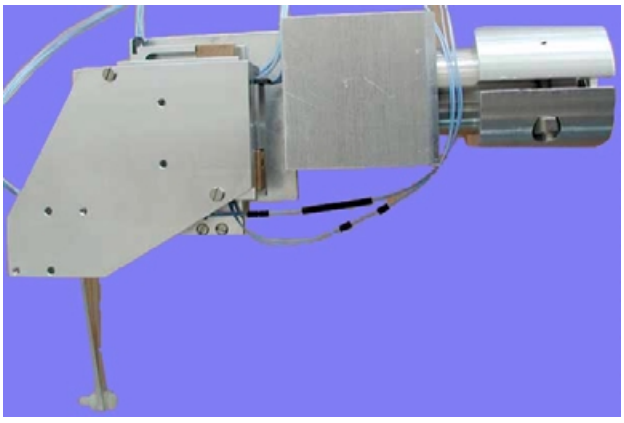
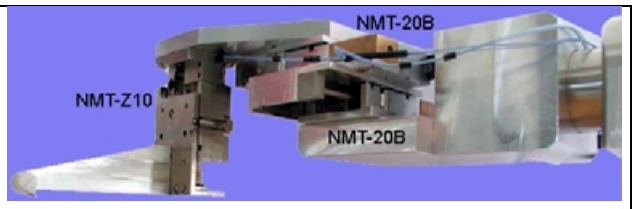
This measurement report shall give a better feeling about the behavior of our Nanorobotics manipulators.

Attention: The values described here are typical measured values, but not identical with the guaranteed values of our product specifications!

The following measurements were made in a SEM to identify movement resolution, vibration sensitivity, repeatability and absolute positioning accuracy of our Nanorobotics manipulators.

A manipulator consisting of three Nanorobotics stages was installed in a Scanning Electron Microscope. The following pictures show the manipulator in minimum and maximum stroke position:

<table>
<tr>
<td>  </td>
<td> 

NMT manipulator consisting of 2 x NMT-20B, which move a mounting plate, that carries a hanging module NMT-Z10 for the vertical movement. Positioning area: 20x20x10 mm^3. The Z-module moves a sample holder for fixing objects like a probe tip or a tool.</td>
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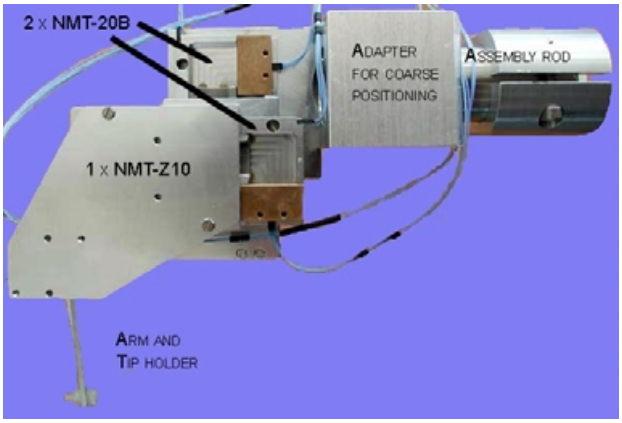
<td> 
</td>
<td>Pictures left:
View from the top with closed and opened modules. The „Adapter for coarse positioning“ permits the adjustable attachment on a rod, which ends in this case at a SEM port.

Picture top right:
View from the bottom with modules opened. This view shows also the Z-module.</td>
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</table>

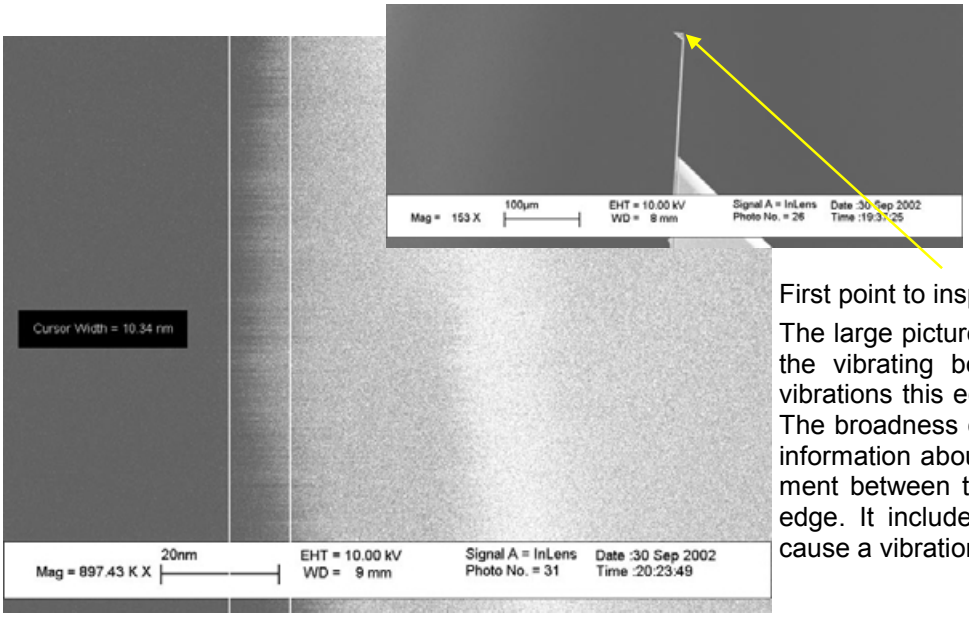
This manipulator is made out of relatively large stages. Each module contains a position sensor. For the fast assembly in the SEM the manipulator was fixed on an adapter, which can be adjustably clamped on a rod. This rod can be screwed to a port of the front door. All cables can be plugged at the side of the modules and at the feedthroughs of further ports. The assembly of this manipulator is done in a few minutes. Disadvantage of this flexible construction is its vibration sensitivity. Compared with other substantially smaller Nanorobotics modules this construction is relatively large. The assembly at the front door leads to a very long mechanical path from the tip of the manipulator to the e-beam:

tip → holder → manipulator → rod → port → front door → chamber roof → e-beam source.

This path has a length of about one meter. An assembly at the top of the chamber beside the electron gun would be substantially shorter and insensitive for vibration. So the vibration measurement results are a worst case estimation for all NMT manipulators.

Measurement of vibrations:

The NMT manipulator was equipped with a Cantilever as tool tip. The vibration of the entire manipulator was measured by SEM pictures, first at the tip of the Cantilever:

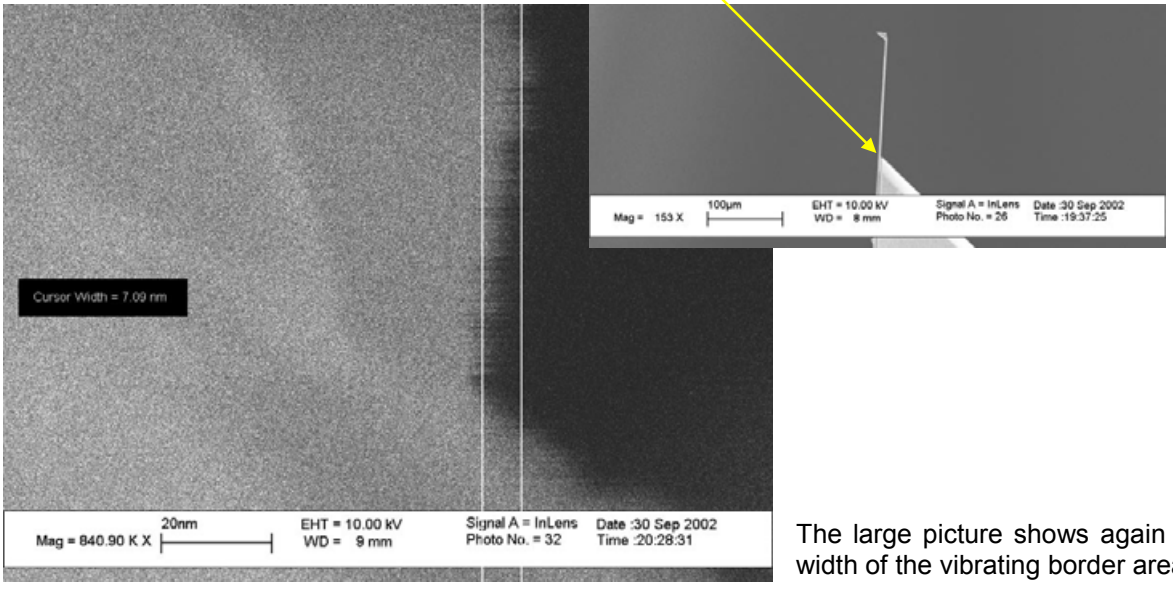


First point to inspect vibrations.

The large picture shows the width of the vibrating border area. Without vibrations this edge would be sharp. The broadness of this area gives an information about the relative movement between the e-beam and that edge. It includes all parts that can cause a vibration.

The amplitude of the vibration is about 10 nm, a value by far good enough for wafer probing. For comparison: The standard sample stage of the SEM oscillates with an amplitude of 3-5 nm.

The tip of the Cantilever can oscillate more than the rigid part of the manipulator. Therefore a second measurement at the fixed end of the Cantilever was made:



The large picture shows again the width of the vibrating border area.

Now the amplitude of the vibration is only approx. 7 nm. Thus the flexible part of the Cantilever adds a vibration of 3 nm.

The entire manipulator shows an oscillation with approx. 7 nm amplitude.
This is the worst case for all Nanorobotics manipulators
fixed in a SEM chamber with a typical damping system.

Resolution:

The resolution of the movement was determined with a SEM picture like in the case of an XY-stage, see measurement report of our XY-stages. Since the NMT manipulator uses the same high resolution Nanorobotics stages NMT 20-B for the XY-movement the resolution is the same as that of the XY-stage: Movements below 1 nm have been determined in the SEM picture. The vertical axis was made by a stage NMT–Z10 that shows a resolution in movement between 1.5 and 2.0 nm.

This resolution in movement is by far enough for all kinds of positioning in Electron or Ion Microscopes and often below the resolution of the microscope itself. This fine positioning mode of all Nanorobotics stages has a range of more than a micron without making coarse steps (except the small NMT-05L with half of that range). This property is important e.g. for wafer probing or handling of smallest objects like TEM lamellas or nanotubes.

Repeatability and absolute positioning accuracy:

When our Nanorobotics stages are equipped with a position measurement system absolute positioning is possible. The repeatability and absolute positioning accuracy mainly depend on the corresponding values of the individual stages of the manipulator. Values therefore are described in the measurement report of our XY-stages. In the combination as manipulator the loads may be assembled outside of the central axis of the stages. Then additional shear forces occur that induce cross-talk and backlash. The values for these effects depend on the individual design of the manipulator and the tool holder attached to it. In any case the excellent repeatability of the individual stages offer still extremely precise values for complete manipulators.

The absolute positioning accuracy of a manipulator with a long arm as tool holder may be worse. But in most cases the repeatability is important, not the absolute position.