1.1 Basics: scanner motion when loaded

Consider a scanner with a specified range of motion x_{spec} (at no load) and a drive stiffness c_d [N/m], which is the stiffness that is felt by the user at the point of motion output. Now assume that the scanner is experiencing an external load from a spring with stiffness c_l [N/m]. This can be an actual spring, but items like wires and thermal conductive braids also behave like a spring.

When applying such a load we can identify 2 scenarios

1. An initial load F_0 that will compress the scanner, resulting in a position offset $x_0 = F_0/c_d$. A load of 1N working against a drive stiffness of 1E4 N/m would already result in an offset of 100 micron. This is more than the specified (no-load) range of a typical scanner and deformations of such magnitude can easily damage the scanner.
2. A varying load that occurs when the scanner is commanded to move. The external spring starts to push back harder, and in its turn starts to compress the scanner further. Effectively the scanner output motion will be less than the specified range of motion: $x_{out} = x_{spec} * c_d/(c_d + c_l)$. Consider the following situations, also see figure 1:
    - $c_l = 0$, which is the case for a simple mass. The scanner will experience the offset from scenario (1), with $F_0 = mg$, but after that it can move the full no-load range.
    - c_l is $0{,}1*c_d$; the motion range of the scanner is reduced to 91% of the no-load range.
    - c_l is $1*c_d$; the motion range of the scanner is already reduced to 50% of the no-load range.
    - c_l is $10*c_d$; the motion range of the scanner is reduced to 9% of the no-load range.

If a scanner is to have a meaningful motion range under load also, we have to minimize the effects from (1) and (2), by maximizing the drive stiffness.

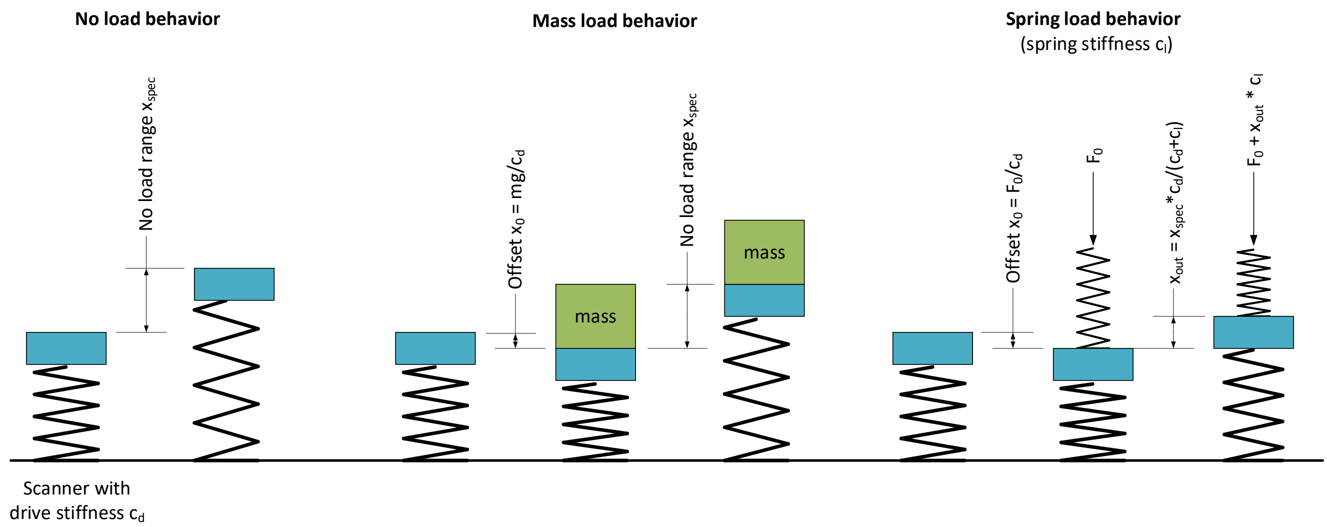

Fig 1: Scanner motion output at several load conditions.

1.2 Drive stiffness versus scanner range

JPE's CLS scanners use piezos as basic drive element, which have a high stiffness c_p but have very limited range x_p. Especially in cryogenic conditions the range typically reduces to approximately 1 micron, and a range increasing mechanism is used.
In figure 2 a basic lever mechanism with ratio $i_d = (A+B)/A$ is depicted. However, it is important to realize that, independent of the practical implementation of such a mechanism, the unavoidable consequence is that the scanner drive stiffness is severely reduced: $c_d = c_p / i_d^2$. In practice the situation will be even worse because the equation assumes the mechanism itself to have infinite stiffness. in practice the Beam and Pivot will have a finite stiffness, which will contribute significant in the overall scanner drive stiffness, especially when further increasing i_d.
Referring to section 1.1 it becomes clear that this reduction in drive stiffness c_d will severely affect scanner output motion x_{out} and high lever ratios are therefore to be avoided, thus also accepting a limitation of the specified motion range x_{spec}. Exactly this strategy is implemented in the CLS scanners;

Do not simply maximize the scanner range at no load, but find a balance between range and drive stiffness.

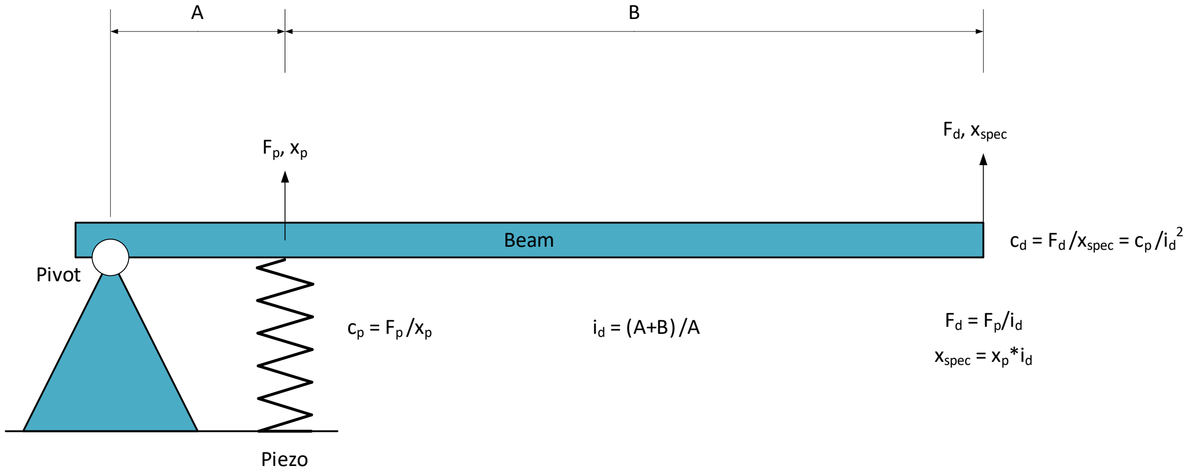

Fig 2: Relation between scanner motion range and drive stiffness (no load).

1.3 Load capacity and dynamical behavior

When applying an external load F on the scanner it will load the piezo and lever mechanism inside by a force $F*i_d$. Increasing i_d will therefore make the scanner progressively sensitive to damage and the maximum allowable load needs to be reduced to very low numbers. Even to a level that handling them becomes a risk. This is another reason to limit i_d and accept a limitation of the specified motion output x_{spec}. Stacking scanners to realize xy or even xyz is a common requirement and this makes the setup even more delicate, especially for the lowest scanner in the stack. For this reason, the CLS scanners have been designed such that;

The CLS scanners can take high loads and are optimized for a lower sensitivity to floor vibrations when multiple axes of motion are needed.

These claims are possible because of 2 features of the CLS-XY scanners;

1. A xy guide is introduced, separated from the piezo and lever mechanism, see figure 3. By doing so external z loads will not reach the piezo and lever mechanism, mitigating the risk of damage.
2. Stiffness in all directions is increased significantly. It is important to realize that this will reduce the sensitivity to floor vibrations and therefore position stability is improved. This will also be the case when an additional z scanner is placed on the xy scanner. The gain in stiffness is achieved in different ways;
    a. The xy guide increases the z stiffness, typically by an order of magnitude which improves z resonances by approximately a factor 3.
    b. xy motion is based on parallel kinematics which means that each drive axis is connected to a common sample table, as shown in figure 3. In figure 4 a simplified dynamical model of the concept is shown. The xy resonances f_{xy} increase by 41% respectively 22% for the xy and xyz configuration, compared to traditional stacked stages.

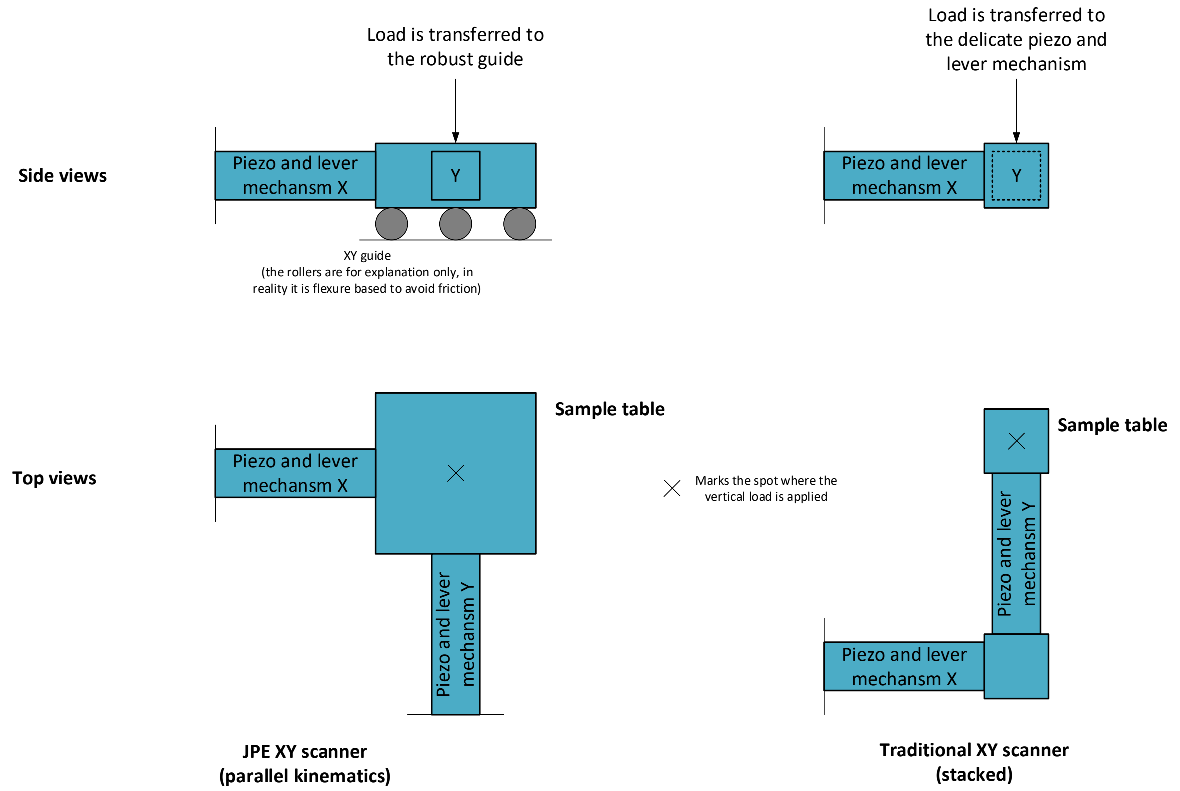

Fig 3: JPE XY scanner with parallel kinematics and a load bearing xy guide to increase z load capacity and improve dynamics in all directions.

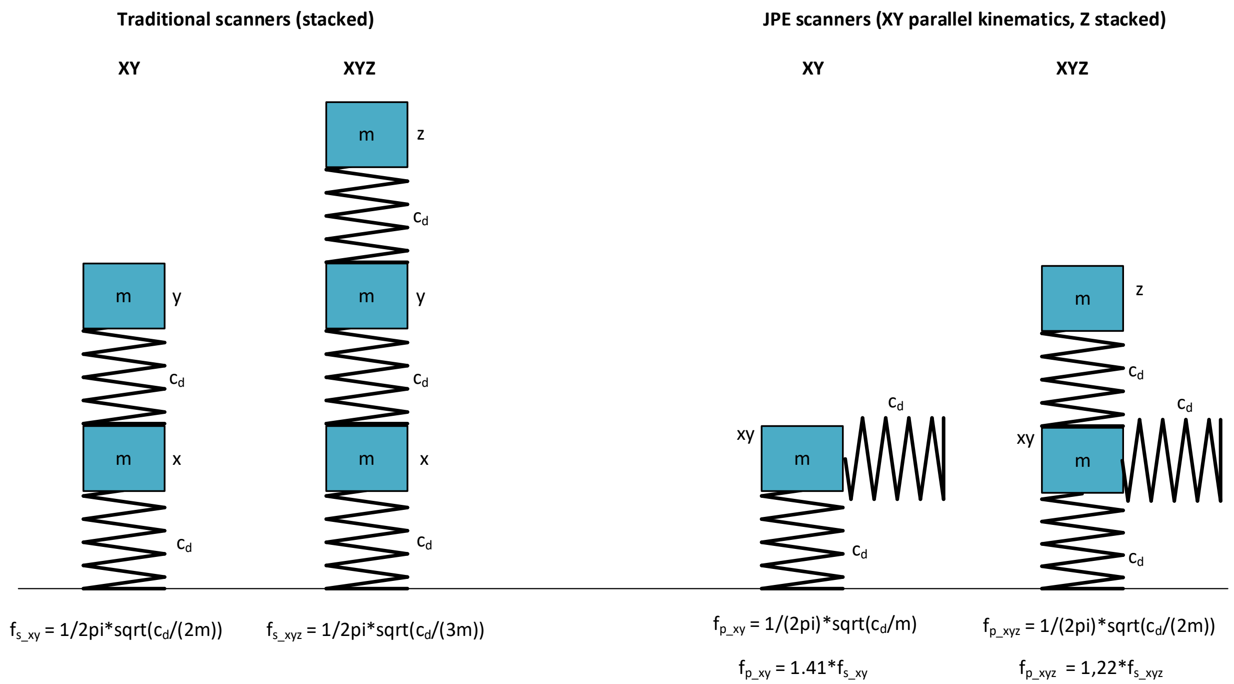

Fig 4: JPE XY scanners with parallel kinematics will have reduced sensitivity to xy floor vibrations because of their intrinsic higher mechanical resonances, in comparison with traditional stacked scanners. This advantage remains when a z scanner is added.

1.4 Summary

JPE's CLS scanners are not single mindedly designed for maximum range. Instead, a balance between no-load range, drive stiffness and load capacity is sought. This is somewhat of a grey area because each experiment has specific motion requirements, but in general it can be said that a higher drive stiffness will;

- Increase the effective range of motion when connected to springlike parts. These springs can be an intrinsic part of the experiment, but also include wires and thermal braids.
- Increase mechanical resonances, which makes it less sensitive to position errors from floor vibrations.
- Increase the load capacity.
- Make it less vulnerable to damage.

The xy scanner has several features to improve performance in comparison to a traditional xy stack;

- A xy guide is introduced that will prevent vertical loads to damage the scanner
- Position stability in all direction is improved by increasing the resonance frequencies, thereby reducing position errors from floor vibrations. This beneficial effect also remains for xyz configurations.
  - Parallel kinematics are used to increase xy resonances
  - The xy guide raises the z resonance