

# Sample Height LVDT Sensitivity Compensation on Cypher

Notes on how the Cypher XY LVDTs are calibrated and compensated for samples of different heights.

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## 1 Background

Similar to the earlier MFP3D, the Cypher sample movement is achieved by piezos pushing on a flexure. However, unlike the MFP3D, the flexure in the Cypher is a constrained pillar. A benefit of this design is that the piezo can be directly across from the position sensing element, simplifying mechanical design and possibly reducing distortion introduced into the sensor by the flexure itself. It also means the tip does not move while imaging. However, this means that the top of the sample stage traces out an arc when moving. Because of this, samples of differing thickness travel different distances. Because the positional relationship between the piezo (moving element) and the LVDT (sensing element) does not change with varying sample thickness, this means that we need some method of compensating for different sample thicknesses.

The method used in the software for compensating uses the height of the tip as a reference for the top of the sample, since the two will be very near when interacting with the surface.

## 2 Optical Calibration

During factory testing, the optics of the Cypher head are calibrated in reference to the top surface of the sample stage on the scanner, which is set at 0m. Then, the limit switches are mapped by the amount of motor counts between the nominal 0 position and the limit switch. The optical limit switches have a very low hysteresis of just a few counts (error on the order of several tens of nm). This means that after homing, since we know the distance from the nominal 0 position and the focal length of the objective, we can calculate the distance from the sample surface to the focal plane. Because of this, we can determine the sample thickness just by focusing on the top surface viewable in the camera, or by focusing on the probe while engaged (since the probe does not move, due to the ‘sample scanner’ design). We use the calibrated sample height information to adjust the sensitivity of the LVDT in order to compensate for the scan pillar distortion.

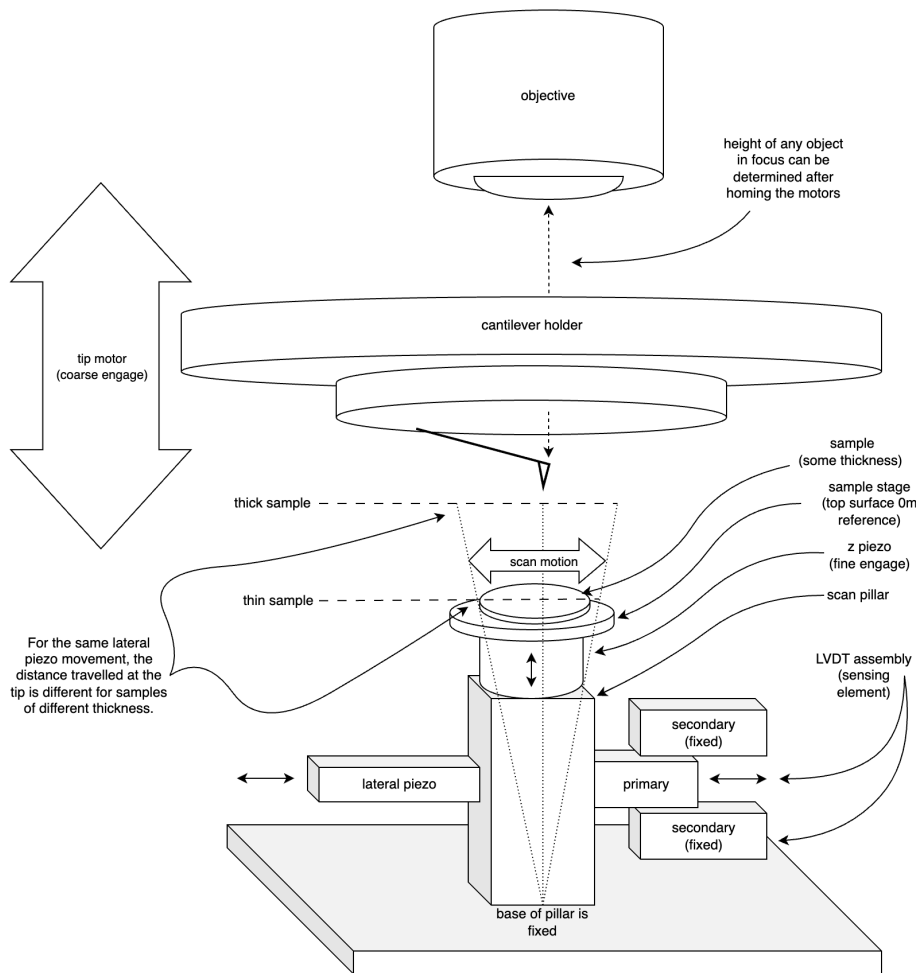


Figure 1: A mechanical schematic of the Cypher scanner, which details how sample translation and probe/sample height are measured.

### 3 Sensor Calibration

Calibrating the lateral axis LVDTs is done in three identical steps. This process involves mounting a calibration grid with a known pitch, and scanning the surface. This step is then repeated with the calibration grating mounted on a 3.6mm spacer, and again with a 5.4mm spacer. For each of these measurements, the height of the sample and the measured pitch are recorded. This sensitivity in m/V is the amount of distance travelled as experienced by the tip (on the imaged surface of the sample) per volt measured on the LVDT. Since no calibration has been done yet, it's possible to notice that there is a small difference in the pitch of the grating between the images, due to this displacement of the pillar (Fig. 2) and could be considered the "apparent sensitivity" at each height. To fix this, we adjust the sensitivity of both X and Y LVDTs for each image by taking a cross-section and measuring the pitch across multiple pits (to average any error). The adjusted sensitivity for each image section can be calculated with a simple formula  $NewSensitivity = OldSensitivity * (ActualPitch/MeasuredPitch)$ . This produces a set of three heights and three sensitivities for each axis, where thicker samples have higher LVDT sensitivities and thinner samples lower.

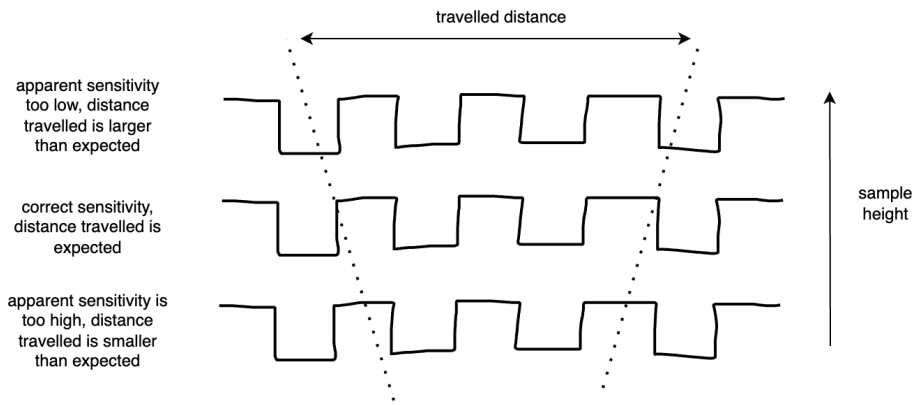


Figure 2: With a fixed sensitivity, scaling error is produced for samples that are thicker or thinner than the reference sample that was used to calculate that sensitivity.

As mentioned previously, because the LVDT does not change positions between different samples, a single calibration is not valid for samples with different thicknesses. Because the amount of displacement on the scan pillar is very small compared to the height (at most  $30\mu\text{m}$  laterally at the top of the pillar compared to a pillar height of several cm), we can consider the pillar to have no radial bending and instead just consider the pillar tilting linearly during the scan motion. This is confirmed experimentally later. In order to determine the sensitivity at any given height, we can fit the samples collected earlier to a line:  $y = m * x + b$  where  $y$  is the sensitivity ( $m_{xy}/V$ ) for any sample height  $x$  ( $m_{height}$ ), with  $m$  as the slope of the line ( $m_{xy}/m_{height}V$ ) and  $b$  the intercept ( $m_{xy}/V$ ).

The sensitivity we calculated at each sample height using a calibrated grating can be plotted to show this slope, shown in Figure 3. This also confirms that we can model the displacement of the pillar as a first order function and that no additional terms are required in order to properly fit the curve.

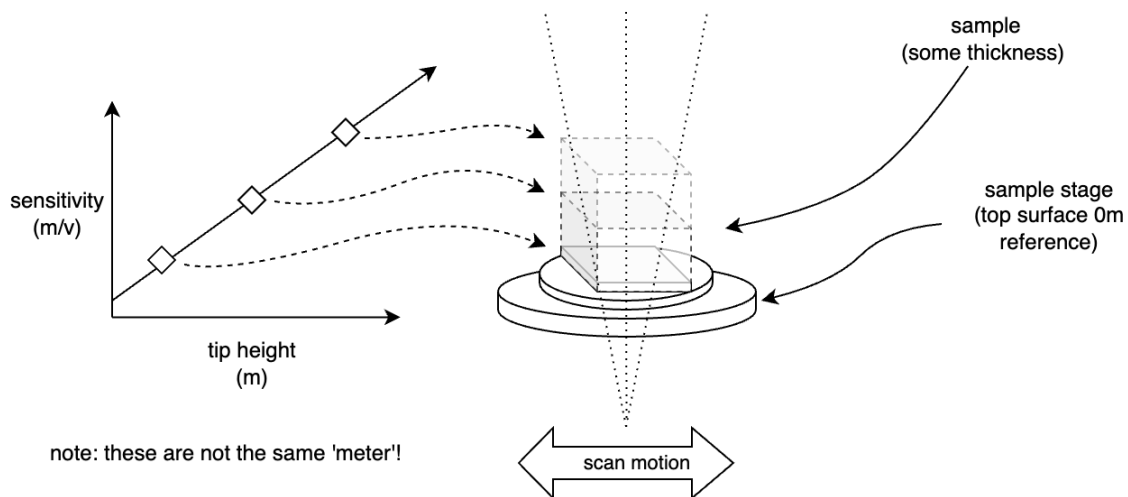


Figure 3: The samples collected can be used to fit a first order function, which is be used for dynamic setting of the sensitivity prior to imaging.

## 4 Using the Adjusted Sensitivity

Because our software uses this "adjusted sensitivity" for all closed loop lateral movement, it is stored in an easy to reach place. You can read this sensitivity and use it in any custom code by just using the value returned from the function `GV("XLVDTSens")` and `GV("YLVDTSENS")`. The GV function returns any (global) variables that can be found in the Master Variables Table, which you can find under the Programming tab in the top bar of the software. Any time the tip motor is moved, this value is updated so that you can be ready to start scanning at any time. **Something that can be misleading is that there are parameters named "XLVDTSens" and "YLVDTSENS" in the scanner infoblocks (NOT in the Master Variables Table). These are not the same as the values stored in the Master Variables Table and should not be used.**

If you are interested in manually calculating the sensitivity yourself, the "X LVDT Sens Slope", "X LVDT Sens Intercept", "Y LVDT Sens Slope", "Y LVDT Sens Intercept" are all found in the scanner infoblocks and can be read using either the device manager GUI or by reading them using `td.ReadValue` in a user function. The tip and focus motor positions can be read also from a global variable table, but it is located under Motor GUI Variables. The tip position stored in the scanner motor device group is in motor counts, which needs to be converted to real-world units with a conversion factor. It is recommended to just read the position from the Motor GUI Variables table. Keep in mind that the sensitivity should be calculated in units of meters but that some places in the software may assume units of  $\mu\text{m}$ .

## 5 Notes

Something that can be misleading is that there are parameters named "XLVDTSens" and "YLVDTSENS" in the scanner infoblocks (NOT in the Master Variables Table). These are special values and should only be used in certain circumstances. In essence, these fields store a value that would be the sensitivity at some nominal height. This is used for internal measurements, like doing noise measurements, where the actual sensor noise floor does not depend on the sample thickness, but does require a sensitivity in order to quantify the noise in terms of real-world displacement.

You may also ask why we don't include the Z voltage as some part of the function to determine the sensitivity at a specific height. One issue with this is that it would require knowing what the surface looks like in advance, or at least re-calculating the sensitivity at every pixel of the image. Another is that for resolution reasons, it does not matter because that amount of precision could not be resolved. The Z axis on Cypher has a range of roughly  $5\mu\text{m}$ . On the scale of the sample thickness (several mm) it is a very small contributor to the distortion experienced by the scanning pillar.