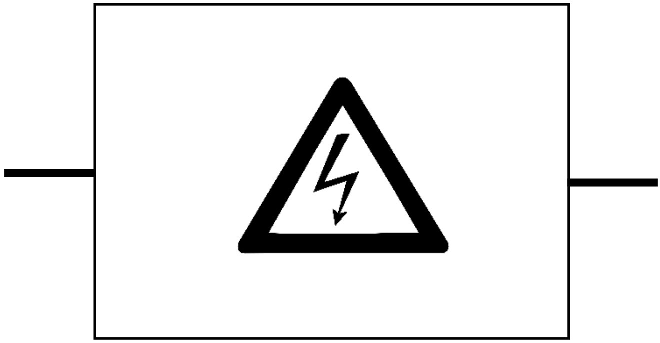
AP002: Drive Electronics



The Razorbill Instruments stress and strain cells use piezoelectric stacks to drive them. These stacks require voltages of up to ± 200 V, with very small currents, to operate. This document describes the way that the cells should be connected, and discusses some of the options for generating the required voltages.

Note that Razorbill Instruments can provide a power supply to work with any of our cells, which substantially simplifies the process of getting up and running. This application note is of more use to customers who plan to provide their own power supply, but also contains some details about wiring and connections which are more broadly applicable.

The strain cells require high voltages to operate, and the piezo stacks within can store dangerous levels of charge. Read and understand the safety notices which apply to your cell, and to the power supply you plan to use.

This document is written for a reader who is familiar with the material in those safety notices and with electrical safety in general. If in any doubt about the safety of your experimental system, contact a suitably qualified person for advice.

Cell operation

Each cell contains several stacks, usually three, which are arranged mechanically so that some stacks tension the sample when extended, and some compress it. This arrangement is designed to prevent unwanted thermal expansion effects (see AP001: Thermal Expansion for more detail). To obtain the full range of motion specified in the datasheet, a two channel power supply is necessary, to control the two sets of stacks separately.

Power supply

Note that Razorbill Instruments offer a suitable power supply for all our cells. The RP100 has been designed specifically to work with stress and strain cells, and has several features designed to protect the cells from damage, and improve safety. Razorbill Instruments recommends the use of this power supply wherever possible. If higher voltages are desired, two RP100 power supplies may be used together to achieve ± 400 V while still taking advantages of the features aimed at improving safety and protecting the cells from damage. Contact Razorbill instruments for a description of how to do this.

Choosing a different power supply

If a different power supply is chosen, for example in order to use the cell at higher voltages, then it should normally meet the following requirements:

- Two channels
- Each channel capable of ± 200 V
- Each channel able to source and sink current at positive or negative voltages (i.e. a "four quadrant" power supply).
- For safety reasons, and to prevent damage to the cell, the current should be limited to a few milliamps wherever possible. If the supply is not limited, a series resistor may be used.
- A supply with a floating output is advantageous, as it reduces the risk or arcs inside the cryostat.

Rated voltage and temperature

Please note that the allowable voltage for both the tension and compression stacks varies significantly with temperature. The cells are designed and warrantied for use at - 20 to + 120V at room temperature, and ± 200 V at 10 K. Intermediate allowable values are shown in **Figure 1** and piecewise linear equations for the limits are shown in **Table 1**.

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 1: *Recommended voltage limits*

At most temperatures, the devices can withstand smaller negative voltages than positive voltages.

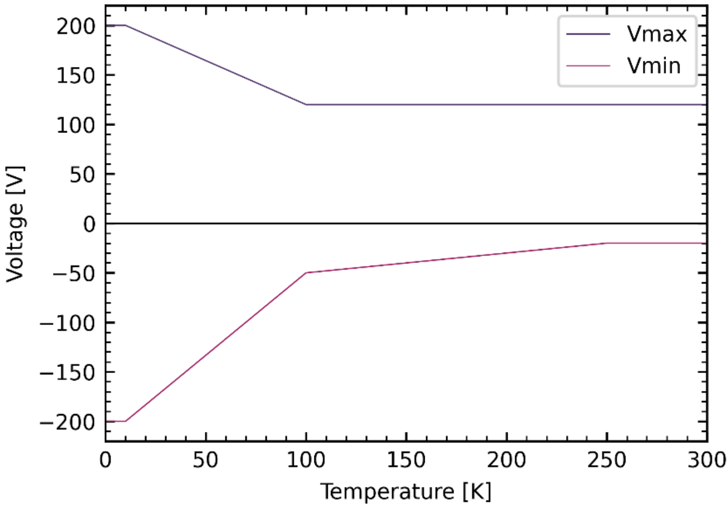


Figure 1: *The graph of allowable voltages for the piezoelectric stacks, with respect to temperature.*

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. The cells still meet the rated performance, but with the old voltages it was possible to go well beyond the room temperature performance around 100K, and this could reduce the life of the cells.

Exceeding the rated voltage

Exceeding these levels will greatly reduce the life of the cell, with expected lifetime scaling as approximately voltage to the sixth power for small increases. Large increases may cause immediate failure. Exceeding these levels also increases the risk of electric shock and increases the stored energy and thus the severity of any shock.

Users who wish to operate their cells at higher than rated voltages should contact Razorbill Instruments for advice on how to adapt them, and for suggestions of power supplies.

Standard wiring scheme

If the cell is being driven by a two-channel power supply and there are 4 compatible feedthroughs into the cryostat, the wiring scheme for the cell is straightforward, and is shown in **Figure 2**. We would recommend keeping the outputs floating, as this means no arc can form to ground, but it is also acceptable to ground the negative wire from one stack to reduce noise if adequate steps are taken to avoid shorts to ground elsewhere.

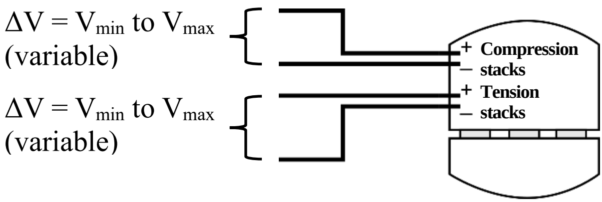


Figure 2: *The standard wiring scheme using two channels, 4 wires and floating outputs.*

Using only 3 wires

If it is undesirable to install 4 wires and feedthroughs into the cryostat, the cells can be operated with just 3 feedthroughs by using a common return to the compression and tension stacks. This does not reduce the performance but does make the system less robust, as a failure or short will mean that the cell cannot be operated at all, where in the four wire scheme the other channel can still be used. If used with the RP100 power supply, this wiring scheme will make the measure subsystem inacurate, as it monitors the return wire.

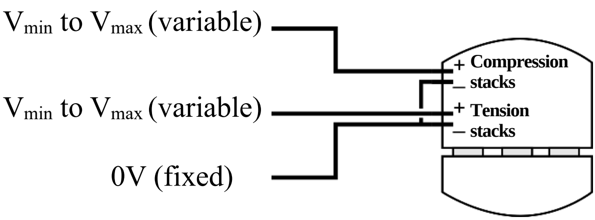


Figure 3: *Alternative wiring regime with a common return for the two outputs.*

Using a single channel power supply

If no two-channel power supply is available, it is possible to operate the cell with a single channel supply, albeit with reduced range, shorter operating life, or both.

Single channel without bias (2 wire)

If the compression and tension stacks are connected antiparallel and wired to a single channel power supply, then more or less of the operating range can be achieved depending on temperature.

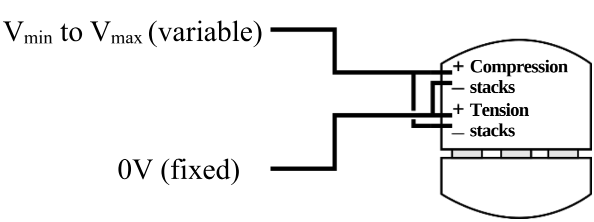


Figure 4: *Diagram showing how the cell can be wired so that the tension and compression stacks receive equal and opposite voltages.*

As previously discussed, the maximum voltage tolerated by the stacks will depend on temperature (See Figure 1), and this will have an especially big impact on the achievable range under this wiring scheme. The power supply voltage will be applied forwards across one set of stacks, and backwards across the other, so must be limited to the smaller of the permitted positive and negative voltages for that temperature. For example, at room temperature (where the voltage rating is typically – 20 V to + 120 V) in this wiring scheme only – 20 V to + 20 V can be applied without damaging the device, meaning only a quarter of the normal range is available. At low temperature the voltage range is typically ± 200 V, so the full range is available, and there is little disadvantage to this scheme.

Single channel with bias

Using a power supply with a variable output and a constant bias output (such as are designed for use with piezo benders) it is possible to access the whole operating range. This arrangement applies large voltages to the stacks even when only small strains are required, and will reduce their lifetime by a moderate amount. It also needs a different bias voltage for different temperatures if the full operating range is to be accessed. Please contact Razorbill Instruments for advice before attempting to use a power supply in this configuration.

Wires and cables

Outside the cryostat, any wire or cable rated for greater than 250 V may be used for connecting to the power supply. Inside the cryostat, there are three additional considerations: Low temperature, heat load, and gas pressure.

The low temperature mostly affects the insulation materials available. Many wires or cables which would otherwise be suitable use PVC insulation, which may crack off when cold. Always use wire which is rated for, or has been tested in low temperatures. Even insulation materials which are commonly used at low temperature can crack or flake off if the wire is bent, so take extra care if, for example, the cell is to be mounted on a cryogenic rotator.

Heat load is discussed in more length in application note AP004. In short, a conductive cable will also carry heat down to the cell. Fortunately, as the currents required to operate Razorbill Instruments cells is low, there is no problem in using resistive wires such as manganin, phosphor bronze, stainless steel or nichrome. These are not readily available with suitable insulation, but Razorbill Instruments can provide them.

The third problem is arcing in a low pressure atmosphere. While air at room pressure requires a minimum of 300 V and 3 MV/m to arc, lower pressure gasses may arc over long distances at a little over 100 V. Arcing to the body of the cryostat is a safety concern, and arcing wire-to-wire can abruptly discharge the piezo stacks, causing damage to the cell and/or sample.

The biggest risk is in cryostats which use a low pressure helium exchange gas to conduct heat around the sample chamber, but arcs can also happen in sample-in-vacuum designs if there is a leak. To prevent arcing, there should be no exposed conductors. Joints should be covered with heatshrink or encapsulated with a suitable epoxy. Connectors with shrouded or stepped contacts are recommended as they will prevent arcing even if they are not fully mated.

Cell connectors

The Razorbill CS1X0 and FC100 strain cells are provided with PTFE insulated wiring terminated with two two-pin hermaphrodite stepped connectors of the type shown below. Four more mating connectors are provided with each cell for the customer to use in their wiring.

These connectors are actually contact blocks from Lemo 0S series circular connectors, but are available from Lemo with part number FGG.0S.302.ZLAT or in smaller quantities from Razorbill Instruments.

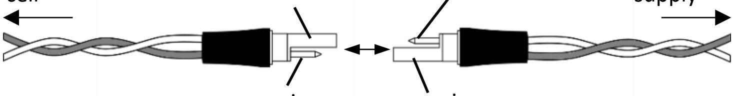


Figure 5. *The connectors on the drive wires for CS1X0 and FC100 devices.*

There will be two twisted pairs coming from the cell, and they are connected as follows:

Connection	Colour	Pin (cell side)
Compression stack positive	Brown	Male
Compression stack negative	Blue	Female
Tension stack positive	Red	Male
Tension stack negative	White	Female

Table 2: *Wire colours*

To integrate the strain cell into your system, it will be necessary to terminate your wiring with the loose LEMO connectors provided with your strain cell. These connectors should be soldered onto the wires, and then encapsulated. The easiest way to do this is to use a cryogenic compatible heatshrink, and then fill with a low-viscosity epoxy such as Stycast 2850FT with Catalyst 23LV.

Vacuum feedthroughs built by Razorbill Instruments usually use Lemo part number HGG.0B.302.CLLPV. Cables designed for use outside the cryostat typically use Lemo part number FGG.0B.302.CLAD**xx**, where **xx** indicates the outside diameter of the cable.

Cryogenic piezoelectrics

The stacks used in Razorbill Instruments products are provided by PI and use their PICMA technology. Room temperature properties of these stacks are available on their website. On cooling, there are several effects:

- Capacitance decreases, typically by a factor of about 5 at 4 K.
- Stroke decreases, by a factor of about 7 to 4 K. This makes larger voltages somewhat less damaging.
- Hysteresis decreases.
- Re-poling voltage increases, so larger negative voltages may be used without damage.

Generally speaking, the changes with temperature and the hysteresis of the stacks means that controlling voltage is a poor substitute for controlling strain. Razorbill Instruments cells have built-in force or displacement sensors, which can be used as part of a closed loop system to control stress or strain.