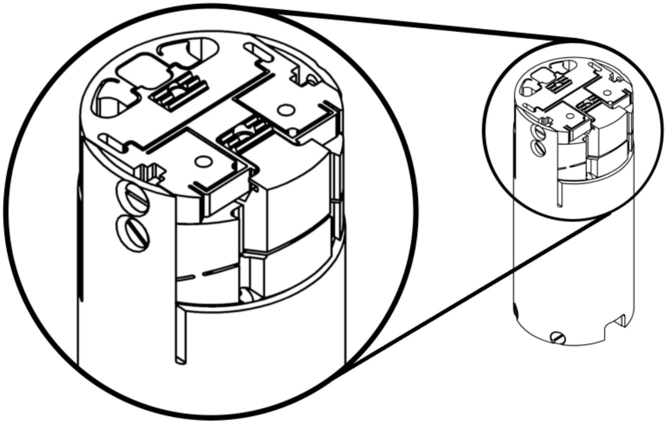
DATASHEET



FC1X0: STRESS CELLS

This datasheet covers the FC100 and FC150 stress cells. 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 a broadly applicable research tool, designed to be 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 FC150 Max	0.7 0.1	%
Drift (vacuum)	24 hours	0.01	%FSR

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

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

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	< 100 mK	
	max storage	25 °C	
	min storage	5 °C	
	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 MOUNTING

The method of sample mounting is fundamentally the responsibility of the user, and must be adapted to suit the users' samples and intended measurements.

Selecting a sample

The most important parameter to bear in mind when specifying a sample and sample mounting method is the sample stiffness. This means the spring constant for compressing or tensioning everything that the user mounts between the two sample mounting screws. At 4 K, the FC1x0 can provide a displacement of ± 25 µm if the sample is very soft. Alternatively, the cell can provide a force of ± 100 N (FC100) or ±40 N (FC150), if the sample does not stretch at all. It can be accurately modelled as a ± 25 µm displacement in series with a 4 N/µm or 2.5 N/µm spring respectively.

For a FC100, a typical sample might be 2 mm long, with 0.5 mm held at each end by the sample plates and epoxy. This will leave 1 mm suspended between the sample plates which will be the effective length of the sample (the part that will actually experience strain). This typical sample may also be 0.4 mm wide and 0.3 mm thick. Assuming a Young's modulus of 120 GPa, this sample would have a spring constant of approximately 15 N/µm. By comparing this with the spring constant above, we can see that the maximum extension would be 6 µm and the force would be 80 N. This corresponds to a strain of 0.6 % and a stress of 750 MPa, so the actual achievable strain will most likely be limited by the sample being damaged. Thicker samples will see a higher maximum force, but lower displacement, stress, and strain. So sample size is a trade-off between achievable stress/strain, and ease of handling.

For a FC150, the same sample would have a maximum extension of 3.5 um, a strain of 0.35 %. This is still likely to break the sample, so in this case, the higher force capability of the FC100 doesn't gain any extra data, but for larger or stiffer samples it could be needed.

Mounting the sample on the cell

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 333 um by turning the plate end-to-end. By rotating both plates and moving them over the teeth, the gap may be adjusted in 333 um increments from approx. 200 um to 2.8 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.

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.

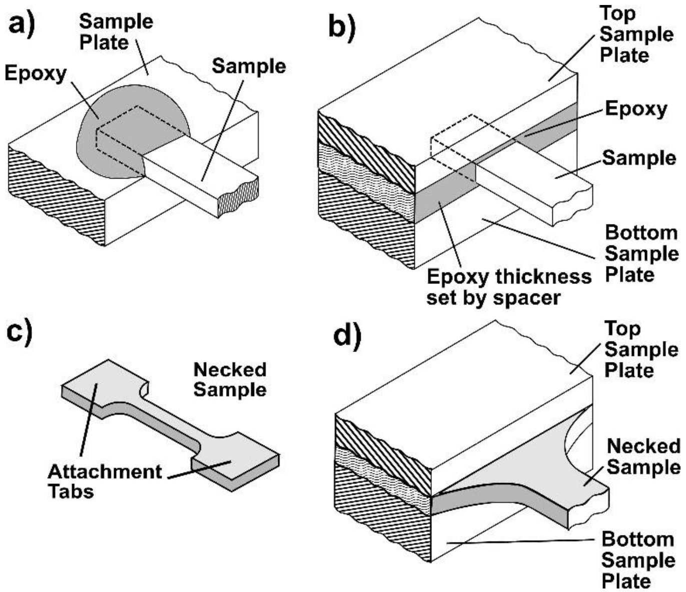


Figure 1. a) It is possible to simply glue the sample to sample plates with a drop of epoxy. b) A more rigorous mounting method, in which the sample is sandwiched between upper and lower plates, to achieve higher strain homogeneity. c) If the sample can be machined or etched, it can be necked. d) Illustrates 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.

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

The maximum operating temperature is dictated by the piezo stacks and epoxies used in the device. The recommended maximum is 50 °C and the absolute maximum is 100 °C. This value 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. It should be noted however that operation at higher temperatures greatly reduces the life of the stacks, and may necessitate early replacement. Increasing the operating temperature from 20 °C to 50 °C reduces the expected life by a factor of 10. Operating at 100 °C reduces expected life by a factor of 200.

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. Other cells in our product range have been operated below 300 mK. The body of the strain cell may become superconducting below 400 mK, but only at very low magnetic fields, $B_c < 6$ mT. The cell functions correctly when superconducting, but maintaining good temperature control of the sample may be harder.

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. If moderately rapid temperature changes are desired, the force sensor may be monitored and the FC1x0 operated to minimize displacement (and hence force) 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 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.

Corrosive or explosive atmospheres must be strictly avoided. Hydrogen rich and high humidity atmospheres will also damage the cell. Moderate humidity will also make the capacitor less accurate, until the cell is dried out.

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

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 15 for details.

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 two 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.

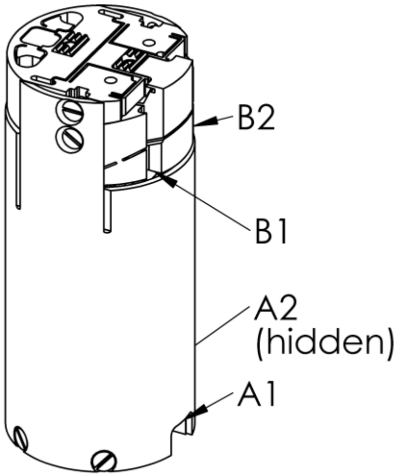


Figure 2. Wire exit points. A1 and A2 are openings on the bottom edge of the cells 180° apart. They are large enough for all the wires, which can exit vertically or horizontally. B1 and B2 are small slots allowing wires to exit upwards. Max 4 wires per slot. The default configuration is drive wires through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

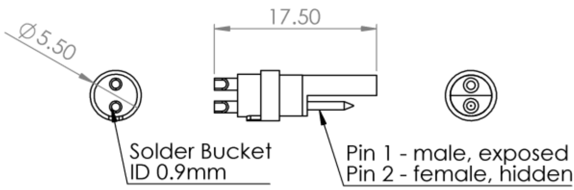
OPERATING THE FC1X0

Drive electronics

There are two sets of stacks inside the cell, and they work in opposite directions. A positive voltage on the inner stack will tension the sample and a negative voltage will compress it. For the outer 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. Razorbill Instruments can provide a suitable power supply. The mechanism is described in more detail in application note AP001, which also covers other power supply options.

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 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 colour, pinout and assignments

Operating Voltage

At room temperature, the voltage applied to either the inner or outer stacks is limited to the range - 20 to + 120 V. As the temperature of the device is reduced, it becomes possible to increase the positive voltage limit (V_{max}) and to reduce the negative voltage (V_{min}). Figure 3 shows the safe voltage for different temperatures.

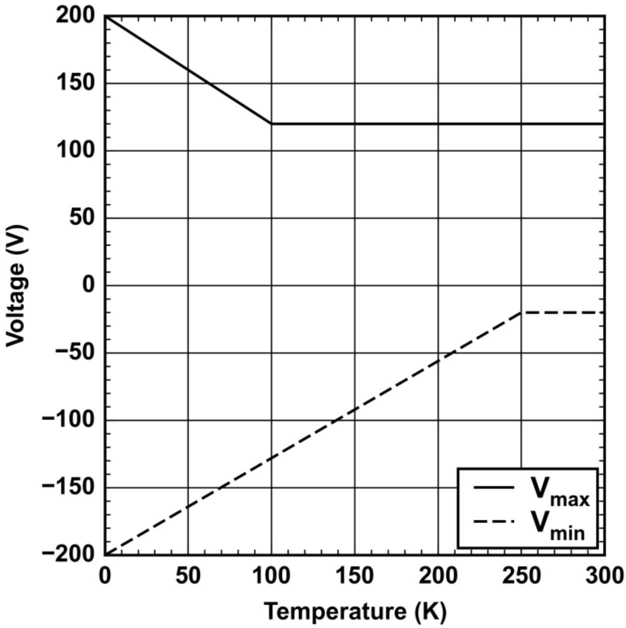


Figure 3: Voltage limits for the piezo stacks at different temperatures. The full rated range is achieved with one set of stacks at V_{min} and one at V_{max}

Measuring the capacitance sensor

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.

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.

In general, lower noise will be obtained if the low plate is connected to the "low" or "sense" terminal of the capacitance bridge/meter, and the high plate is connected to the "high" or "force" terminal. The low plate coax is marked by a black band and the high plate is marked with a yellow band.

Accuracy and resolution

Precision is typically limited by the resolution or noise of your capacitance bridge. A resolution of better than 0.1 N 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 force sensor also has some temperature dependence. Each cell is provided with a capacitance curve which shows how the zero force capacitance changes with temperature. This can also be measured easily by cooling the cell with no sample attached. If this offset is subtracted from the measured capacitance before converting to force, the result will be accurate to a few percent. If a higher absolute accuracy is required, it is possible to calibrate by hanging masses from the cell inside a cryostat.

The cell is designed to operate in a vacuum or dry gas atmosphere. In air, the changes in ambient humidity will cause drift on the scale of 0.2 % of the full range. This is normal, and will go away when the cell is dried out in the cryostat. For best results, keep the cell at 300 K in vacuum for a few hours before cooling, as this will ensure no moisture remains in the capacitor.

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.

Calibration

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. The easiest way to recalibrate the cell is to support the cell at one sample mounting point and hang known masses from the other.

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.
- **WP100 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.