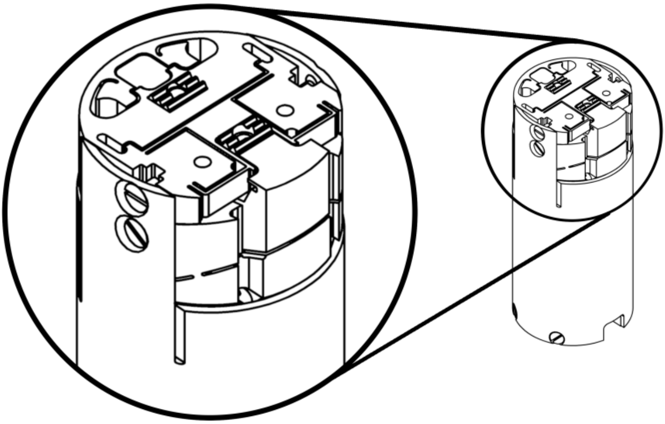
FC1x0 Datasheet

Applies to FC100 and FC150



These cells are compact devices for applying tunable stresses to small samples at temperature down to less than 1K. The devices are temperature compensated, meaning that the thermal expansion of the piezoelectric stacks used to operate the cell is cancelled out and does not affect the sample. The cells are highly compact, fitting into most modern cryostats, including the Quantum Design PPMS. It is compatible with a wide range of experimental probes, including electrical transport, susceptibility, NMR, and a wide range of scanning probe microscopy measurements. The force applied to the sample is measured by an integrated capacitance sensor, which is well shielded and electrically isolated from the rest of the apparatus. The FC100 force sensor measures up to 200 N, and the FC150 measures up to 50 N.

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

It also contains preload springs, which can violently expel parts if the cell is damaged or dismantled.

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

Specifications

Physical Specifications

Diameter		25.4 ±0.1	mm
Height	To top surface	57.9 ±0.1	mm
	To Sample	59.4 ±0.2	mm
	Including bump guard	77.0 ±0.3	mm
Weight	approx.	100	g

Output

Displacement (at zero force)	At 300K, no load	±45	µm
	At 4K, no load	±25	µm
Force (at zero displacement)	At 300K, FC100 At 300K, FC150	±170 ±110[2]	N
	At 4K, FC100 At 4K, FC150	±100[1] ±40[1]	N

Feedback Sensor

Range[2]	FC100 FC150	±200 ±50	N
Sensitivity	FC100 Typ FC150 Typ	0.5 2	fF/N
Capacitance	Typ	1.1	pF
Hysteresis	FC100 Max	0.7	%

[1] Assumes sample has thermal expansion matched to titanium.

[2] Output may exceed sensor range. This should be avoided. See p4

	FC150 Max	0.1	
Drift (vacuum)	24 hours	0.01	%FSR

Piezoelectric Stacks

Drive Voltage	At 300K	-20 to 120	V
	At 4K	±200	V
Drive Current	Min	0.1	mA
	Do Not Exceed	10	mA
Capacitance (300K)	Tension Stack	3.1	µF
	Compression Stacks	6.2	µF

Typical Sample

Length		0.1 to 1.5	mm
Cross Section	FC100 FC150	0.05 to 0.25 0.01 to 0.1	mm^2

Construction Materials

Piezos	PZT ceramic
Chassis	Titanium, pure, grades 1-4
Drive wires	⌀0.8mm PTFE insulated copper[3]
Capacitor cable	⌀1mm coaxial, copper/FEP[3]
Solder	Cryo-compatible Sn/Pb solder
Connectors	PEEK with gold plated inserts MMCX with PTFE insulators
Epoxies	Various low outgassing cryogenic types
Insulators	Kapton film

Environmental

Temperature	max operating	50 °C (recommended)
	min operating	< 200 mK
	max process (e.g. epoxy cure)	100 °C (recommended)
Humidity range	0 – 80% non-condensing Humidity above 0 reduces accuracy	

[3] The FC1x0 is normally provided with 10 cm length cables and wires of the type specified in the table above. Alternative lengths or construction of wire/cable can be supplied on request.

FC100 and FC150 Differences

The key difference between the FC100 and the FC150 is that the FC100 is designed to measure sample forces of ±200 N, and the FC150 is designed to measure ±50 N. In order to transfer such high forces to the sample, the FC100 uses toothed sample plates, which engage with teeth in the top of the cell. The FC150 uses flat sample plates similar to the CS and UC line of cells.

The pizeo stacks, preload system, compliant mechanism for tensioning/compressing the sample, cover components and capacitive sensor are the same in the two cells. The only differences are in the sample interface and the compliant mechanism which converts the force on the sample into a motion the capacitor measures. As the drive components are the same, the force which can be applied to the sample is the same. However, if a force of over 50 N is applied to the 50 N sensor, it may cause a calibration shift. Repeated use above 50 N will degrade the accuracy of the sensor.

In general, the limiting factors for resolution and accuracy of the force sensor scale with the range of that sensor. So as the 50 N sensor has ¼ of the range of the 200 N sensor, it also has four-fold better resolution and accuracy. The exception is the hysteresis of the sensor, which shows an eight-fold improvement in the 50 N sensor. So the choice of FC100 or FC150 is usually driven by the expected sample size and stiffness.

Thermal Compensation

The FC1x0 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.

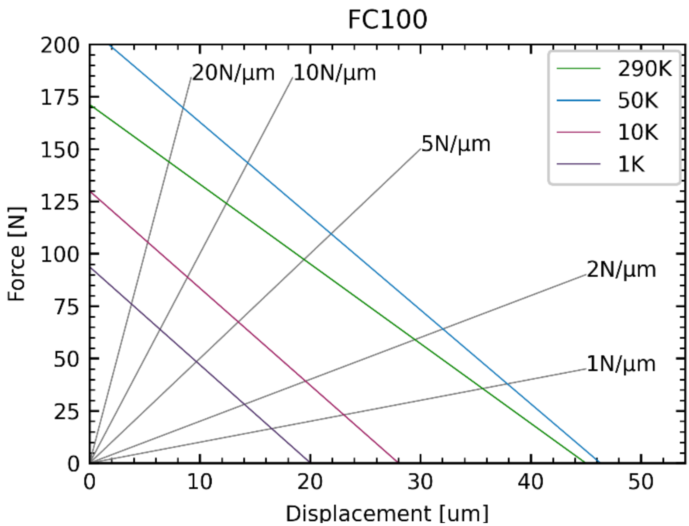


Figure 1: *Reachable force and displacement as a function of temperature and sample spring constant for the FC100. To use this figure a) Estimate the combined spring constant of your sample and sample mounts. b) draw a line on the figure passing through the origin with the spring constant you have estimated 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.*

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.

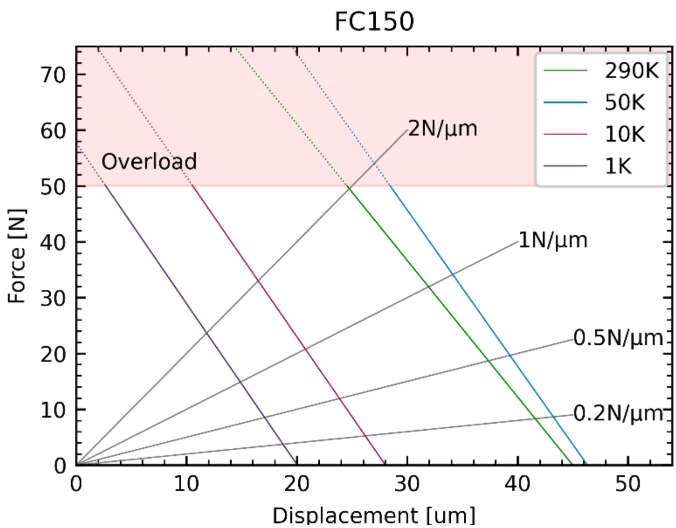


Figure 2: *Reachable force and displacement for the FC150. See figure 1 for a description of how to use this figure.*

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. Figure xxx shows 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.

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 FC100 cell is provided with toothed sample plates, to enable high forces to be transmitted to the sample. This means however that the spacing between the plates is discrete, not continuous as in lower force models. The gap may be adjusted by 1 mm by moving the plates one tooth together or apart and by 1/3mm by turning the plate end-to-end. By rotating both plates and moving them over the teeth, the gap may be adjusted in 1/3mm increments from less than 300um to more than 2.5 mm.

The FC150 uses flat sample plates, the same as the ones used on the CS100 series cells. These allow the gap to be adjusted continuously from 0.6 to 2.8 mm. Other sample plates compatible with the CS100 can also be used.

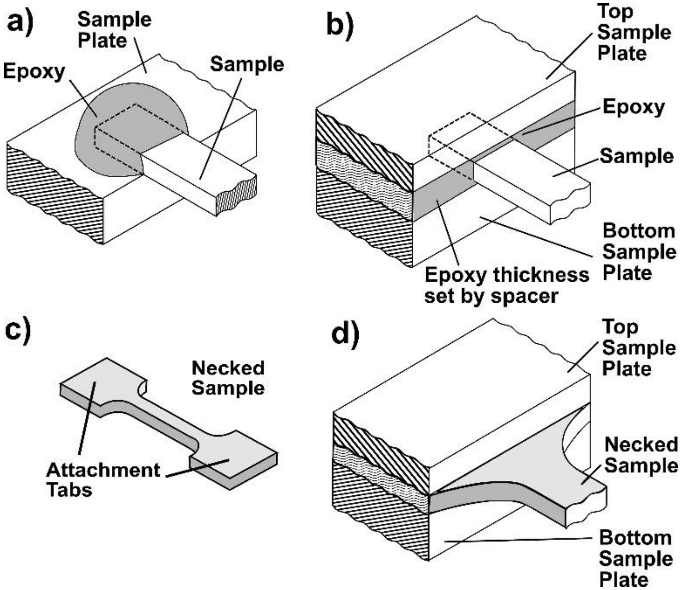


Figure 1: *a) It is possible to simply glue the sample to sample plates with a drop of epoxy. b) A more rigorous mounting method, in which the sample is sandwiched between upper and lower plates, to achieve higher strain homogeneity. c) If the sample can be machined or etched, it can be necked. d) Illustrates how a necked sample may be attached to the strain cell. If the attachment tabs are large enough relative to the width of the necked section, the top sample plate can be neglected altogether.*

The simplest method to mount a sample is to simply glue it to two sample plates, as illustrated in Figure 4a). 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 bend upwards (or downwards), imposing a strain gradient across the thickness of the sample.

A more rigorous method, that limits bending and so yields higher strain homogeneity, is illustrated in Figure 4b). Here, the sample is secured between lower and upper sample plates. A spacer foil may be included to protect the sample when the bolt holding the top plate is tightened. By sanding or grinding the spacer carefully, epoxy thicknesses in the range of ~10 µm are achievable.

The maximum temperature to which the cell may be exposed during curing of epoxies is 100 °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 K/min.

In some situations it may be possible machine or etch or otherwise shape 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 sample plates.

A more in-depth discussion of mechanical considerations for sample mounting can be found in *'Review of Scientific Instruments'* **85**, 065003 (2014). A photographic guide including some practical tips is also available as Application Note AP005.

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 FC1x0 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

10 K/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 FC1x0 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

Some of the tapped holes in this cell lead into internal voids containing delicate components. Inserting too-long screws may damage the cell. Refer to the technical drawing for allowable lengths.

There are several ways to route the drive wires and coaxial cables out of the cell, with each alternative having advantages for different mounting geometries or sample spaces. Figure 2 shows the points the cables can run through. Cells will normally be provided with capacitance cables through A2 and drive wires through A1. Other configurations can be supplied on request. It is possible to convert a completed cell from one configuration to another, but this requires removing the cover tube – refer to page 20 for details.

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)

There are mounting screws on the sides of the cell near the top, and on the bottom of the cell. Some of these have limited depth, and using screws which are too long may cause serious damage. See drawings at the back of this folder for details. It is also possible to mount the cell by putting a collet or clamp around the tube, though care should be taken not to apply excessive force.

The holes on each side near the top are intended to be used with the "bump guard". A bump guard is supplied with each cell, and attaches to the top of it, forming a cage over the sample and any wiring required for measurement. It reduces the risk of knocking or damaging the sample, especially when inserting the cell into a cryostat with a 1" bore. It also provides additional mounting points on the top surface. Bump guards are not generally exchangeable between cells, and from September 2020 onwards are marked with the serial number of the cell they fit.

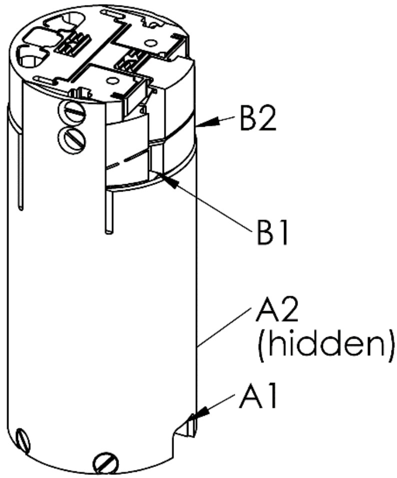


Figure 2: *Wire exit points. A1 and A2 are openings on the bottom edge of the cells 180° apart. They are large enough for all the wires, which can exit vertically or horizontally. B1 and B2 are small slots allowing wires to exit upwards. Max 4 wires per slot. The default configuration is drive wires through A1 and capacitance cables through A2.*

The M1.6 holes on the bottom match the end plate of a Quantum Design P450 probe, as used in their PPMS system, and with the bump guard fitted the puck can be attached to the other end, giving access to the PPMS built in wiring. Most other cryostats will need some form or mechanical adapter, contact Razorbill Instruments if you would like assistance in designing or making one.

Operating the FC1x0

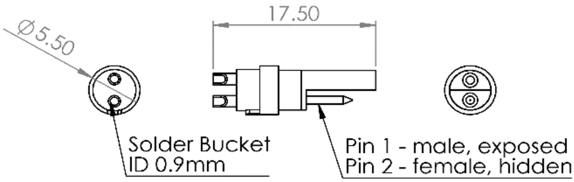
Drive electronics

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 ±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 kΩ, 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.

The four drive wires can be identified by colour and pin on the connector. This connector is hermaphroditic: is it mates with another copy of itself, though pin 1 mates with pin 2 and vice versa.



Connector pin (cell side)	Connector pin (power supply side)	Insulation colour	Connected to
2	1	white	Tension stacks -
1	2	red	Tension stacks +
1	2	brown	Compression stacks +
2	1	blue	Compression stacks -

Table 1: Wire colours and pin assignments

The drive wires will be terminated with the connector shown above. This connector is hermaphroditic: is it mates with another copy of itself, though pin 1 mates with pin 2 and vice versa. 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.

Operating voltage

Recommended voltage limits are given as piecewise linear equations in Table 2 and plotted on a graph in Figure 3.

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.

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*

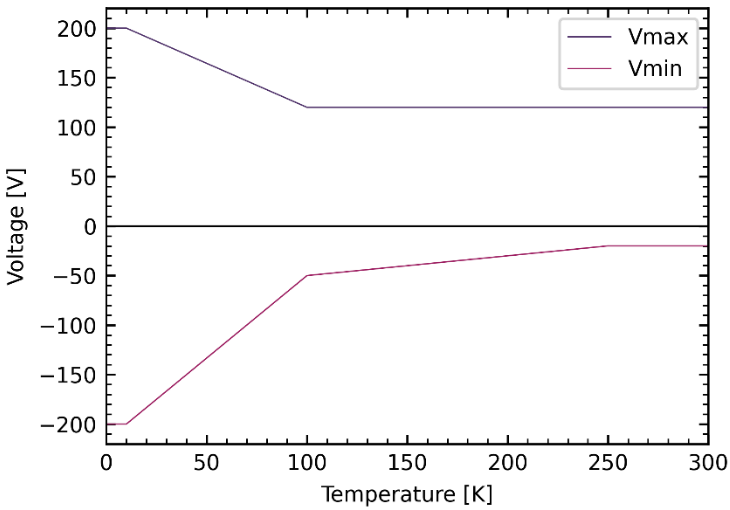


***Figure 3**: Voltage limits for the piezo stacks at different temperatures. The full rated range is achieved with one set of stacks at V_{min} and one at V_{max}*

Force feedback

Force feedback is provided by a parallel plate capacitor built into the cell, which is designed to measure ± 200 N in the FC100, or ± 50 N in the FC150. The capacitance of this sensor is small, similar to 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 ptp, in most cases much smaller voltages will be adequate.

Unless requested otherwise, the cell coax cables will be about 7cm 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-50-1-2/111OE.

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 body 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 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

Precision is typically limited by the resolution or noise of your capacitance bridge. A resolution of better than 6mN/√Hz for the FC100 or 2mN for the FC150 should be achievable in most cases.

The force sensor does show some hysteresis. The maximum hysteresis is given in the specifications table, but in most cases the actual hysteresis will be less. Small changes in force will show smaller hysteresis, meaning that if the force increases from 0 to 0.1 N, and back to 0, there will be no detectable hysteresis. For the FC100, a loop from 0 to 10 N and back will show a hysteresis of perhaps 0.07 N and from 0 to 100 N and back may show as much as 0.7 N. For the FC150, these values are a factor of 8 smaller, and both cells also show lower hysteresis at lower temperatures.

The main limits on accuracy of the sensors are temperature and humidity dependence. All FC1x0s 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 force 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). The gain of the sensor also changes, as the titanium it is made from stiffens. This can be represented by a change in the coefficient α, and the temperature dependent form is given on the calibration sheet.

Humidity causes offsets in the force 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 force, the same as for temperature.

More information about the accuracy limits, including advice on how to repeat the temperature calibration is included in AP006.

As the force sensor, sample, and sample mounts are connected in series, the force on the sensor is the same as the force on the sample. Thermal contraction of the sample does not effect this – the force is still as measured. This is one advantage of a force sensor over a displacement sensor. For more detail, see 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 tube. If liquid enters the cell, allow it to dry completely before cooling or operating it.

Recalibration

The force sensor will generally be quite stable. It may need recalibration if it is stressed beyond the rated force, or if any part of it has been dismantled. It is difficult to obtain an accurate calibration without the specialist jigs at the Razorbill Instruments factory, so please contact us if you think your cell would benefit from recalibration. Temperature calibrations are much easier – refer to AP006 for more information.

Stack replacement

The piezo 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 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 cell are designed to be replaceable. Replacing the all three stacks requires only screwdrivers and a soldering iron. It does however require the removal of the cover tube, as described below, so should only be done by a suitably experienced person, or the cell should be returned to Razorbill Instruments for the replacement.

To obtain replacement stacks, contact Razorbill Instruments.

Removing the cover tube

In order to replace the piezo stacks, re-route wires and cables, or perform repairs, it may be necessary to remove the cover tube from the cell. The cover tube serves two important safety roles:

- It covers the stacks and high voltage components. It is important that the cell is disconnected from the power supply and fully discharged before the cover is removed.
- It contains any small parts which may be ejected at high speed if the preload springs are damaged. Appropriate PPE, including eye protection, should be used.

Only a suitably experienced person should remove the cover tube. If in doubt, contact Razorbill Instruments for advice, or return the cell to the factory for the necessary work.

Recommended accessories

Some of the items described below are included with the cell, or with the first order. All of them are also available separately.

- **RP100 Power Supply.** A two channel ±200 V power supply, specially designed to operate Razorbill Instruments stress and strain cells.
- **SR100 sample carrier.** A flexure guided sample carrier allows samples to be prepared and mounted off-cell; rapidly exchanged; or removed and archived undamaged
- **WP101 wiring platform.** A small PCB and copper heatsink which bolts onto the cell, allowing easier electrical

connections to the sample. Also has space for a thermometer or heater.

- **TB100 worktable.** An optical breadboard with a hole in the middle to fit a workstand. This is designed to give a large flat surface to make sample mounting easier, and can support a variety of XYZ stages and micromanipulators from different manufacturers.
- **TB100_STDFC100 workstand.** This stand safely supports the cell while samples are being mounted, or epoxy is being cured. One is included with each FC1x0.
- **PPMS1 probe or kit.** For customers using a Quantum Design PPMS, Razorbill instruments can provide a complete probe, or a kit to convert a P450 probe to fit the cell.
- **Sample plates.** More sample plates to replace those supplied with the cell, if they are lost, damaged, or modified to suit different samples. For the FC100, one type is available, for the FC150 there are several types. Contact Razorbill to discuss what will work best with your samples.

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 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.