

Technical Procedure: High Aspect Ratio Tomography (HART)

1 Abstract

This document describes the HART technique which can be used to improve image quality and reduce scanning time for high aspect ratio samples. It allows user to acquire higher angular density projections for the long views, while preserving the total number of projections. Theoretical background and operational procedures are described. Two use cases are discussed: improve image quality and reduce scan time.

2 Introduction

High aspect ratio tomography (HART) is developed for better imaging of samples that are thin and wide, for example, semiconductor packages. Normal tomography uses evenly distributed projections along the rotation angles. However many features could be obscured due to low signal to noise ratio and streak artifacts along the long views which are critical for visualization. HART allows user to acquire more projections for long views than short views so that these features, such as bump cracks, are better visualized. In addition, various artifacts, mostly ‘streaks’, are largely reduced because of increased number of long views. The main advantages of the HART technique over a normal tomography are:

- i) Improve image quality for the same scan time.
- ii) Generate equal or better results for a shorter scan time.

2.1 Applicable Platform

VersaXRM-520, and
Scout-and-Scan™ (V10.6 or above)

2.2 Definition

- 1) Long View = Projection image through the longer beam path through the sample
- 2) Short View = Projection image through the shorter beam path through the sample
- 3) Long View Transmission = Transmission through the long views
- 4) Short View Transmission = Transmission through the short Views
- 5) HART Width = angular span of ‘Gaussian’ shaped HVAT curve (Figure 1)
- 6) HART Strength = Multiplicative factor over the standard angle increment for each angle, reduces theta stage rotation by this factor (Figure 1)
- 7) HART Center = angle where angular speed of the theta stage is minimized – Long view angle (Figure1)

2.3 Operation Theory

During acquisition setup, the software calculates new angles for each projection based on the HART parameters chosen by user. Each projection can have a unique angular span. When applying reference scans, no compensation will need to be made for the different angles, as the exposure will not change. In reconstruction, the software automatically compensates for any input angular distribution. No other corrections need to be made.

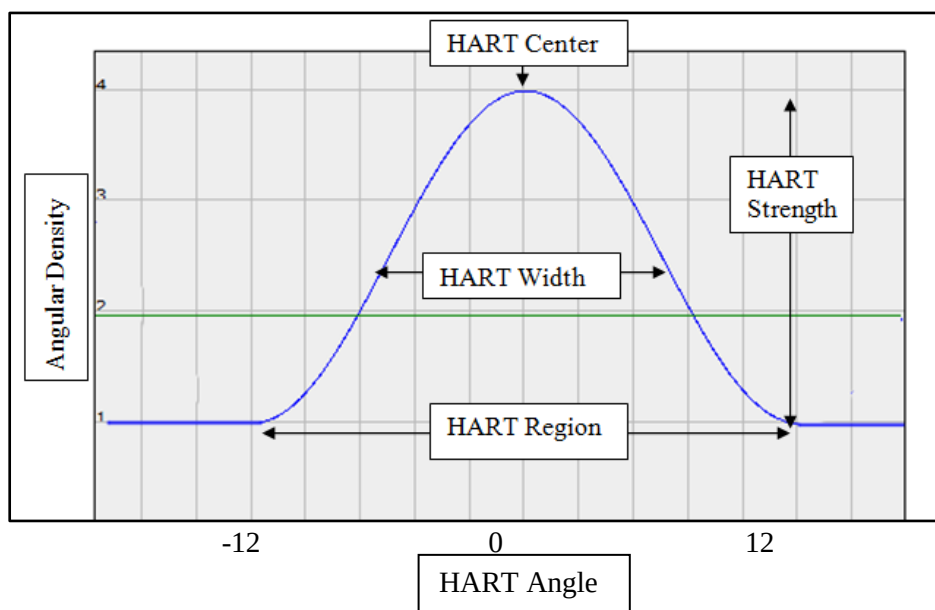


Figure 1: Theta stage slows down in the HART region and reaches at the minimum, defined by the HART strength, at the HART center angle.

Figure 1 illustrates how angular speed of theta stage to be adjusted to achieve variable angle scans. In the Gaussian-shaped HART, the HART region is composed of projections with variable angular spans. The angular density increases to the full strength at the HART center, long view angles. Single and double HART regions in a tomography are supported.

3 Overview

Proper use of the HART technique follows these basic steps:

- Determine if the sample is suitable for HART
- Select parameters and run HART
- Reconstruct and Analyze HART data

4 Procedure

4.1 Determine if the sample is suitable for HART

HART is only suitable for flat samples and the region of interest (ROI) is best viewed by long views. A symmetrical specimen, for example, a cylinder or cube-shaped sample is not suitable for HART.

The purpose of the following steps is to determine whether a sample is suitable for HART. However, the improvement of image quality by HART is strongly dependent on other factors: region of interest (ex. defect types), transmission and other imaging parameters. A successful HART application should be satisfied with: **i) The transmission in the short views is > 4 times as much as in the long views; and ii) the transmission is at least 1% at the long views.**

1. Mount a flat sample straightly: either parallel to the beam path (0 degree as long views) or vertical to the beam path (0 degree as long views).
2. Locate the region of interest (ROI) with desired objective:
Note: Transmission could slightly vary by different objectives
3. Set source and detector distance
4. Select proper source filter determine kV
Note: rotate the sample to 45 degree for selecting source filter and determining energy.
5. Obtain transmissions at long and short views:
 - a) Move the theta stage to 0 degree, take a single shot with the exposure time which makes at least 5,000 counts through the ROI, and Click the "Ref" button. The software automatically acquires a proper reference image and calculates transmission. Move the cursor to the ROI and mark the transmission number.
 - b) Move the theta stage to 90 degree, take a single shot with the exposure time which makes at least 5,000 counts through the ROI, and Click the "Ref" button. The software automatically acquires a proper reference image and calculates transmission. Move the cursor to the ROI and mark the transmission number.
 - c) Divide the transmission of the short view by the long view.

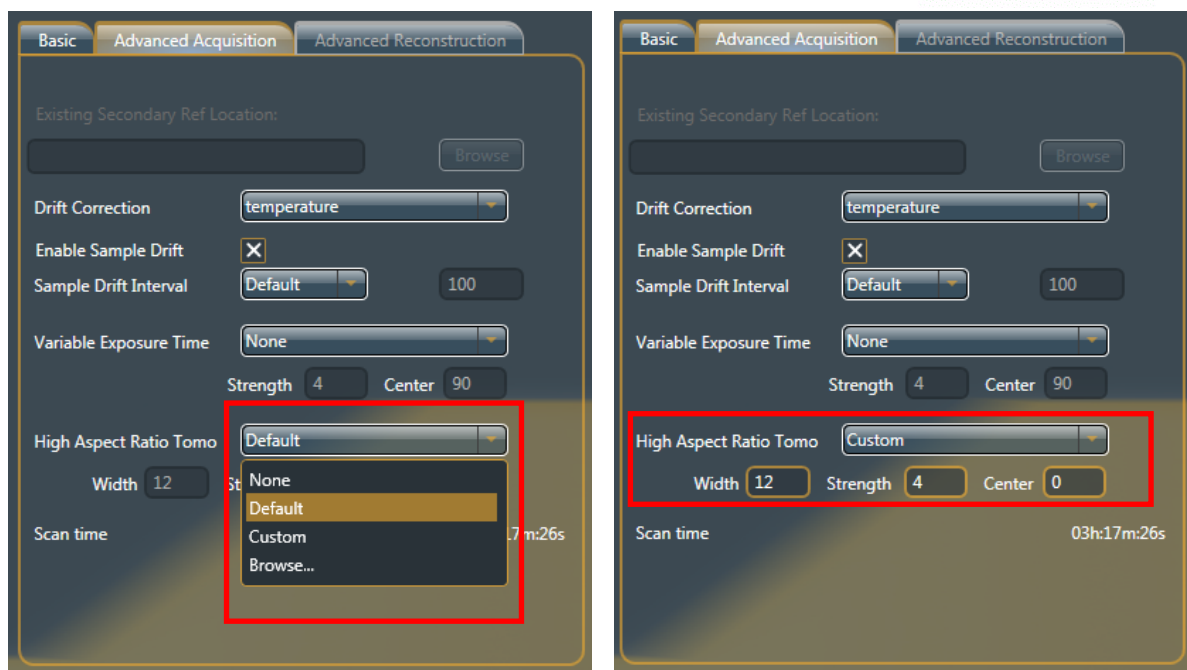


Figure 2: Set HART parameters in Scan page of Scout-and-ScanTM.

If the transmission at the long view is < 1%, or the transmission at the short view is less than 4 times as the transmission at the long view, please consider to perform a normal tomography because the HART advantages may not fully realized in this sample. If the two criteria are satisfied, perform the next step.

4.2 Select HART parameters and Run

6. Set exposure time, scan angle, and # of projections.
It is recommended to use the “180_fan” angle option for a high aspect ratio sample.
7. Set HART parameters
 - a) Click “Advanced Acquisition” tab in Scan page.
 - b) Select one of four options in “High Aspect Ratio Tomo” (Figure 2 Left)
 - i) None (the Default option) - run normal, equally-spaced, projection tomography
 - ii) Default – a set of HART parameters: Width 12 (half of the HART region), Strength 4 (Multiplicative factor), Center 90 (long view angle).
This setting is good starting point for imaging new sample; Center angle being 90 means that two HART regions at 90 and -90 degrees are selected; These parameters cannot be changed by user.
 - iii) Customer – allows user to enter non-default HART parameters (Figure 2 Right).
 - iv) Browse – allows user to load an existing HART file.
8. Run HART

4.3 Reconstruct and Analyze HART data

For initial scans of a new sample, performing the following steps will help user understand the benefit of HART scans over normal scans. It is possible to further optimize scan parameters based on the analyzed results.

9. Verify angular span change
This step helps validate if the movement of theta axis complies with the HART scan.
 - a) Open raw projection txrm file acquired by HART with XMController.
 - b) Click “Image Control”, “Axes” tab and select “sample theta” in the drop-down manual.
 - c) Select “plot graph”: a plot of theta axis position will pop-up (Figure 3).
 - d) If “180+fan” scan angle is chosen and HART center is “0”, one HART region (Figure 3 Right) is shown in the red box. If “180+fan” scan angle is chosen, and HART center is “90”, two HART regions should be shown.
10. Reconstruction
The software automatically compensates for variable angular distribution of projections. No special attention is needed for reconstructing a HART data. If compare a HART data with a normal tomography data, same beam hardening correction constant and Gaussian filter are recommended to use.
11. Analyze HART data
The two main advantages of the HART technique are: *i) Improve image quality for the same scan time; ii) Generate equal or better results with reduced scan time.* Performing the following steps helps user to understand how a sample benefits from HART. The analysis is also useful for further optimizing the imaging quality.

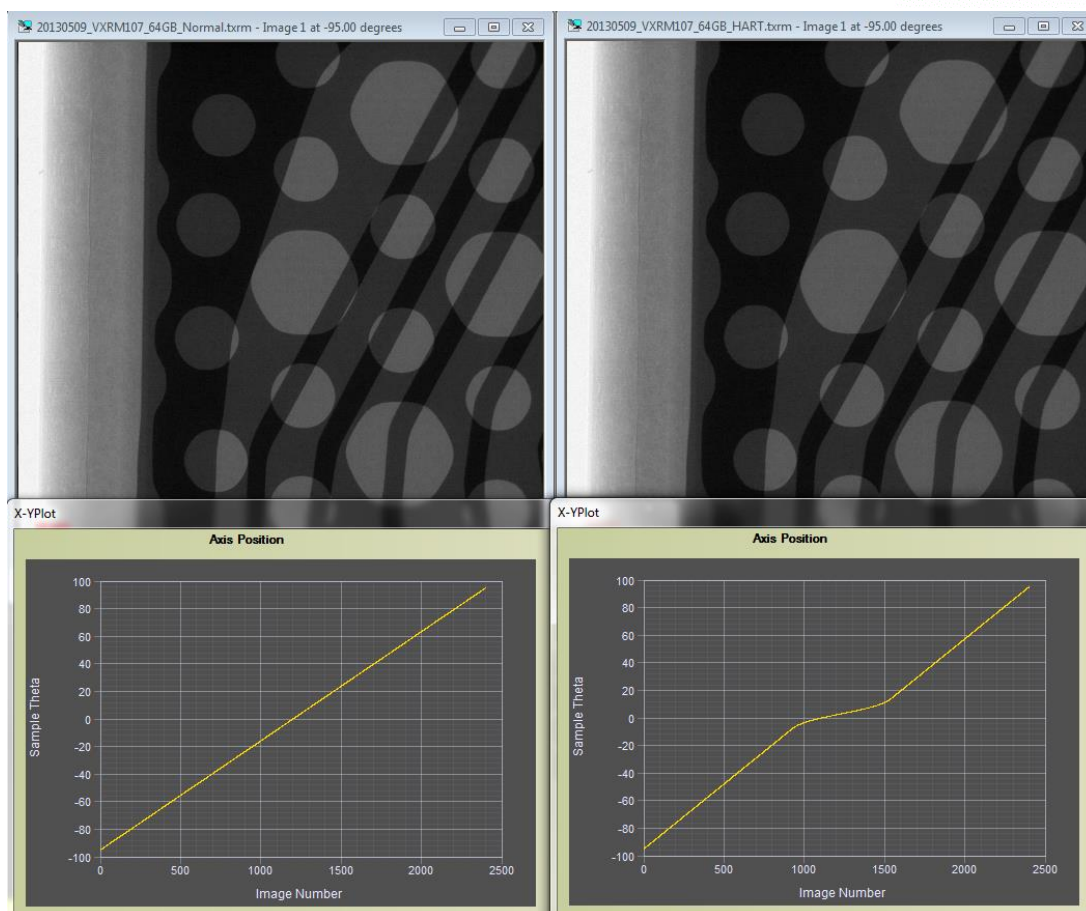


Figure 3: The plot of Theta axis Vs. image number shows the change of angular density for HART scan (Right), and no change of angular spacing in a normal tomography (Left).

i. Improve image quality with the same scan time

To make the comparison of a HART data with a normal tomography data, the scan condition must be kept the same. This includes field of view, objective, pixel size, energy, power, reference, exposure time and number of projections.

In this use case here, the only difference is that HART uses variable angular spanned projections while a normal tomography uses equivalent angular spacing.

- a) Open reconstructed .txm files from HART and normal tomography with XMController
- b) Locate same features in both files by typing in the same slice number
- c) Adjust histogram (if needed) to highlight the feature in ROI.
- d) Compare the results
 - i) Visually check the reduction of streaks (often parallel to the long views) in HART image. If the streaks are significantly reduced, HART is successful.

For example, the HART image (Figure 4 Right) has much less pronounced streaks than the non-HART image (Figure 4 Left). The HART technique for improving image quality is demonstrated.

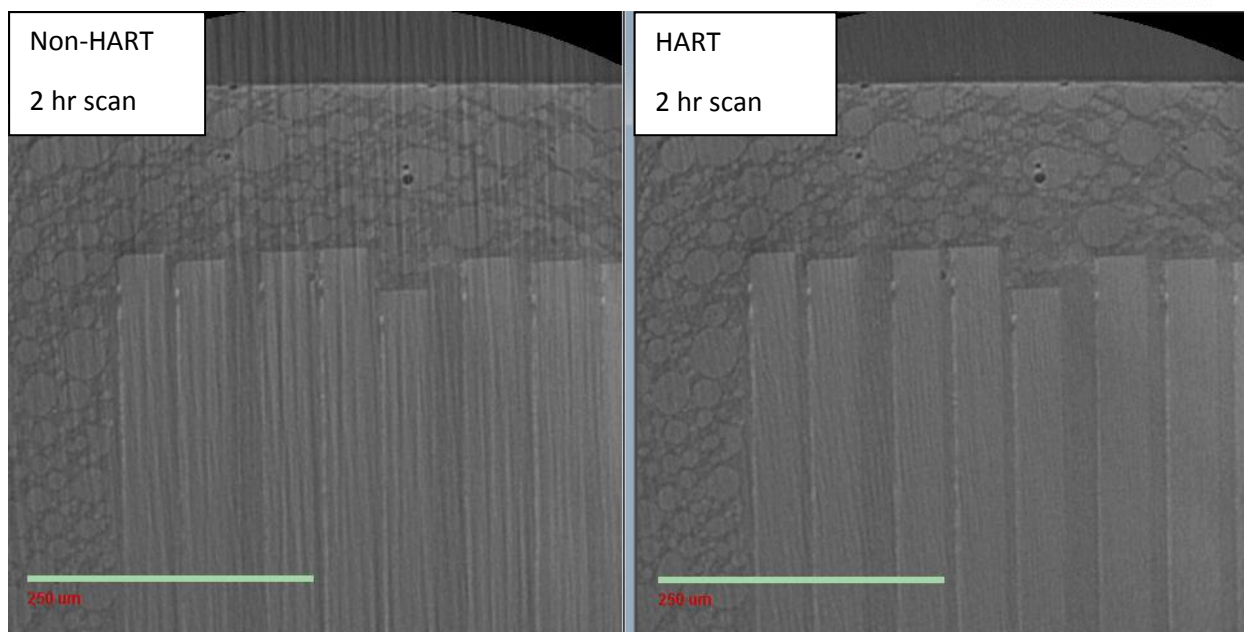


Figure 4: HART (Right) results in better image quality for a MicroSD card sample than normal tomography (Left) with the same scan time. The scan condition is: 4X, 1.1 μm pixel size, 60 kV/5W, 5 sec exposure time, 1,200 projection, beam hardening 0, and Gaussian 0.7 during recon. HART parameters are: width 12, strength 4, and center 0.

Note: The “steak” artifacts are often present in X-ray tomography images of high aspect ratio samples, particularly in high-throughput scans. It mainly results from under-sampling in angular spaces along the long views. HART is useful to reduce this type of artifacts.

- ii) Visualize the clarity of the features of interest. If HART image reveals better visibility on the structures than normal tomography image, HART is useful for this type of sample.

For example, one feature of interest in Figure 4 is the spacing between two dies. HART image (Figure 4 Right) appears much better than non-HART image for visualizing the die space. The die space in non-HART image (Figure 4 Left) becomes obscured due to the presence of streak artifacts. The HART technique for improving image quality is demonstrated.

ii. **Generate equal or better results with reduced scan time**

To make the comparison of a HART data with a normal tomography data, the scan condition must be kept the same. This includes field of view, objective, pixel size, energy, power, reference, exposure time and number of projections.

In this use case here, the only difference is that HART uses less number of projections (so shorter scan time) than a normal tomography.

- a) Open reconstructed txd files from HART and normal tomography with XMController
- b) Locate same features in both files by typing in the same slice number

- c) Adjust histogram (if needed) to highlight the features of interest.
- d) Compare the results
 - i) Visually check the streak presence from both images. If the streak intensity in HART image is equal or less than in normal tomography image, HART is successful.
For example, the streaks in the HART image (Figure 5 Right) appear to have similar intensity and abundance to the non-HART image (Figure 5 Left). The HART technique is demonstrated to improve scan throughput.
 - ii) Visualize the features of interest from both images. If HART image reveals equal or better results on the structures, HART is successful.
For example, one feature of interest in Figure 5 is the spacing between two dies. The HART image (Right) reveals similar quality to the non-HART image (Left) for visualizing the die space. The HART technique is demonstrated to improve scan throughput.
- e) Scan sample with further reduced imaging time

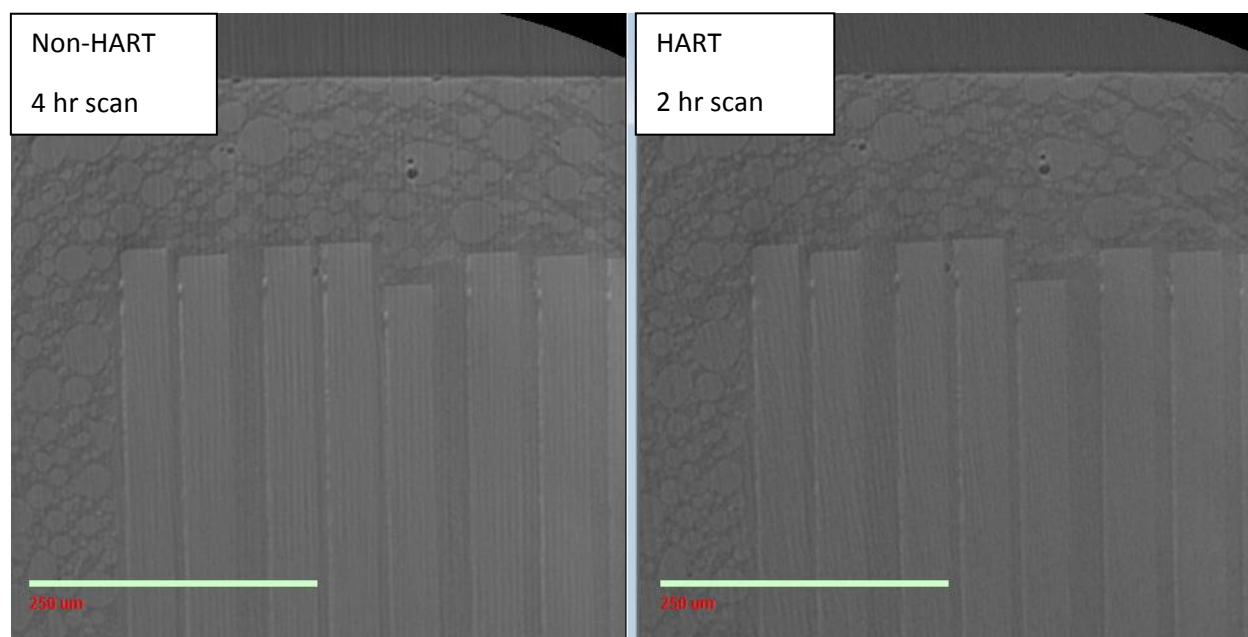


Figure 5: The HART image (Right) has the equal image quality with 50% of the scan time used in the normal tomography (Left). The scan condition is: 4X, 1.1 μm pixel size, 60 kV/5W, 5 sec exposure time, 1,200 projection, beam hardening 0, and Gaussian 0.7 during recon. HART parameters are: width 12, strength 4, and center 0.

5. Summary

Applying the HART technique to high aspect ratio samples is highly effective for improving image quality and/or reducing scan time. This document has outlined the procedure for properly collecting 3D tomography images utilizing HART. A few use cases are presented.