1. Introduction

The terms stepping and scanning are often mentioned when discussing the use of cryogenic positioners for an experiment. Although these are fundamentally different types of motion, they are in practice frequently used interchangeably and a potential source of confusion. A correct understanding of the differences between stepping and scanning is of importance when selecting positioners, this application note aims to clarify these terms.

2. Stepping

Most cryogenic positioners use piezo ceramics and the so-called stick-slip concept to travel distances up to 50 mm. Stick-slip positioners operate by driving the piezo with a sawtooth-like voltage at pk-pk amplitude U_{pp}, equivalent to the piezo motion range S_p. During the **slow** ramp t_0 - t_1 the table sticks to the plate, but during the **fas**t ramp t_1 - t_2 table inertia will cause it to slip with respect to the fast-retracting plate. After a cycle t_0 - t_1 - t_2 the piezo and plate have returned to their initial positions, but the table has **stepped** a distance S_p. The (sub-)micron piezo range at cryogenic conditions will limit the maximum step size accordingly, but r**epeating such microscopic steps will result in macroscopic motion.** Motion in the opposite direction is achieved by reversing to a fast-slow sequence of the ramps.
By setting U_{pp} to a percentage of the maximum value U_{max}, the **relative step size** with respect to the maximum can be set. The step size will reach a practical lower limit when the table does not break free from the plate anymore and no slip will occur during the fast ramp. A second drive parameter is the **step frequency** (number of steps per second), used to set the **relative speed** with respect to the maximum allowed step frequency. The relative step size and step frequency parameters can be set via the controller software.
After a sequence of steps, the table is held in place by friction between the table and plate, the so-called **holding force**. This also means that power to the positioner can be turned off and the table will not slide if not pushed against above the holding force, typically in the order of several Newtons[1].

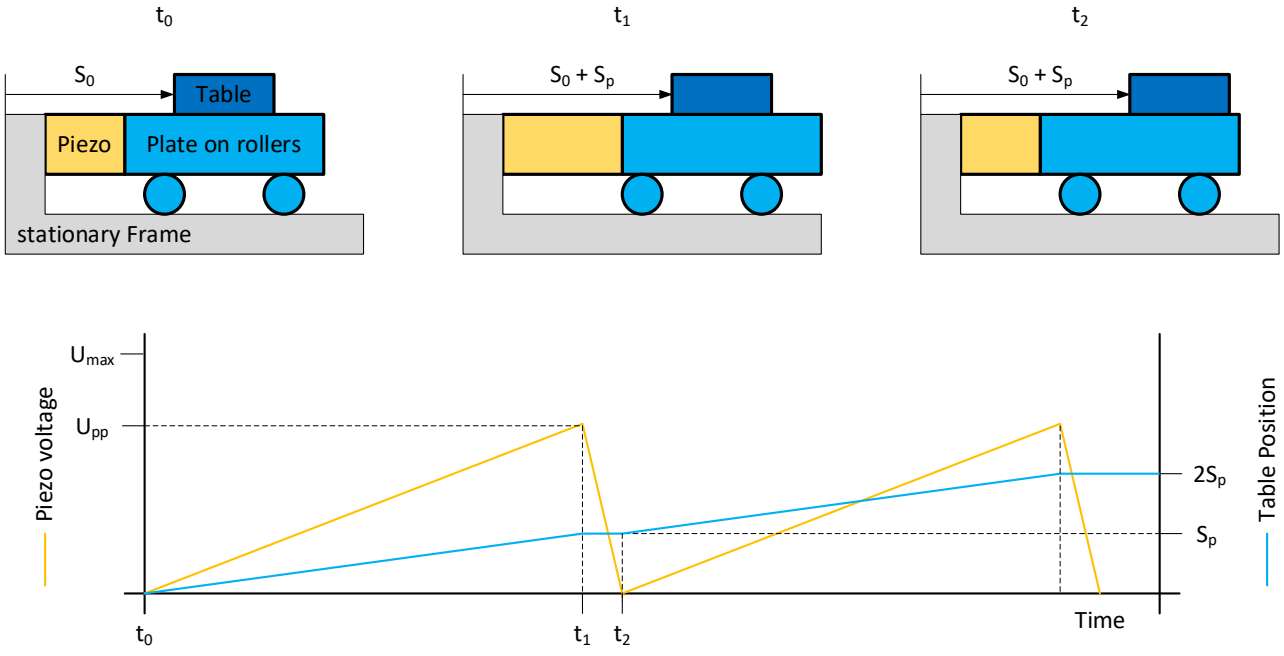


Fig 1: Stick-slip positioners and drive signal for STEPPING.

Other motion concepts besides stick-slip are possible but the main characteristic of stepping is that a sequence of microscopic steps is made to cover macroscopic distances.

1 A unique exception to this is JPE's CLA actuator which has so-called **self-locking** behavior, meaning that its holding force is only limited by the point of structural damage, which can be well over 100 N.

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3. Scanning, small range

JPE's stick-slip positioners typically have the possibility to switch to **scanning** after having finished stepping[2]. Scanning is the ability of **fine positioning to the nanometer level within the (sub-)micron range of the piezo**. It is good to realize that although the scan range is small, it is by definition larger than the smallest achievable step size. Consequently, the combination of stepping followed by scanning allows nanometer level positioning over the millimeter order range of a positioner. Scanning can in principle be done with arbitrary motion profiles, but the frequency content must be modest, preventing the table to slip with respect to the plate. In contrast to stepping, it is required to **maintain a voltage on the piezo to stay in position**, otherwise it will return to its initial non-extended length at t_0.
Although the rollers are of high quality, there will still be some minimal rolling friction between the plate and stationary frame. This friction is "fighting" the piezo and can cause unpredictable behaviour at the nm level that limits the achievable scan resolution.

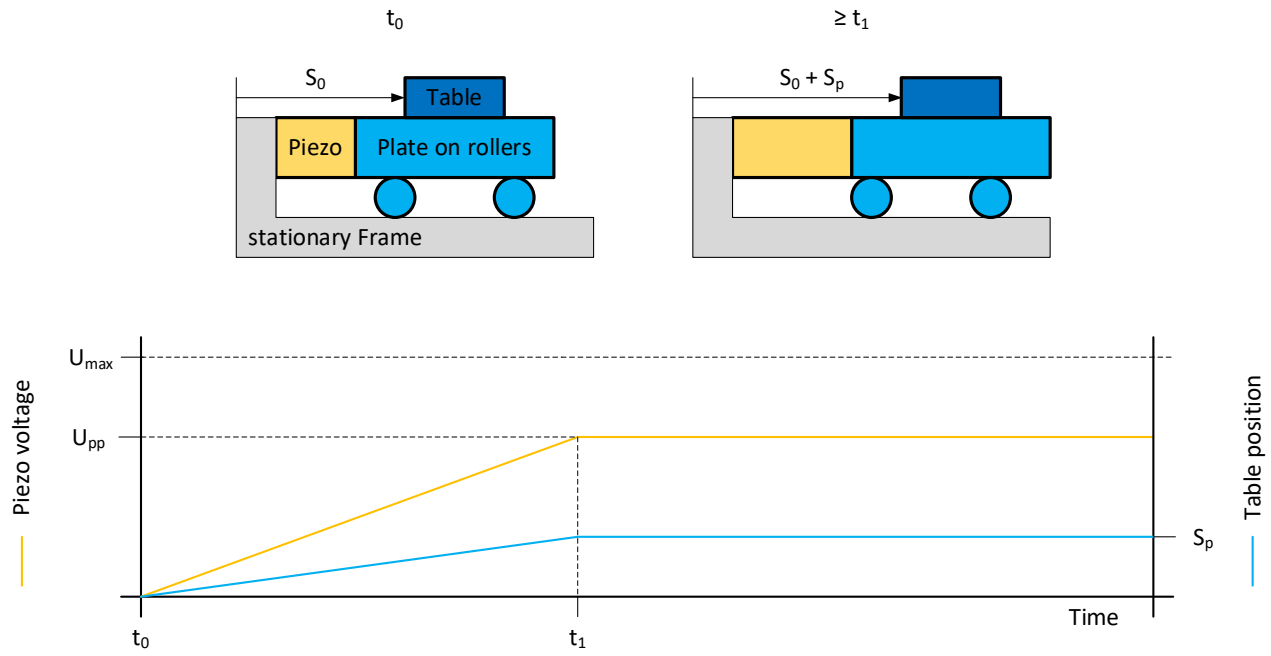


Fig 2: Stick-slip positioners and drive signal for SCANNING.

Using a stand-alone piezo is also a form of small-range scanning. Because there is no attached mass from the positioner it is possible to achieve very high bandwidths with such a basic scanner.

2 Except for instance the CLA. The internal layout of the CLA makes scanning impossible, but in return stability is optimized because piezo creep is not visible on the output motion.

4. Scanning, long range

The intrinsic small scan range of a piezo is not sufficient for many experiments. Long range **scanners** are part of a separate product line and do not have stepping capability anymore, but in return they offer a significant increase in the scanning range. These scanners are often used in combination with steppers.
The increased scanning range is achieved by the introduction of a mechanism that amplifies the piezo stroke. Using **flexures** for such a mechanism will also eliminate friction that negatively impacts positioning. These scanners therefore combine **increased range with optimized resolution**.
The theoretical resolution of flexure-based scanners is only limited by the piezo, which is capable of (sub-)nm resolution when powered with low noise voltage amplifiers. However, piezos also exhibit significant hysteresis and creep. Mitigating this non-ideal behavior requires some form of position feedback, usually from the experiment itself.
The implementation of the mechanism can take different forms, but they all share the fundamental drawback of reduced rigidity by a factor i_d^2, as felt at the point S_{scan}. This will negatively impact dynamic behavior, resulting in increased sensitivity to cryostat vibrations and added mass and cabling from the experiment. So, **increasing range comes with a reduction in positioning stability**. Limiting i_d to find a good balance between scanner range and rigidity is therefore a critical point of consideration by JPE when designing these scanners.

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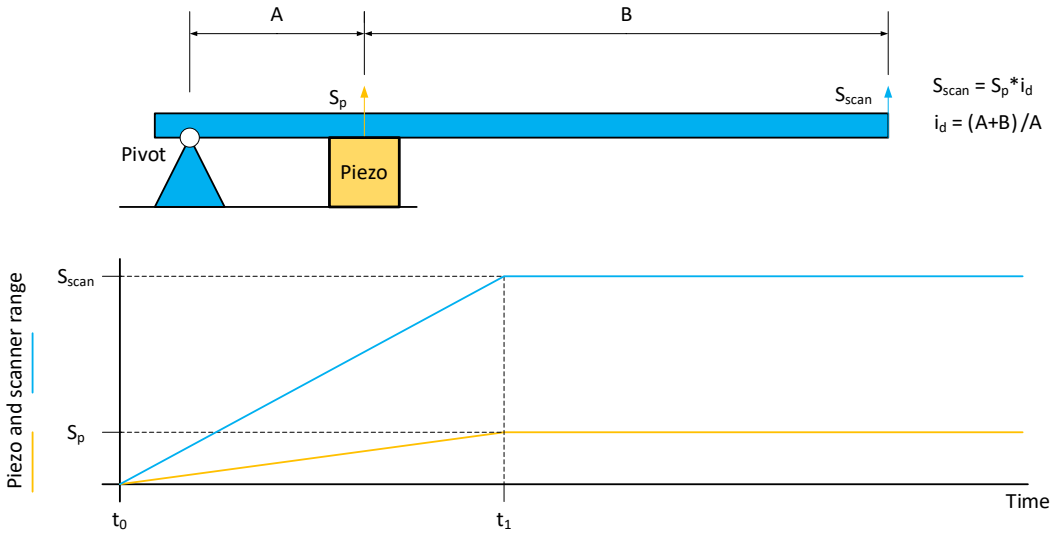


Fig 3: Scanners: relation between piezo range S_p and scanner output range S_{scan}.

5. Summary

The motion of cryogenic positioners can be split in stepping and scanning, with 2 sub-classes of scanning:

- **Stepping**: many (sub-)micrometer steps are made sequentially to cover millimeter distances. JPE product example: CBS, CRD, CSR and CLA.
- **Small range scanning**: fine positioning to the (sub-)nanometer level with (sub-)micrometer range. Most JPE stepper positioners have this functionality integrated also. In its simplest form a simple stand-alone piezo is used. JPE product example: CBS, CRD and CSR.
- **Long range scanning**: a separate product line that uses flexure-based mechanisms to increase the scan range but stepping functionality is lost. JPE product example: CLS.

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