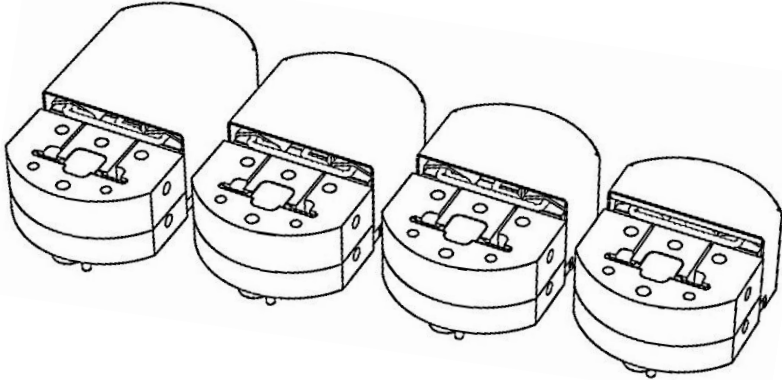


# CS1x0 Datasheet

Covers the CS100, CS110, CS120 and CS130.



These cells are piezoelectric, temperature-compensated apparatus for applying tunable uniaxial strain to test samples. They are designed for use at low temperature, high magnetic field and within a highly constrained sample space in e.g. a PPMS. They are suitable for general use, and may be combined with a range of measurements, including electrical and thermal transport, magnetic susceptibility, and scanning probe microscopy. The CS100 is sized to fit vertically or horizontally in a 1 inch (25 mm) diameter sample space, and the other cells in the series are slightly larger. Spare tapped holes are incorporated, for attachment of, e.g., measurement apparatus or thermometers.



The strain cell uses high voltages to operate, and there is a risk of shock if it is misused.



Read and understand this document and the safety information sheet provided with your cell before using it. The safety sheet is also available online on the Razorbill Instruments website.

## Intended Use

The CS1x0 series strain cells are intended to be installed in a piece of laboratory equipment, such as a cryostat, in order to add strain functionality to an existing measurement system. This installation and subsequent use must be carried out by an appropriately trained professional. This product is available for sale to business customers only and is not suitable for use by household consumers.

## Specifications

|                                |   | CS100  | CS110 | CS120 | CS130 |                   |                  |
|--------------------------------|---|--|-------|-------|-------|-------------------|------------------|
| <b>Dimensions<sup>1</sup></b>  |   |  |       |       |       |                   |                  |
| <b>Height</b>                  |   | 13.3   |       |       |       | ±0.1              | mm               |
| <b>Width</b>                   |   | 20   |       |       |       | ±0.1              | mm               |
| <b>Length</b>                  |   | 24.2   | 28.2  | 32.7  | 37.2  | ±0.1              | mm               |
| <b>Weight</b>                  | inc. cables   | 23   | 25    | 28    | 31    | typ.              | g                |
| <b>Performance</b>             |   |  |       |       |       |                   |                  |
| <b>Displacement</b>            | at 300K   | ±6   | ±7    | ±13   | ±17   | ± 10%             | µm               |
|                                | at 4K   | ±3   | ±4    | ±7    | ±10   | ± 10%             |                  |
| <b>Force</b>                   | Max safe  | 50   |       |       |       |                   | N                |
| <b>Typ. sample</b>             | Length  | 2.0  |       | 2.5   |       | note <sup>2</sup> | mm               |
|                                | Width   | 0.3  |       |       |       |                   | mm               |
|                                | Thickness   | 0.2  |       |       |       |                   | mm               |
|                                | Stiffness   | 5  | 5     | 3.5   | 2.6   |                   | max <sup>3</sup> |
| <b>Operating Environment</b>   |   |  |       |       |       |                   |                  |
| <b>Temperature</b>             | Operating   | <0.2 to 325  |       |       |       | range             | K                |
|                                | Bakeout   | 105  |       |       |       | max               | C                |
| <b>Magn. Field</b>             | Operating   | 0 to >30   |       |       |       | range             | T                |
| <b>Compatible environments</b> | Operating   | Atmosphere; low pressure helium; high vacuum. Contact Razorbill for UHV. |       |       |       |                   |                  |
| <b>Humidity range</b>          | 0 – 80% non-condensing<br>Humidity above 0 reduces accuracy |  |       |       |       |                   |                  |
| <b>Drive Electronics</b>       |   |  |       |       |       |                   |                  |
| <b>Drive Voltage</b>           | At 300K   | -20 to +120  |       |       |       | range             | V                |
|                                | At 4K   | -200 to +200   |       |       |       | range             | V                |
| <b>Capacitance at 290K</b>     | Comprn.   | 0.41   | 0.6   | 1.1   | 1.5   | typ               | µF               |
|                                | Tension   | 0.82   | 1.3   | 2.2   | 3.0   |                   |                  |

<sup>1</sup> Height excludes cables, which exit on the bottom. See also technical drawings.

<sup>2</sup> A wide range of different sample sizes and geometries are possible, see text

<sup>3</sup> All cells can accept 5 N/µm with limited travel range, see text.

|  |  | CS100  | CS110 | CS120 | CS130 |                 |       |
|--|--|--|-------|-------|-------|-----------------|-------|
| <b>Capacitance Sensor</b>                |  |  |       |       |       |                 |       |
| <b>Area</b>                              |  | 10   |       |       | typ   | mm <sup>2</sup> |       |
| <b>Initial gap</b>                       |  | 40   | 60    |       | typ   | μm              |       |
| <b>Initial value</b>                     |  | 1.2  | 0.8   |       | typ   | pF              |       |
| <b>Sensitivity</b>                       |  | 20-50  |       | 10-50 |       | typ             | fF/μm |
| <b>Calibration</b>                       | Each cell provided with unique calibration curve |  |       |       |       |                 |       |
| <b>Cell Mechanical Parameters</b>        |  |  |       |       |       |                 |       |
| <b>Stiffness</b>                         |  | 26   | 22    | 19    | 16    | typ             | N/um  |
| <b>Electrical Connectors<sup>4</sup></b> |  |  |       |       |       |                 |       |
| <b>Drive Wires</b>                       | two  | Lemo FGG.0S.302.ZLAT                         |       |       |       |                 |       |
| <b>Sense Cables</b>                      | two  | MMCX Female (Huber+Suhner 21MMCX-50-1-2/111) |       |       |       |                 |       |
| <b>Construction Materials</b>            |  |  |       |       |       |                 |       |
| <b>Chassis</b>                           |  | Titanium, unalloyed (Grades 1 and 2)         |       |       |       |                 |       |
| <b>Piezos</b>                            |  | PZT Ceramic                                  |       |       |       |                 |       |
| <b>Drive Wires<sup>5</sup></b>           | four   | ∅0.8mm PTFE insulated copper                 |       |       |       |                 |       |
| <b>Sense Cables</b>                      | two  | ∅1mm coaxial, copper/FEP                     |       |       |       |                 |       |
| <b>Solder</b>                            |  | Cryo-compatible Sn/Pb (non RoHS)             |       |       |       |                 |       |
| <b>Epoxy</b>                             |  | Cyro compatible low outgassing               |       |       |       |                 |       |

<sup>4</sup> Mating connectors are provided with every order

<sup>5</sup> Cables and wires 120 mm long unless provided as part of an order including a PPMS probe. Other lengths are available on request.

## Thermal compensation

The CS1x0 Cell is thermally compensated, and matched to titanium. The special arrangement of piezo stacks inside the device cancels out their thermal expansion. This means a wide range of sample stresses remain accessible across the full temperature range. For more information about the principle of operation, or how to deal with samples with very large or small thermal expansion ratio, refer to application note AP001.

## Sample size and operating range

The achievable strain depends on the model of cell, applied voltage, temperature and the spring constant of the sample and sample mounts.

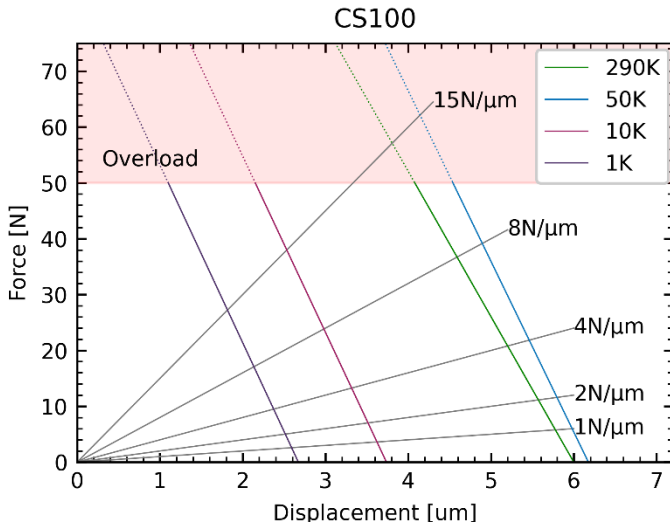
To work out how much force and displacement can be applied to a sample, we can model the cell as a (temperature and voltage dependent) displacement in series with (temperature dependent) spring constant of the cell, sample and sample mounts. Two limiting cases are:

- ✦ If the sample is very soft: It changes length without any reaction force, so there is no force on the cell, and the cell delivers its full rated displacement.
- ✦ If the sample and mounts are very stiff: They do not change length at all, and all the cell's stroke goes into deforming itself. The force applied to the sample is the rated displacement multiplied by the spring constant of the cell.

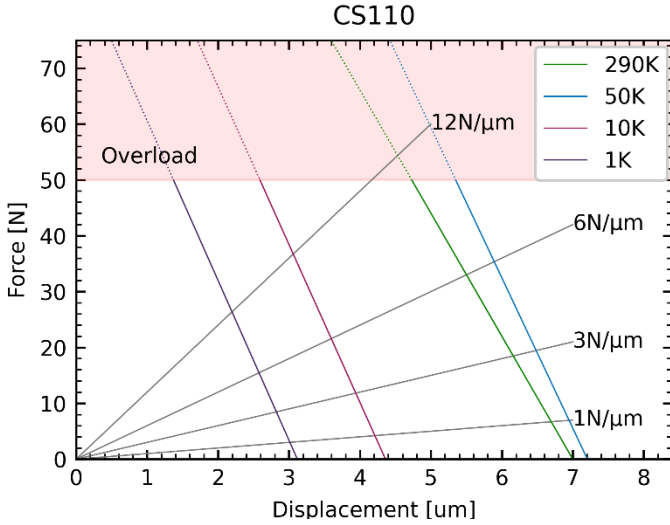
For intermediate cases (including all real samples) the stroke of the cell is divided between force and displacement. How much of each depends on the ratio of the spring constant of the cell to the spring constant of the sample plus sample mounts.

As the cell cools, the stroke per volt of the PZT actuators falls, the voltage limits change as described above, and the titanium and

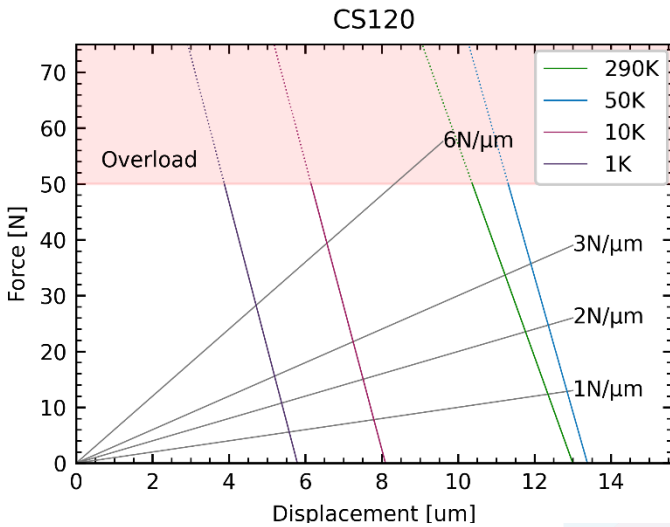
PZT materials get stiffer. These things combine in a relatively complicated way. Figures 1 to 4 show the reachable sample force and displacement at different temperatures. All the area under the coloured curve is accessible by the cell. Any given sample and sample mount combination has a fixed spring constant, so only combinations of force and displacement along a line with that spring constant as the gradient are accessible with that sample mounted. You can use the figure to read off the expected maximum force and displacement for any spring constant and temperature.



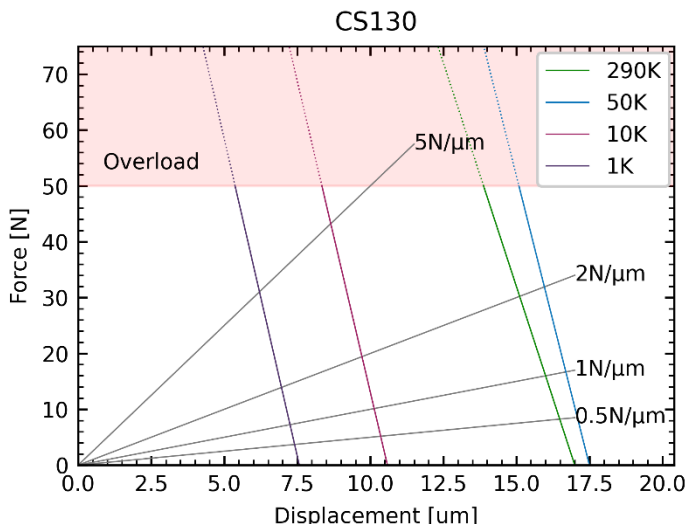
**Figure 1:** Reachable force and displacement as a function of temperature and sample spring constant for the CS100. To use this figure a) Estimate the combined spring constant of your sample and sample mounts. b) draw a line on the figure passing through the origin with the spring constant you have estimated as the gradient, several examples are drawn on in grey c) The force and displacement where the drawn line crosses the line for your operating temperature are the maximum achievable within the recommended voltage limits.



**Figure 2:** Reachable force and displacement for the CS110. See Figure 1 for a description of how to use this figure.



**Figure 3:** Reachable force and displacement for the CS120. See figure 1 for a description of how to use this figure.



**Figure 4:** Reachable force and displacement for the CS130. See figure 1 for a description of how to use this figure.

Larger cells in the series have lower spring constants but larger displacements. Generally speaking, the larger cells can do anything a smaller cell can do, so it is usually best to choose the largest cell in the series which fits into the space available in the cryostat.

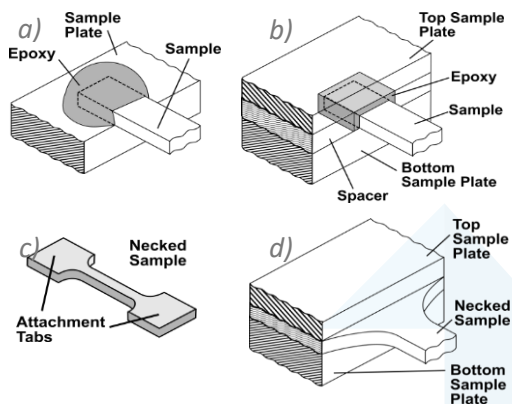
Note that the maximum permissible force for any of the CS1x0 cells is 50N. This is marked on the figures as a pink-shaded area. Operating in the overload area may damage the cell. It is easier to accidentally enter this area with the larger cells. To reduce risk, it may be useful to choose a sample stiffness such that the stiffness line does not go into the overload region, otherwise, take care to limit the voltage applied to prevent damage.



## Sample mounting

These cells are used with a wide variety of different samples, and each research group will need to develop their own technique for mounting their specific materials. Here we provide a few suggestions as a starting point. More information, including a guide to mounting small metal or ceramic matchstick shaped samples is available as application note AP005. We also have some information about mounting 2D materials, either unsupported or glued to a substrate, on our website.

The simplest method to mount a sample is to simply glue it to two sample plates, as illustrated in Figure 5a). 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.



**Figure 5:** 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.

A more robust method is illustrated in Figure 5b). 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 bolts are tightened. By sanding or grinding the spacer carefully, epoxy thicknesses in the range of  $\sim 10 \mu\text{m}$  are achievable. A more complete overview of the considerations behind this sample mounting method is given in *Review of Scientific Instruments* 85, 065003 (2014).

The maximum temperature to which the cell may be exposed during curing of epoxies is  $100^\circ\text{C}$ . The Piezo stacks must be attached to a suitable discharge resistor. The optional RP100 power supply provides a suitable resistance (but must not be placed in the oven). Thermal shock should be minimised, under no circumstances exceeding  $10 \text{ K/min}$ .

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. 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.

## 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.*

The drive wires *must* be attached to a suitable discharge resistor during any heating or cooling, as damaging pyroelectric voltages can build up in the piezoelectric stacks. The RP100 has integrated discharge resistors so that it is sufficient to simply ensure that the stress-strain cell is correctly plugged into the RP100 during temperature changes.

The maximum permissible short-term temperature for bakeout and epoxy curing in the specifications table is set by the epoxies used to hold the cell together and to insulate the stacks. Exceeding this temperature, or holding it for long periods, degrades the insulation and may cause a hazard. The structural epoxy is also weaker above the maximum operating temperature, which is why the cell may be heated above that temperature but not operated. These values assume 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 temperatures due to power dissipated in them.

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. CS100 series cells have been operated successfully below 200 mK. The body of the strain cell may become superconducting below 400 mK, 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 CS100 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. We recommend avoiding very rapid temperature changes, and under no circumstances should the heating or cooling rate exceed 10K/minute. The sensor in the cell is quite sensitive to temperature gradients, so if you need to adjust the voltages to stay close to the thermal expansion of your sample, it is best to do that by stepping the temperature and waiting for the reading to settle before adjusting the voltage at each step.

The CS1x0 is designed to be operated in a vacuum, dry air, or low pressure helium (exchange gas). When operated in some fluids, dielectric breakdown of the fluid becomes a risk. This is particularly the case in low pressure helium. Insulation prevents arcing within the cell, but the user must take care to ensure that other wiring and connectors inside the cryostat are also appropriately insulated. For more information see application note AP002. Humid atmospheres will affect the sensor, and the affect can last for some time after leaving the humid environment. See AP006 for more details. Do not use the cell in corrosive, explosive, or high-hydrogen environments.

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 CS1x0 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. The CS100 should be mounted using the taps on the sides, with either:

- ✚ A compliant holder, such as that shown in Figure 6, where the sides for the yoke can bend in and out to take up thermal expansion, or
- ✚ A one-sided holder, which screws to one side of the cell only.

There should be nothing in contact with the “bridge”, i.e. the part at the other end of the stacks from the body of the cell, covered by a thin foil, as this needs to be free to move during operation. Figure 6 shows a yoke suitable for use in a 1-inch sample space with the cell horizontal or vertical. For the Quantum Design PPMS, Razorbill instruments can provide complete probes, contact us for more information. For other cryostats, 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 sample rotator. 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.

When bending the wires leading out of the cell to install the cell in the cryostat, avoid bending them tighter than necessary or running them over a sharp edge. As a rule of thumb, the minimum bend radius is:

- 1mm, if bending once and then keeping in the bent position with a clamp or tape
- 5mm, for occasional bending and unbending

- 10mm, for large numbers of cycles (for example on a goniometer)

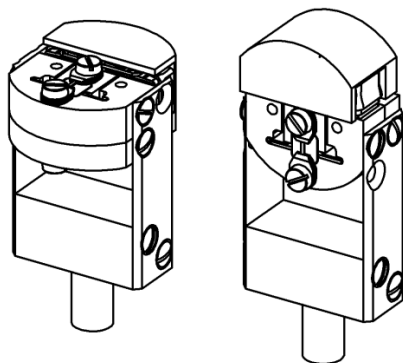


Figure 6: Typical mounting for use in a 1-inch sample space

## Operating the CS1x0

### Drive electronics



**DANGER!** The voltages required to operate the cell are high enough to cause serious injury or death. Use a current limited supply – 10mA is sufficient for most experiments. Use suitable cables and wiring. Only operate the cell above 50V 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.

There are two sets of stacks inside the cell, and they work in opposite directions. A positive voltage on the tension stack will tension the sample and a negative voltage will compress it. For the compression stacks, a positive voltage compresses and a negative voltage tensions. Both sets of stacks must be used together to

obtain the full range of the cell, which needs a 2-channel  $\pm 200$  V source and sink (also called four-quadrant) power supply. The Razorbill Instruments RP100 is specifically designed to drive the cells, and includes various features to improve safety and minimise the risk of equipment damage. AP001 gives more detail on the arrangement of the stacks, and AP002 has more on the power supply and ways of operating with less capable supplies. AP004 has useful information about installing new wires and cables in an existing cryostat.

When the power supplies are not connected, each pair of drive wires should be connected together, preferably via resistor of a few k $\Omega$ , to discharge any charge which builds up on the stacks as a result of temperature changes. The RP100 does this automatically if connected, even if powered off.

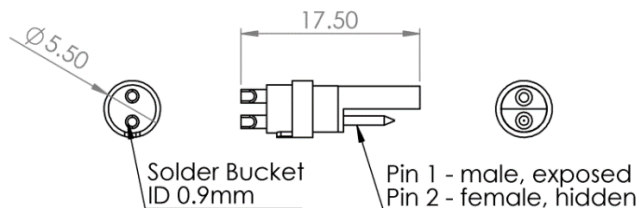
| Connection                        | Colour | Connector | Pin |
|-----------------------------------|--------|-----------|-----|
| <b>Compression stack positive</b> | Brown  | C         | 1   |
| <b>Compression stack negative</b> | Blue   | C         | 2   |
| <b>Tension stack positive</b>     | Red    | T         | 1   |
| <b>Tension stack negative</b>     | White  | T         | 2   |

*Table 1: Pin assignments and wire colours*

The four drive wires can be identified by colour or, on earlier models, by the labels engraved on the base of the device. Earlier models of CS1x0 refer to the compression stack as “inner” and the tension stack as “outer”, and have corresponding labels engraved on, but to avoid confusion in cells where the stacks act in the opposite direction that nomenclature is no longer used.

Unless requested otherwise, the drive wires will be 12 cm long and terminated with the connector shown in Figure 7. Mating connectors are supplied with each order, along with a short piece

of cryogenic heatshrink to make it easy to encapsulate the solder joints. Connectors are also available directly from LEMO (subject to minimum order) or from Razorbill Instruments. If the strain cell is to be used in a low pressure gas atmosphere, such as helium exchange gas, take extra care to fully insulate all wire and solder joints.



*Figure 7: Lemo FGG.05.302.ZLAT connector. This connector is hermaphroditic, i.e. it mates with another copy of itself. Pin 1 mates with pin 2 and vice versa.*

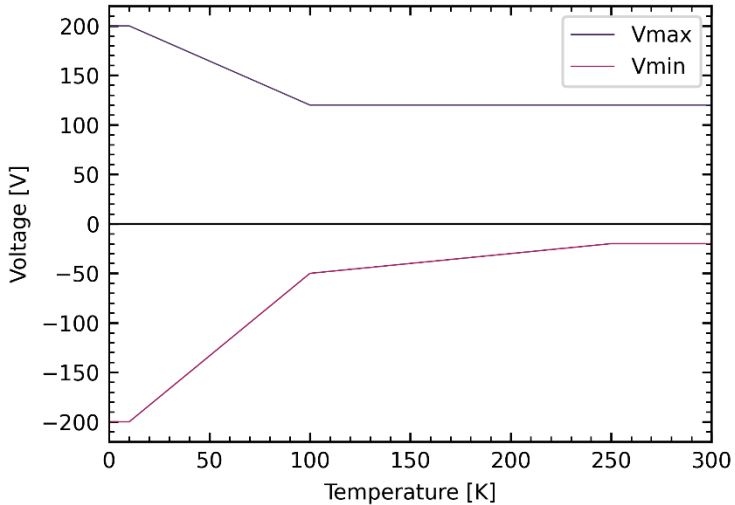
## Operating voltage

Recommended voltage limits are given as piecewise linear equations in Table 2 and plotted on a graph in Figure 8:

| T (K)   | Vmin (V)                     | Vmax (V)                    |
|---------|------------------------------|-----------------------------|
| >250    | -20                          | 120                         |
| 100-250 | $-50 + \frac{1}{5}(T - 100)$ | 120                         |
| 10-100  | $-200 + \frac{5}{3}(T - 10)$ | $200 - \frac{8}{9}(T - 10)$ |
| <10     | -200                         | 200                         |

*Table 2: Recommended voltage limits*





*Figure 8: Recommended voltage limits for various temperatures.*

Prior to 2023, we recommended slightly higher voltages at intermediate temperatures, but we have updated our recommendations based on more recent and more detailed measurements of the piezo stack performance.

## Position feedback

Position feedback is provided by a parallel plate capacitor below the sample. 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 V<sub>ptp</sub>, in most cases much smaller voltages will be adequate.

Unless requested otherwise, the cell coax cables will be 12 cm long, and terminated with female MMCX connectors, Huber and Suhner part number 21MMCX-50-1-2/1110E. Any standard

MMCX male connector should mate with this part, and connectors suitable for use on cables of about 1 mm outer diameter are included with each cell. They are Huber and Suhner part number 11MMCX-50-1-2/1110E.

The cores of the coaxial cables are connected to the capacitor plates. 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.

The low plate coax is marked by a black band and the high plate is marked with a yellow band.

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

### *Accuracy, resolution, and temperature correction*

Resolution is typically limited by the resolution or noise of your capacitance bridge. A resolution of better 0.5nm/VHz should be achievable in most cases.

The main limits on accuracy of the sensors are temperature and humidity dependence. All CS1x0 shipped after May 2021 are provided with a temperature dependence curve on the reverse of the capacitance/displacement curve. The format changed in 2023 to show the change due to temperature in displacement units as well as capacitance units. To correct for temperature, first convert the capacitance reading to displacement, then subtract the displacement offset due to temperature (converting from capacitance as necessary for older calibration sheets).

Humidity causes offsets in the displacement measured by the sensor which are strongly hysteretic and can take several days to equilibrate. The capacitance will be higher if the capacitor has been in a humid environment, and lower if it has been in vacuum. The effect can be reduced by pumping on the cell in the cryostat for a full day or more before starting the experiment. We recommend that the remaining offset is treated as an offset in displacement, the same as for temperature.

More information about the accuracy limits, including advice on how to repeat the temperature calibration if your cell does not have one, is included in AP006.

It is also important to understand that even if the capacitor was perfect, it would not be measuring the strain in the sample directly. It is measuring the change in length relative to the titanium of the cell. It cannot tell the difference between sample strain and strain in the glue holding the sample, nor between sample strain and sample thermal expansion. For more information about exactly what is measured, refer to AP007.

## Care and maintenance

The cell does not normally need any routine maintenance. The outer surfaces of the cell may be cleaned with water, detergent, or common solvents such as isopropanol, acetone, or ethanol. Do not immerse the cell, and minimise the amount of solvent entering the cell through the slots in the top surface or the gaps around the edges of the cover foil. If liquid enters the cell, allow it to dry completely before cooling or operating it.

## Recalibration

The displacement sensor will generally be quite stable. Calibration is straightforward if you have a sufficiently accurate displacement sensor and some way of mounting it on top of the cell, or you can contact Razorbill Instruments if you would like us to do a

recalibration. Temperature calibrations are slightly trickier but can be done in the field. See AP006 for more information.






## Stack replacement

The piezoelectric stacks built into the cell should have a long operating life, however this can be reduced substantially by operating the cell at high temperatures, in a humid atmosphere, or for long times at high voltages. It is also possible to damage the stacks by overloading the cell, charging or discharging them without an appropriate current limit, or changing the temperature with the stacks charged and without a suitable discharge resistor (such as that provided by the RP100 power supply).

The stacks in the CS1x0 are not field replaceable, contact Razorbill Instruments if they are damaged. We usually offer a fixed-price repair, which is priced to cover our costs but not to make a profit.

## Recommended accessories

Razorbill Instruments can provide the following accessories for use with the CS1x0 series strain cells.

-  **RP100 Power Supply.** A two channel  $\pm 200$  V power supply, specially designed to operate Razorbill Instruments stress and strain cells.
-  **WP101 Wiring Platforms.** The WP101 is a small copper and PCB platform which screws onto the top of the cell, and provides four wire-bondable and solderable contacts next to the sample. There is also space for a heater or thermometer. Two WP100s can be fitted to each CS1x0 cell.
-  Alternative sample plate kits:
  -  **SP100 Sample plate.** Additional sample plates, the same design as the ones supplied with the cell.
  -  **SP110 Sample plate.** Sample plates with thin slots cut into them, for mounting matchstick or plate like samples at 90 degrees to the usual orientation.

- ✎ **SP120 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.
- ✎ **SP140 sample plates.** Raised sample plate with recessed screws for improved sample access.
- ✎ **PPMS1 Probe or Probe kit.** This probe kit is designed to convert a standard Quantum Design PPMS probe for use with the CS1x0 cells. It is available as a kit or Razorbill Instruments can purchase a probe from Quantum Design, install the kit, and provide the complete probe to the customer.
- ✎ **TB100 Work table and stands.** The stands provide a convenient way of holding the cell while mounting samples etc. and also fit 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 CS1x0 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 our 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.
- ✦ AP006 Capacitor Performance. A detailed look at what exactly the capacitors measure and the limits on their repeatability and accuracy.

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. Otherwise, they are available on our website.