Technical Note: Wiring of an attocube Piezo Positioner and Effects of Resistive Wiring

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For wiring an attocube piezo positioner different aspects, mainly resistance and thermal conductance of the wires, need to be considered. Different applications like stepping, scanning, and sensor readout require different cabling. This overview wants to shine light on these topics as well as to discuss some examples.

Positioning with a stepper positioner

attocube systems' translation stages are based on slip-stick motion. The basic principle is the play with inertia and friction. When the central shaft is accelerated fast enough, an otherwise clamped (sticking) block can slip along a guided rod to which it is mounted with a certain friction. Hence, a net step can be obtained by applying a sawtooth voltage to the piezo (see Figure 1).

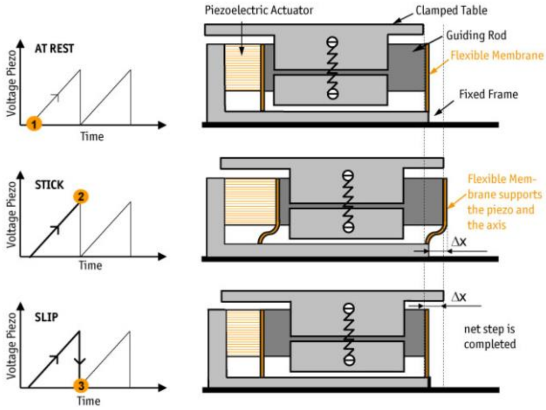

Figure 1: *Slip-Stick positioning principle of attocube systems positioners.*

In detail, this works as follows: At first, the piezo is expanded slowly according to the slow rising flank of the voltage signal ("stick-phase", 1→2). As the central axis is directly connected to the piezo and the table is clamped onto this axis, both move together simultaneously with the piezo. At the steep edge of the voltage pulse, the piezo is contracted very quickly to its original size ("slip phase", 2→3). As the table's inertia is much higher than the one of the axis, the force required to accelerate the table is much higher than the friction force. Hence, the table remains almost unmoved (lowest picture). In total, a net step of the table with regards to the axis is achieved.

To control this stepping procedure precisely, the electrical signal consequently consists of a slow rise and a steep decrease for what is called *forward motion*. Note that for backward motion the signal is inverted in time, not in voltage. This is because the multi-layer piezos used in the positioners can only take unipolar voltages in a range of typically zero to +60 V, +100 V, +120 V, or +150 V, depending on the piezo type.

Note that to initiate stepping, a certain minimum acceleration has to be provided. This is achieved by applying a voltage drop of more than ≈3-5 V/µs to the piezo. As multi-layer piezos often have large capacitances, the stepping process hence requires currents in the ampere regime for very short times. A few calculations are given in the following.

As an example, we consider the current needed to drive an ANPx101 at room and low temperature (RT: 300 K and LT: 4 K). The piezo capacitance is typically about $C_{P,RT} = 1\mu F$ and $C_{P,LT} = 150nF$, while typical stepping voltages are e.g. $U_{RT} = 40V$ and $U_{LT} = 70V$. To generate the sawtooth shaped signal, the generator has to apply a low charging current and then has to discharge the piezo abruptly, thus leading to a short current peak. While the slow rising flank lasts about $\tau_{Rise} = 5ms$ (given by assuming a typical repetition rate of 200 Hz), the fast falling flank has to be shorter as $\tau_{Fall} = 10\mu s$ to initiate stepping (minimum ≈16kHz signal bandwidth). Hence, while the charging current is in this example only:

$$I_{Rise,RT} = CU/\tau \ = 1\mu F * 40V/1ms \ = 40mA,$$

the discharging current reaches already:

$$I_{Fall,RT} = CU/\tau \ = 1\mu F * 40V/10\mu s \ = 4A.$$

With the before mentioned 100/1 duty cycle, the average net current $\overline{|I|}$ flowing through the wires is ≈80 mA.

These calculations were confirmed by measuring the currents towards an ANPx101 with $C_{P,RT} = 0.7\mu F$ while driving it at 40 V step amplitude. Here, a peak current of ~3.7 A could be measured indicating an even faster ramping.

Scanning with an ANSxy100 scanner

While in case of e.g. the ANPx101 *stepping* allows for large ranges of millimeter-range, *scanning* addresses ranges of a few micrometer only, yet with much better control and precision. With the ANSxy100 large range scanner, one can position within over 30 x 30 µm² at LT (50 x 50 µm² at RT) for example. This scanning is driven by a "slowly" changing DC voltage, with the scan speed ranging typically up to 10 Hz maximum, hence $\tau_{Scan} \geq 100ms$.

Calculating the current needed for scanning, with e.g. $C_{S,RT} = 5.4\mu F$ and $C_{S,LT} = 750nF$ and a full scan range of $U_{RT} = 60V$ and $U_{LT} = 150V$ respectively, results in:

$$I_{S,RT} = \frac{C_{S,RT} * U_{RT}}{\tau_{Scan}} \approx 3.2 \text{ mA}$$

and

$$I_{S,LT} = \frac{C_{S,LT} * U_{LT}}{\tau_{Scan}} \approx 1.1 \text{ mA}$$

As mentioned before, these are upper estimates, as one often scans slower due to other limitations (not to damage an AFM tip, required sample time per pixel, etc.). Clearly, the required currents for scanning are much smaller than the average currents needed for stepping, not mentioning the peak currents required for the steep flank of the sawtooth signal shape.

Currents required for resistive sensors

The resistive sensor typically has a total resistance of about 5-50 kOhm. The voltage applied by the ANC350 is typically set anywhere between 0 and 2 V. Thus, the currents resistive sensors require are typically max. $I_{Res} \approx 0.4$ mA.

Effects of resistive wiring

In the following, the effects of resistive wiring on the step signal are considered. Note that the wire resistance is calculated as the sum of both, signal and ground wire resistance.

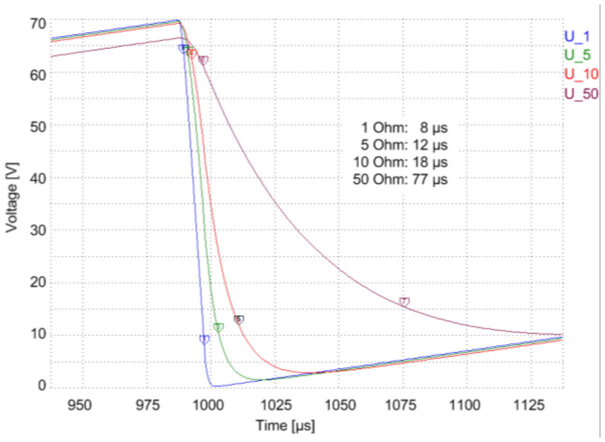

Figure 2: *Shape of the steep flank of the sawtooth signal as a function of the total wire resistance.*

In Fig. 2, a 70 V sawtooth signal has been plotted for different resistances in the cabling towards a positioner having 1 µF capacitance. **Obviously, the larger the resistance, the slower is the signal drop.** As pointed out before, this sharp transition is essential for the strong acceleration of the axis in order to initiate the slip-phase. In many experiments it has been seen that above 10 Ohm wire resistance stepping is no longer possible (this corresponds to a required minimum signal bandwidth of 16kHz). Note, that a typical wiring capacitance of e.g. 10 nF in total is negligible with respect to the piezo capacitances.

Following this consideration, attocube systems suggests using low-ohmic wiring for stepper positioners. Typically, copper (typ. 0.7 Ohm/m @ 0.2 mm diameter) or brass wiring (typ. 1.5 Ohm/m @ 0.25 mm dia) with a total resistance (both wires) of **not more than 2 Ohm** should be used (bandwidth 100kHz). In this case, attocube fully warrants the functionality and the specifications of the positioners.

With a resistance **of 2 to 5 Ohm**, the functionality of the positioner is still warranted, yet some specs can probably not be held anymore (e.g. max. load, min. step size, etc.).

If wiring with a resistance **between 5 and 10 Ohm** is used, we recommend that you contact attocube systems so that the positioners can be specially tuned for this purpose. Again, certain specs cannot be guaranteed anymore (e.g. max. load, min. step size, etc.)

Finally, if resistive wiring with **more than 10 Ohm** total resistance is used in the customer's experimental setup, the correct functionality of the positioner cannot be guaranteed anymore.

Due to the much lower currents for scanning and sensor applications, resistive wiring can be used for these applications.

Wiring in a Dilution Refrigerator / ^{3}He system

For ultra-low temperatures, standard low-ohmic wiring is problematic, as this typically increases the heat load above acceptable values. Here, attocube systems recommends using combinations of copper wiring and superconducting or phosphor bronze wiring.

Copper wires from room temperature can be heatsinked on the 4 K stage or on the 1 K pot. From there, either superconducting wires or phosphor bronze to the positioners have been successfully used. Often NbTi wires are used for applications in He3 systems or Dilution Fridges. Phosphor bronze wires have the advantage that the complete setup can be tested in room temperature, whereas superconducting wiring will typically have very high resistances at room temperature.