titanium)

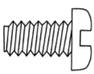
10 Sample plate spacers (titanium)



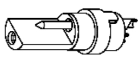
1 Dummy sample for temperature calibration (titanium)



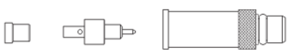
2 sample plate guides (Brass)



6 sample plate and guide mounting screws (M2 x 4 brass)



2 mating connectors for drive voltage (LEMO FGG.0S.302.ZLAT)



2 mating connectors for MMCX (Cinch 135-3436-001) (kit)