Document purpose

The purpose of this document is to describe the tests performed to determine the technical specifications of the S lynx system using SensoSCAN 6.2 and to summarize such specifications.

S lynx

S lynx is a non-contact 3D surface profiler for both industry and research. S lynx is able to measure different textures, structures, roughness and waviness, all across varying surface scales.

The system uses the 3-in-1 technologies, Confocal, Vertical Scanning Interferometry (VSI) and Focus Variation.

Set-up

To perform the tests, we needed to prepare the set-up of the system. In the bottom of the system we had an air vibration isolation table, and on this table laid a smaller electronic vibration isolation table. Above this system we had the microscope, which includes a x-y moving plate and the possibility to adjust the tip-tilt.

Figure 1. Set-up.

Objectives

In the performance tests a set of six different objectives was used. This set was formed by 5XTI, 10XDI, 20XDI, 50XDI and 100XDI interferometric objectives and 5XEPI, 10XEPI, 20XEPI, 50XEPI, 100XEPI and 150XEPI objectives.

Standards used

Most of the standards used were provided by the National Physical Laboratory (NPL) located in Teddington, UK. These standards are insured to be traceable, which means that the values exhibited by the samples are guaranteed to be accurate with high certainty.

Areal Cross Grating

ACG-2.1, ACG-1.2 and ACG-0.5 consist of five cross gratings with pitches ranging from 16 µm to 400 µm, as it follows in the next figure:

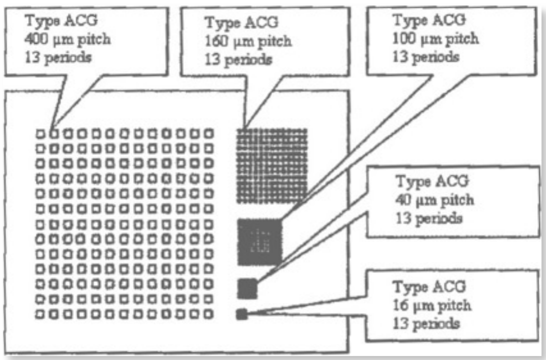


Figure 2. Schematic design of NPL type ACG.

Step height measurements were made on the central protrusion of the 160 µm pitch cross grating on all three ACGs. Three measurements were made and the mean height is given in Table.

Areal Star Pattern

The ASG includes a combination of two areal star-shape grooves of 20 µm and 70 µm radius and thirteen cross gratings with pitches ranging from 20 µm to 600 µm. The design is shown in next figure:

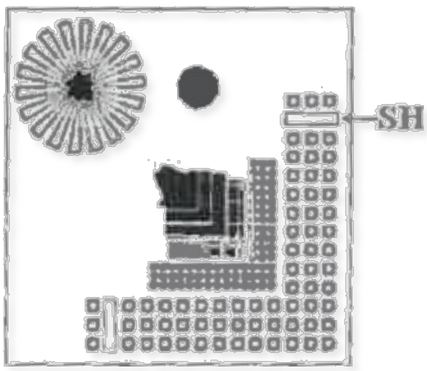


Figure 3. Schematic design of the NPL type ASG-0.2.

Step height measurements were made at the location identified as SH in Figure 3. Three measurements were made and the mean height of the three measurements is shown in Table 1.

Model number	ACG calibration date	Nominal step height (nm)	Measured mean step height (nm)	Expanded uncertainty (nm)	Coverage factor (k)
ACG-2.1	Sep 25, 2013	2100	2048.2	4.1	2.0
ACG-1.2	Sep 24, 2013	1200	1264.0	4.1	2.0
ACG-0.5	Sep 26, 2013	500	499.7	4.1	2.0
ASP-0.2	Sep 27, 2013	200	186.2	2.4	2.0

Table 1. Step height measurement results.

Due to the low magnification of the objectives used in the studies, we proceeded to measure the step height by extracting a circular profile in the 70 µm radius star-shaped groove instead of measuring the step height.

Areal Irregular

These standards include two pseudo-random surfaces with nominally the same surface texture. The working areas of the pseudo-random surfaces are 1.5 mm x 1.5 mm.

Figure 4. NPL type B-70.

The top random surface, see Figure, was measured and the areal parameters evaluated. The mean values of the areal parameters were calculated from nine measurements and the results are given in the next table:

Model number	Calibration date	Parameter	Mean measured value (nm)	Expanded uncertainty (nm)	Coverage factor (k)
AIR-B40	Sep 6, 2013	*Sa*	790.7	26.3	2.0
		Sq	1008.1	21.6	2.0
		Sz	7437.6	439.7	2.4

Table 2. Areal irregular measurements results.

VLSI standards

These standards were accredited by the National Voluntary Laboratory Accreditation Program for the specific step height.

Model number	Mean Value (nm)	Expanded Uncertainty (nm)
SHS-80 QC	10.1	0.5
SHS-440 QC	44.3	0.6
SHS-9400 QC	941.6	5.5
SHS-8.0 QC	7616	62
SHS-50.0 Q	48643	263

Figure 5. VLSI standards measurement results.

The three first standards in this table were categorized as thin step height, so they were manufactured with the configuration shown in Figure 6, while the two last standards were categorized as thick step height, and its configuration is shown in Figure 7.

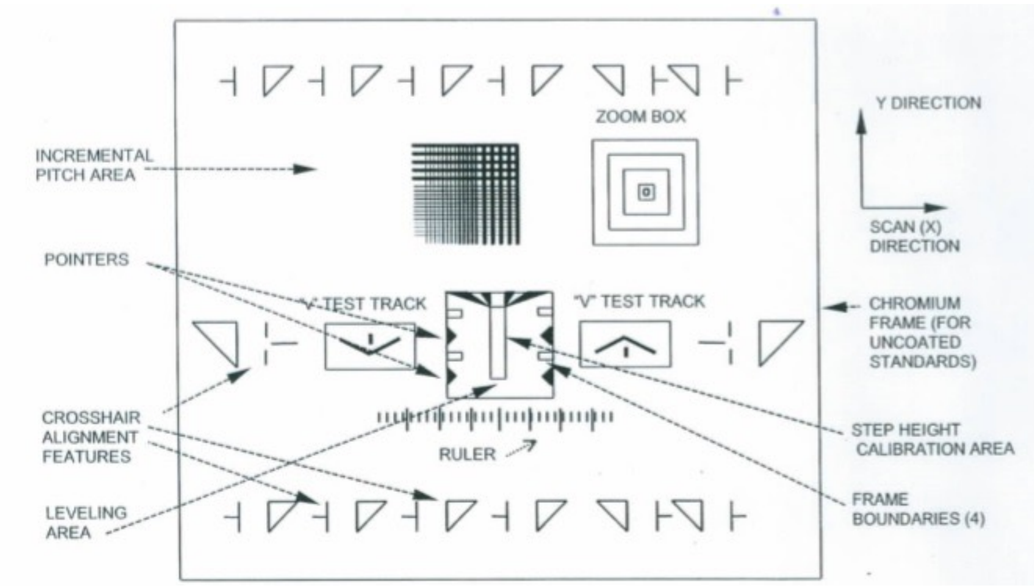


Figure 6. VLSI thin step height configuration.

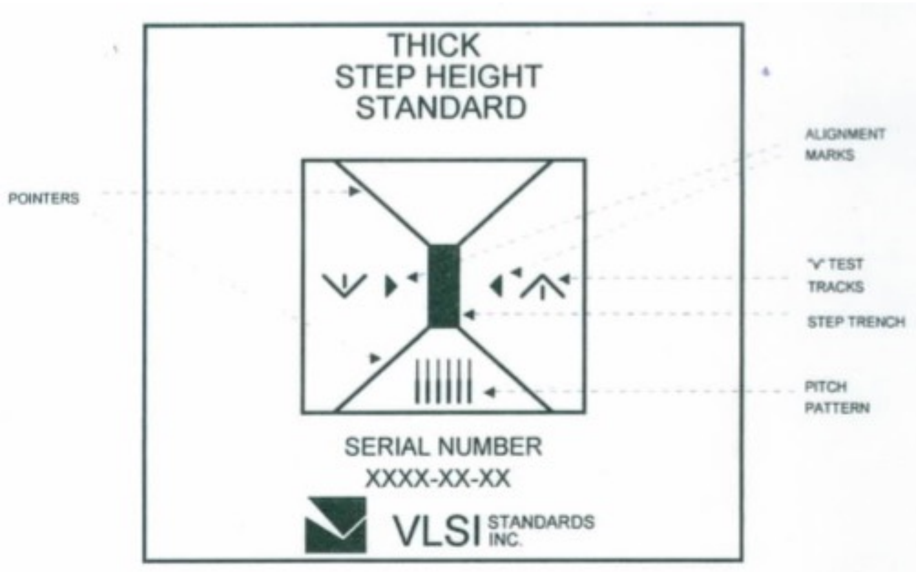


Figure 7. VLSI thick step height configuration.

Tests performed

All measurements were performed using the VSI technique. The following table resumes the tests performed:

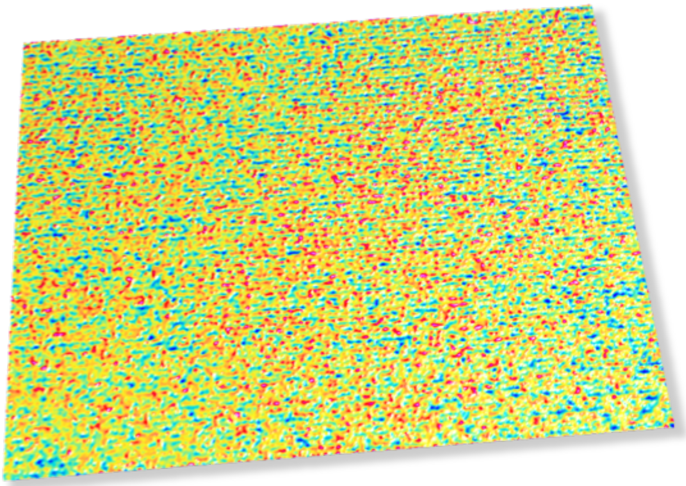
	Specification tested	Standards Used	Objectives	Repetitions
1	Noise Level	SiC Mirror	5XTI, 10XDI, 20XDI, 50XDI, 100XDI; 5XEPI, 10XEPI, 20XEPI, 50XEPI, 100XEPI, 150XEPI	1
2	Sq Repeatability	Areal Cross Grating (ACG) Areal Star Pattern (ASG)	20XDI; 5XEPI, 10XEPI, 20XEPI, 50XEPI, 100XEPI, 150XEPI	30
		Areal Irregular (AIR)	20XDI, 50XEPI	
3	Linearity	Areal Cross Grating Areal Star Patter	20XDI, 50XEPI	10
		Areal Cross Grating Areal Star Pattern VLSI standards	20XDI, 50XEPI	10
4	Vibration	VLSI standards Areal Irregular	20XDI, 50XEPI	10
5	Temperature	VLSI standards	20XDI, 50XEPI	10

Table 3. Test Summary

Tests results

Test 1. Instrument noise

The test was performed on a SiC mirror. The position of the microscope's motor was fixed around the absolute position of -20.0000 mm. The test was made by extracting one topography to a topography of the same field.



With the confocal technique, the entire set of EPI objectives was used (5X, 10X, 20X, 50X, 100X and 150X). In this case, each topography was made by averaging different amount of times, obtaining the following results:

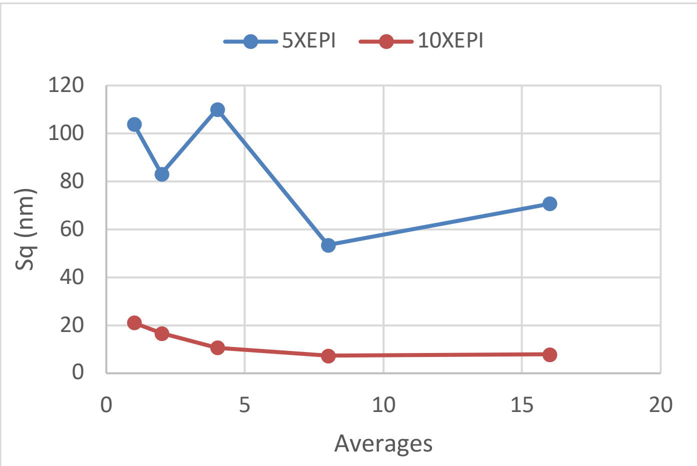


Figure 8. Confocal instrument noise.

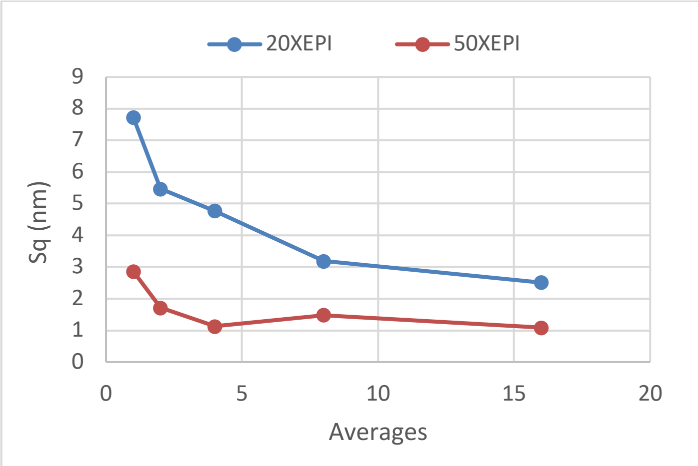


Figure 9. Confocal instrument noise.

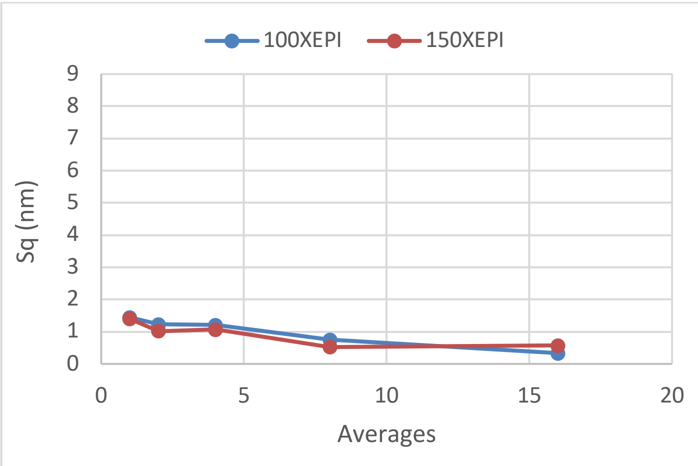


Figure 10. Confocal instrument noise

With the interferometric technique, the objectives used were 5XTI, 10XDI, 20XDI, 50XDI and 100XDI with no averaging.

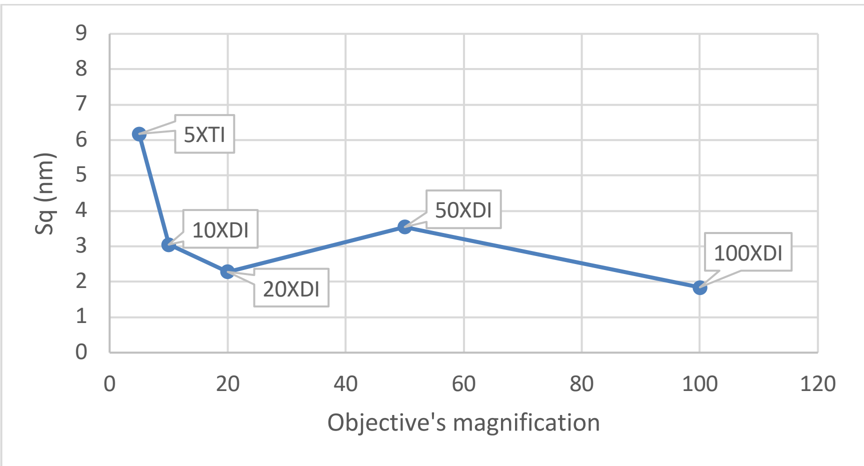


Figure 11. Interferometric instrument noise

Test 2. Vertical Resolution

The aim of this test is to specify the accuracy and repeatability. The test was performed at -20.0000 mm stage height and there were between two and four fringes within the FOV perpendicular to the step. The number of measurements made was 30. Two different studies are made: step height and roughness.

Test 2.1. Step Height

The standards used in this test were provided by NFL and were ACG-2.1, ACG-1.2, ACG-0.5 and ASP-0.2 and different objectives were used on each step height, as shown in Figure 12.

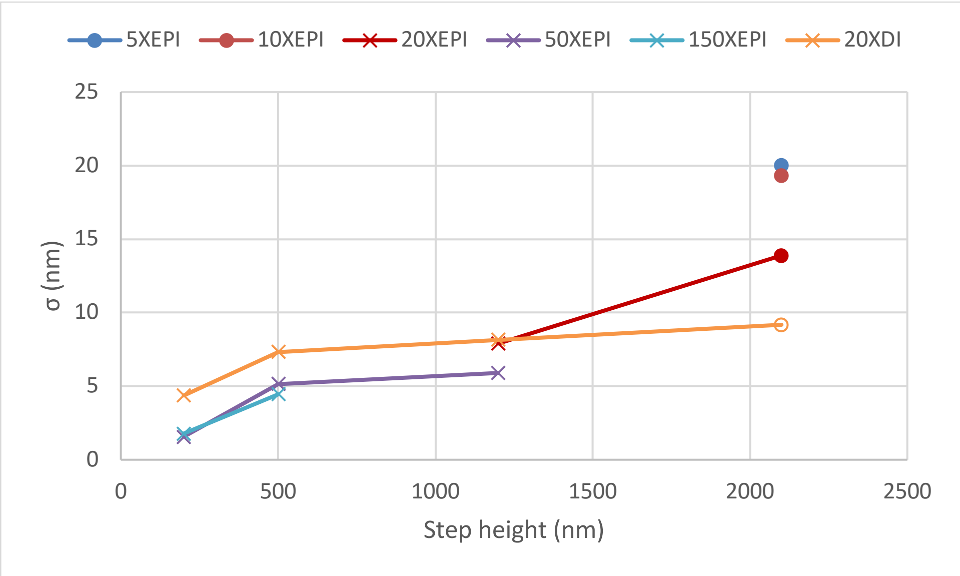


Figure 12. Value of standard deviation over step height with different objectives.

Test 2.2. Roughness

The standard used in this test was provided by NPL and was AIR-B40 while the objectives used were 20XDI, 20XEPI and 50XEPI. The random surface was analyzed in the following way:

- Level the surface using least squares plane
- S-filter nesting index of 8 µm (Gaussian)
- L-filter nesting index of 0.8 µm (Gaussian)

	Height parameter: Sq	
	Average (nm)	Standard Deviation (nm)
20XDI	1054.6	3.1
20XEPI	1007.7	1.5
50XDI	1076.2	3.0

Table 4. Average repeatability value Sq of 30 repetitions.

Test 3. Linearity

Test 3.1. Linearity along the Z axis

On this study, the same step height was measured in different height positions of the stage. Measurements started at -39.000 mm and ended at -1.000 mm in steps of approximately 1 mm. The standard used in this test was SHS-9400 QC. The objectives used were 50XEPI and 20XDI. The room's temperature was in the range of 23.5-23.9 ºC. The number of measurements was 10 for each position.

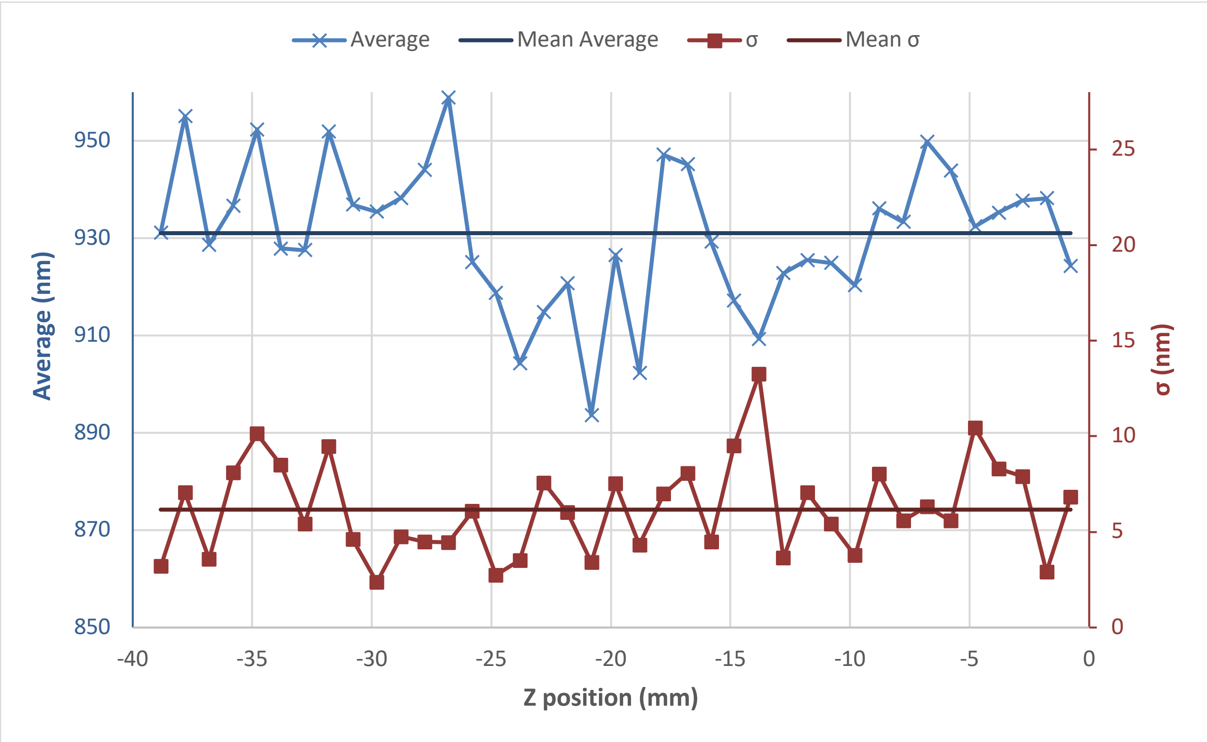


Figure 13. SHS-9400 QC step height with 50XEPI objective.

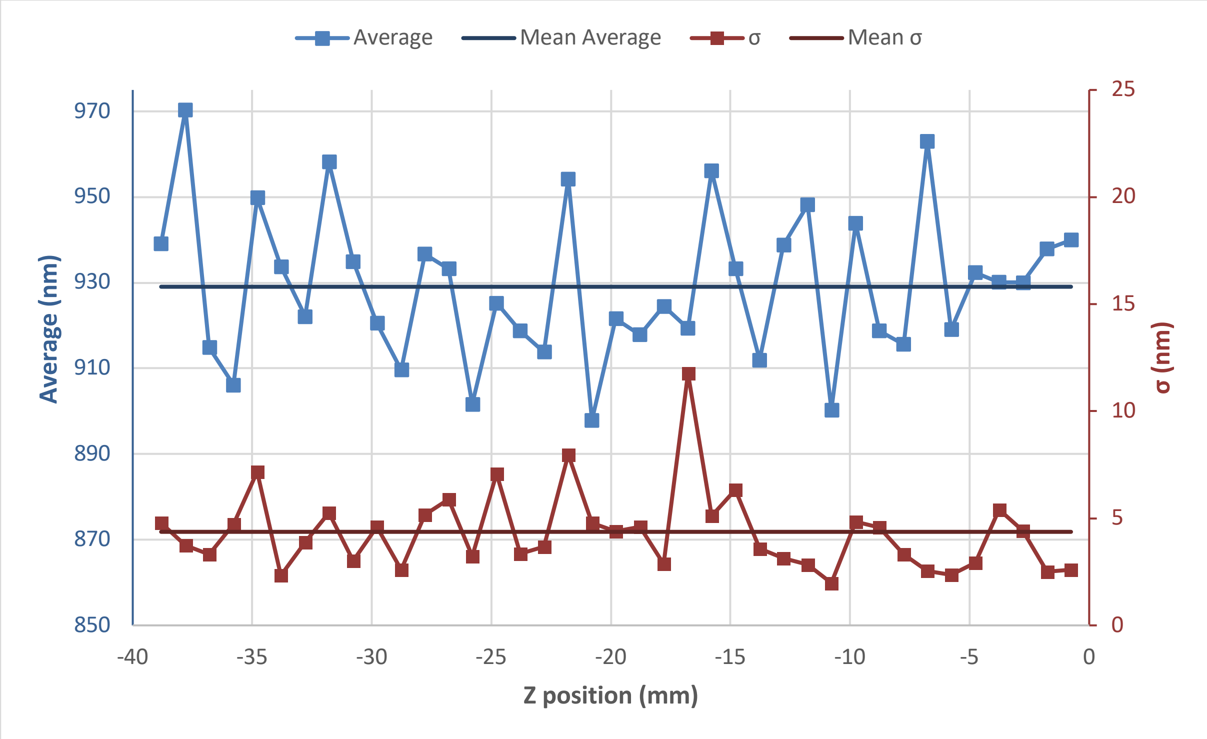


Figure 14. SHS-9400 QC step height with 20XDI objective.

All step height results are summarized in the following table, which contains for each step, the mean of gall measurement's average, the standard deviation of all averages, the mean standard deviation of every measurement and average's peak-to-valley.

	50XEPI	20XDI
Mean Average	931.0 nm	929.1 nm
Standard Deviation of Mean Average	14.7 nm	17.6 nm
Mean Standard Deviation	11.5 nm	7.6 nm
Average's P-V	65.3 nm	72.4 nm

Table 5. Summary of linearity test values on SHS-9400.

Test 3.2. Linearity along stages

In this study, the behavior of the microscope in the different four stages will be analyzed near the position of -20.000 mm.

	20XDI		50XEPI	
	Average (nm)	σ (nm)	Average (nm)	σ (nm)
Position 1	930.1	3.6	918.5	2.9
Position 2	922.6	3.1	952.1	4.0
Position 3	931.3	1.6	910.1	2.8
Position 4	946.7	2.4	912.2	2.2

Table 6. SHS-9400 on different column positions.

Test 3.2. Linearity along Z step height

In this study, the Z stoke was set at the position of -20.000 mm, the room's temperature was 23.4 ºC and for each step a series of 10 measures was made with the 20XDI objective. All standards used are indexed in this table:

Step Height	Theoretical Value (nm)	Step Height	Theoretical Value (nm)
SHS-80QC	10.1	ACG-1.2	1264.0
SHS-44QC	44.3	ACG-2.1	2048.2
ASP-0.2	186.2	SHS-8.0QC	7616
ACG-0.5	499.7	SHS-50.0Q	48643
SHS-9400	941.6		

Table 7. Set of step heights.

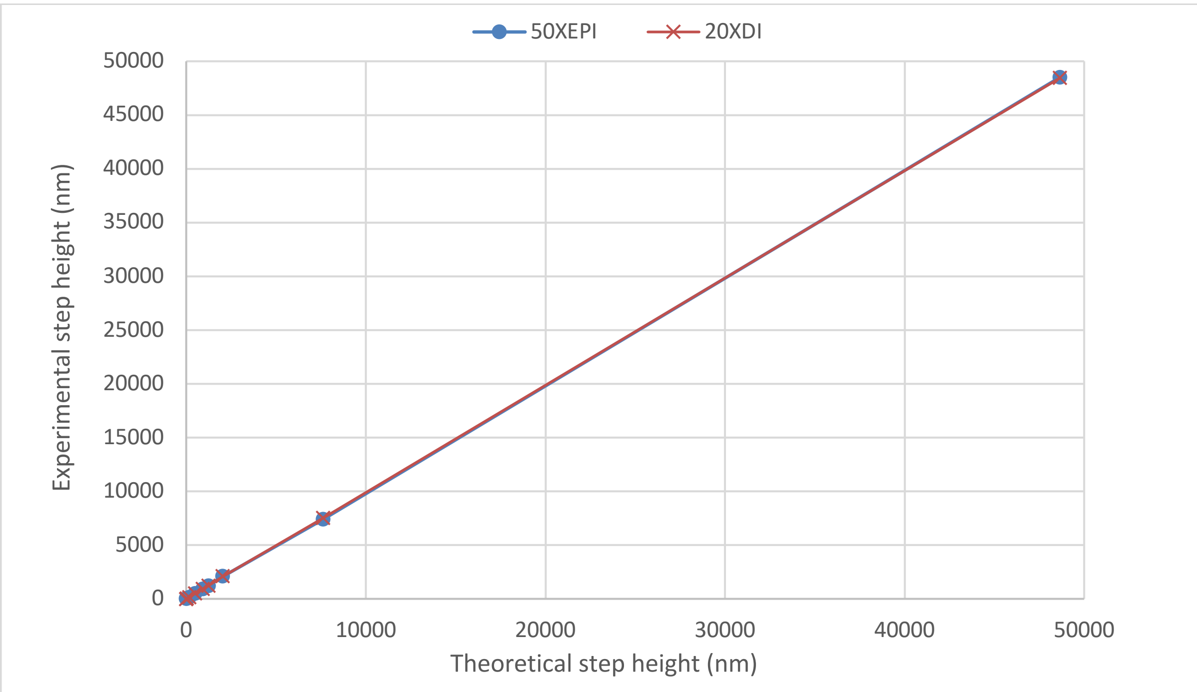


Figure 15. Theoretical vs Experimental step height value.

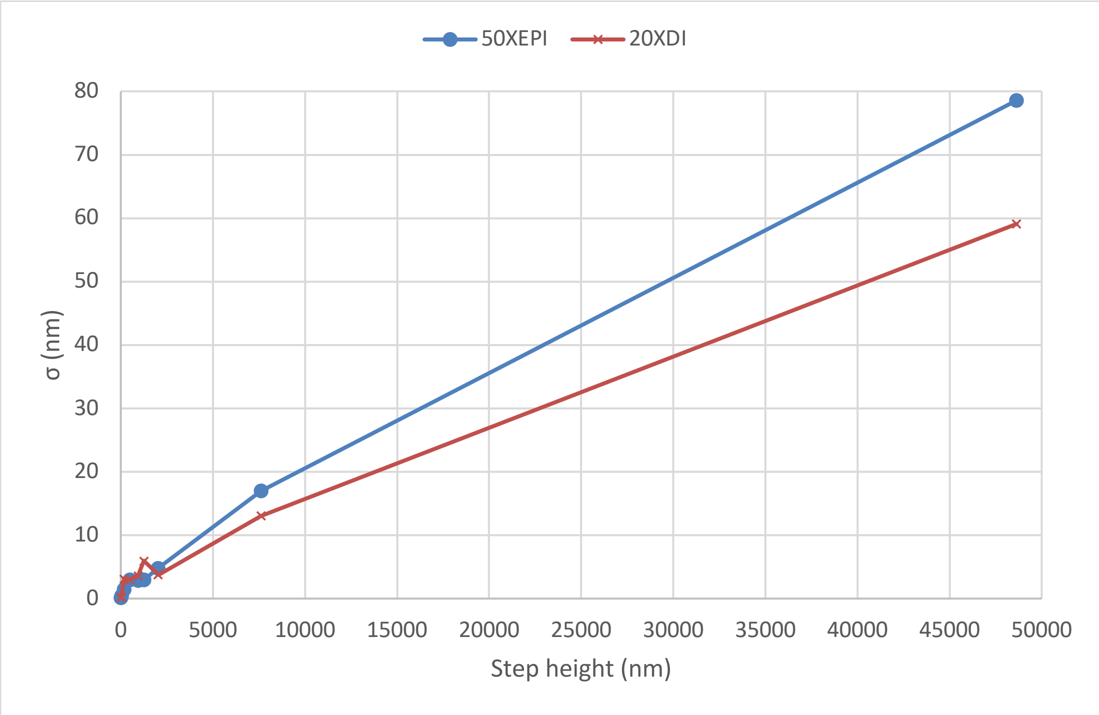


Figure 16. Standard deviation of step heights.

As the two curves are extremely near it is needed to make a different analysis. Therefore, we calculate the step height error (theoretical minus experimental value).

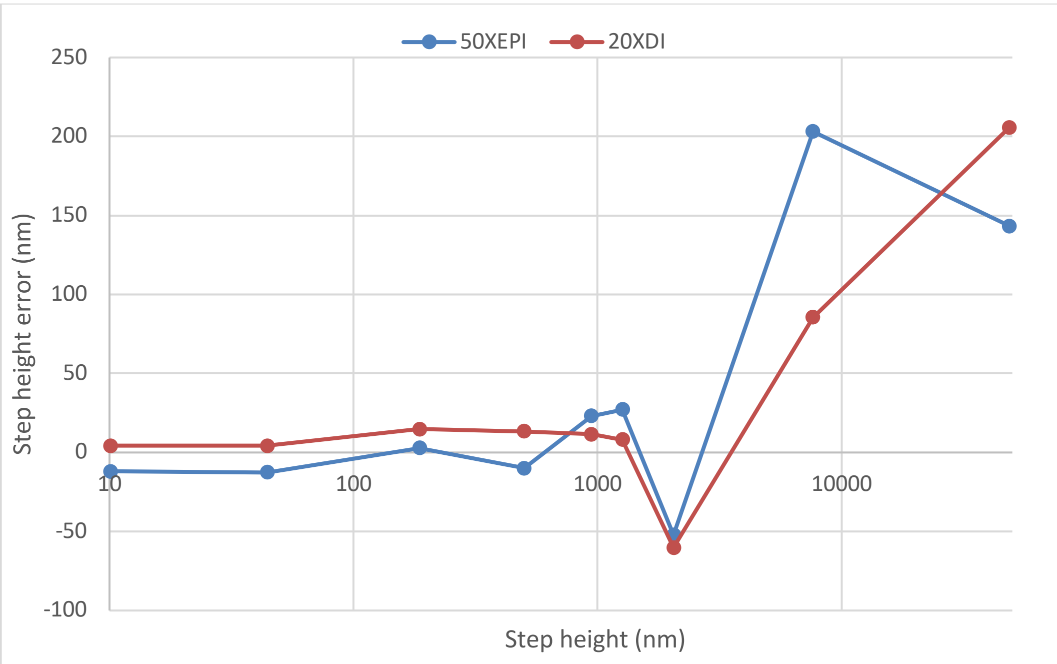


Figure 17. Step height error.

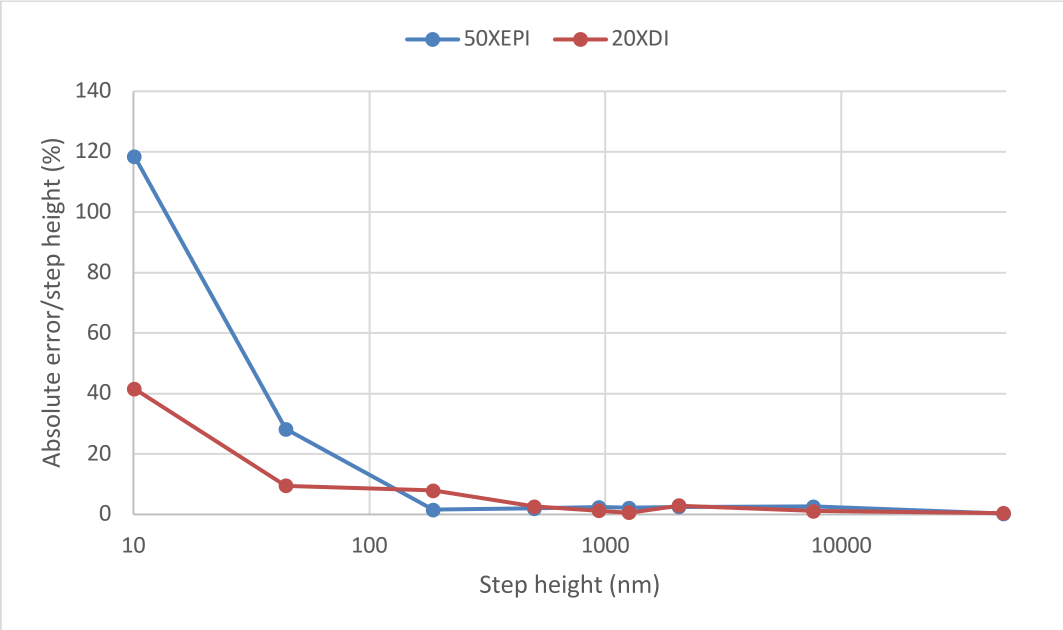


Figure 18. Absolute step height error.

The x-axis is in a logarithmic scale in order to facilitate the understanding of the data.

To minimize the error of the measurements it is necessary to calibrate the system.

Before doing the linear fitting, we add the point [0,0] to make the system behave closer to reality. When we obtain the equation of the straight line, we introduce the values measured by the system in this equation, but changing the sign of the y-intercept. Therefore, we obtain this figure:

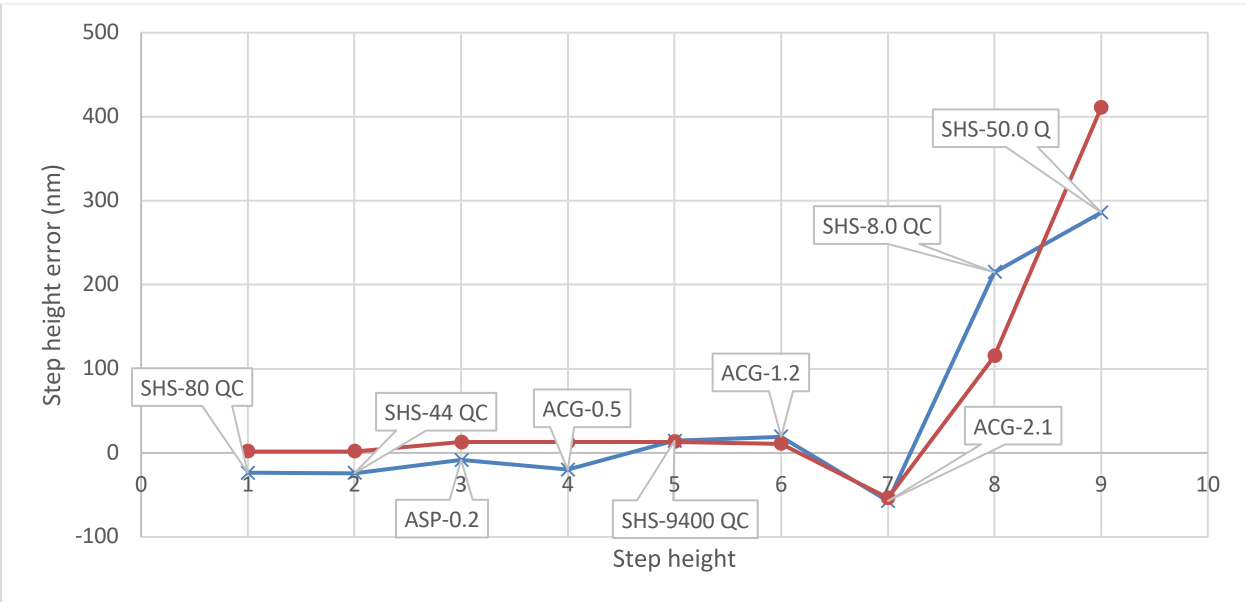


Figure 19. Calibrated step height error.

The conclusion that can be drawn is that with small step heights, the accuracy error is quite low, but if the system measures steps of the order of 10 μm the error becomes very high, meaning that a new calibration is needed with only big step heights.

Considering the case with no different calibrations depending on the step height, a formula that tells how much accuracy error does the system have can be obtained. In the case of interferometry with the 20XDI objective,

$$Accuracy\ error\ (\mu m) = 0.018 + 0.004SH\ (\mu m)$$

where SH is the value in μm of the step height.

If the confocal technique is used, the formula with the 50XEPI objective becomes:

$$Accuracy\ error\ (\mu m) = 0.036 + 0.003SH\ (\mu m)$$

Test 4. Vibrations

On this test, an external vibration was introduced while measuring, with frequencies ranging from 4 Hz up to 100 Hz. The amplitudes of the vibration were those matching the VC-C and VC-E environmental vibration curves. The test was simplified by supposing a horizontal straight line.

Due to the very low effect of the vibration's amplitude on the sample, frequencies above 100 Hz were not studied.

A series of 10 measures at the position of approximately -20.000 mm was taken with the 20XDI and 50XEPI objectives. The room's temperature was near 24.0 ºC. The microscope's camera worked at 28.5 frames per second.

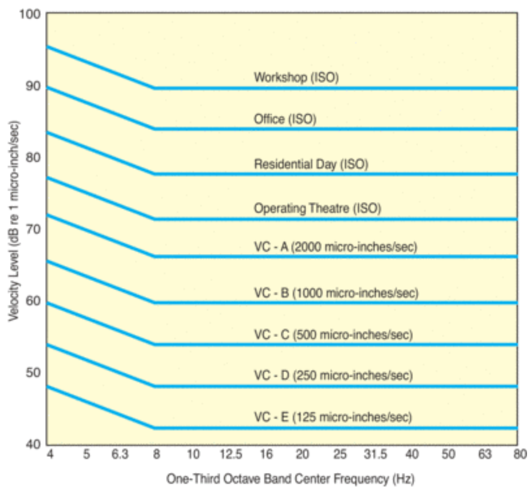


Figure 20. Generic vibration criterion table.

Test 4.1. Vibrations on a step

The step used in this test was SHS-9400. A comparison between the two curves, VCC and VCE, is made using both interferometry and confocal techniques. Afterwards it has been studied how the position of the column of the microscope affects the measure.

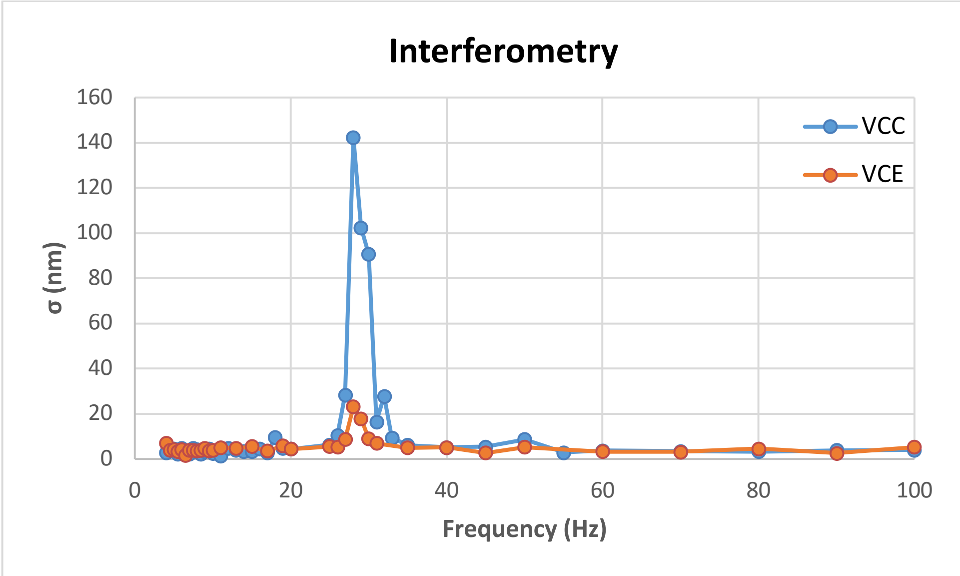


Figure 21. SHS-9400 step height with 20XEPI objective.

The peak of 28-29 Hz is caused by the frame rate of the camera, which is 28,5.

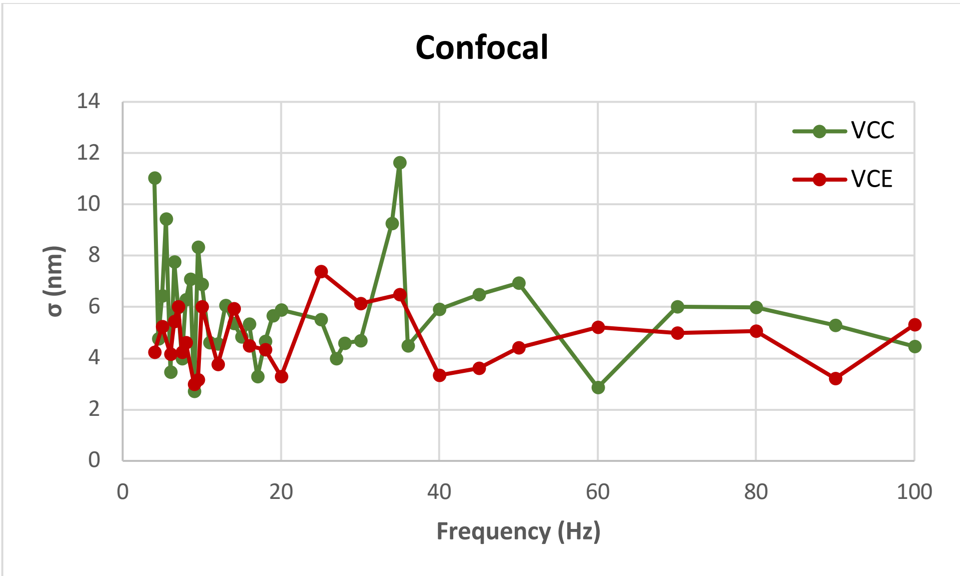


Figure 22. SHS-9400 step height with 50XEPI objective.

By using confocal technique, we don't appreciate any peak, because the 35 Hz peak of repeatability is highly probably caused by the harmonic of this frequency, which had the same amplitude as the frequency itself.

Test 4.2. Vibrations on roughness

The same procedure as the step height study is made to the roughness standard.

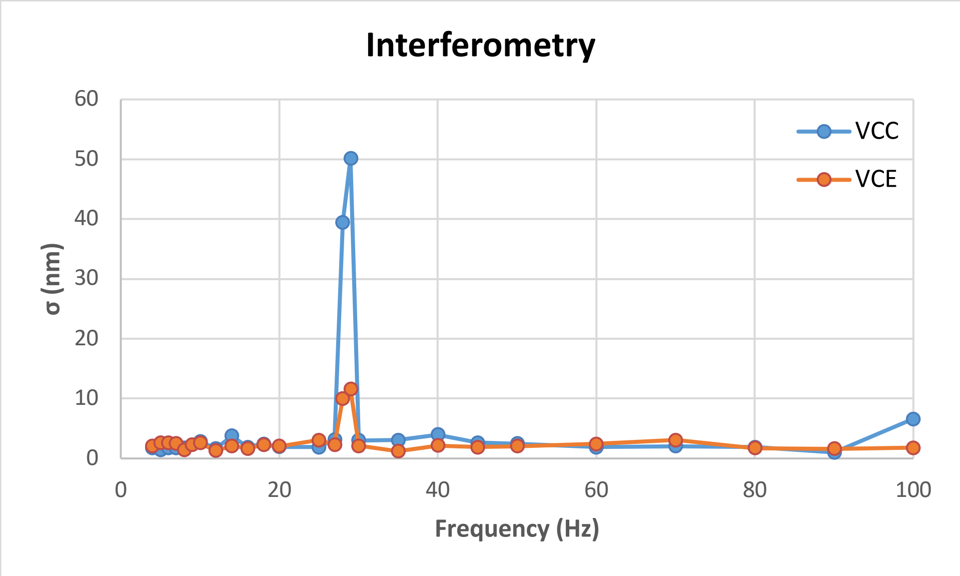


Figure 23. B-40 roughness with 20XDI objective.

The gap in average value of 50 Hz (VCC) is caused by a little adjustment of the range of measurement, so it might have affected the system because of the movement of the mechanical pieces, and then it stabilizes around this value.

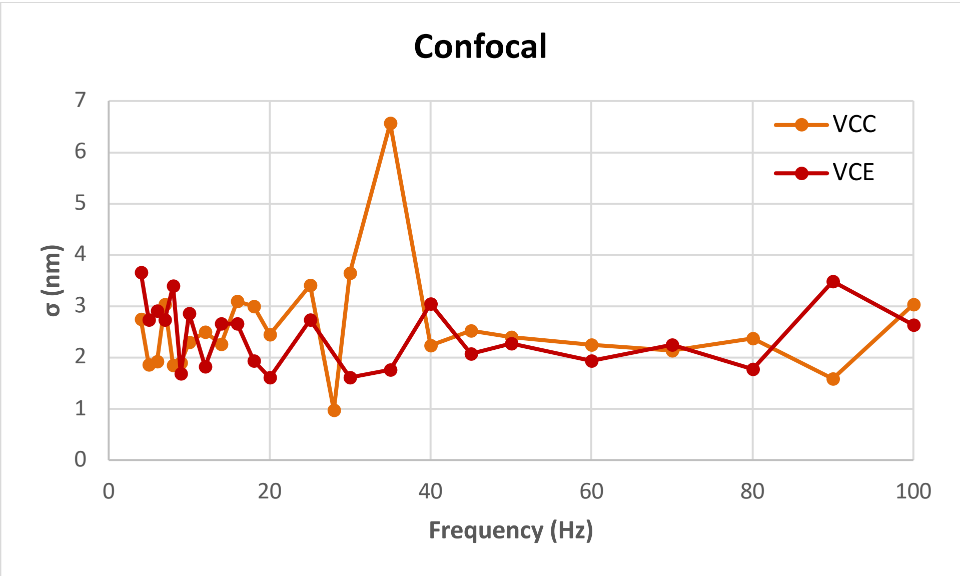


Figure 24. B-40 roughness standard with 50XEPI objective.

By using confocal technique, any peak is appreciated, because the 35 Hz peak of repeatability is highly probably caused by the harmonic of this frequency, which had the same amplitude as the frequency itself.

Test 5. Temperature

This test was performed around -20.000 mm with the 20XDI and 50XEPI objectives. The system was taking measures the entire process steadily, and a series of 10 consecutive measures was selected for each temperature. The range of temperatures was from 23 ºC to 37 ºC. Two thermocouples were measuring temperature; one was fixed to the system measuring its temperature and the other thermocouple was measuring room's temperature a few centimeters from the system. This test lasted one entire day.

To perform the heating curve, the air conditioning was set at maximum power, but the room's equilibrium was at 23.0 ºC. Then air conditioning was turned off and data acquisition was started to be taken. When a new equilibrium was reached, a heater was turned on at minimum power. When no higher temperatures could be achieved, the heater was set at maximum power. The following figure shows room's temperature over time, where the drastic temperature changes correspond to specified temperature heating changing processes:

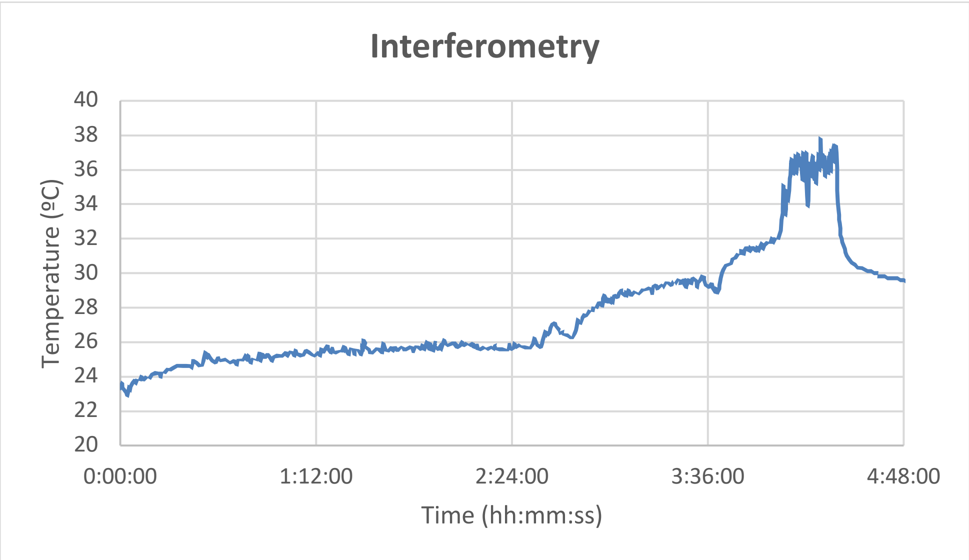


Figure 25. Room's temperature on heating process.

With data obtained the temperature difference of the system and the room can be plotted. As the system is hotter than the room, the plot is T_{system}-T_{room} over time.

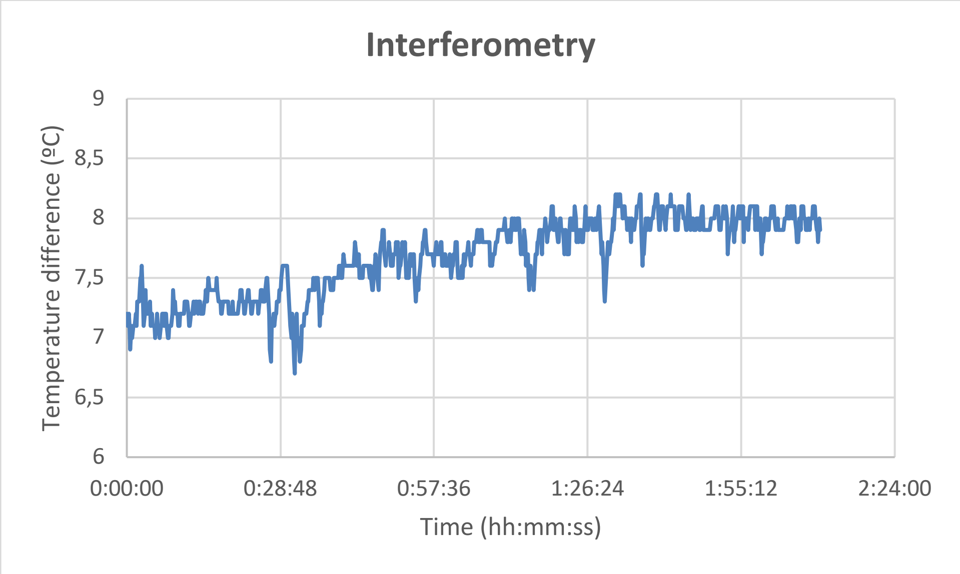


Figure 26. Temperature difference between the system and the room on heating process.

Every 0.5 ºC of Figure 25, a series of 10 consecutive measures is averaged to obtain the following figures. Nevertheless, there are some temperatures with no data associated because either the temperature change was too fast or the temperature was not stable enough to considerer that the 10 measures were approximately at the same temperature.

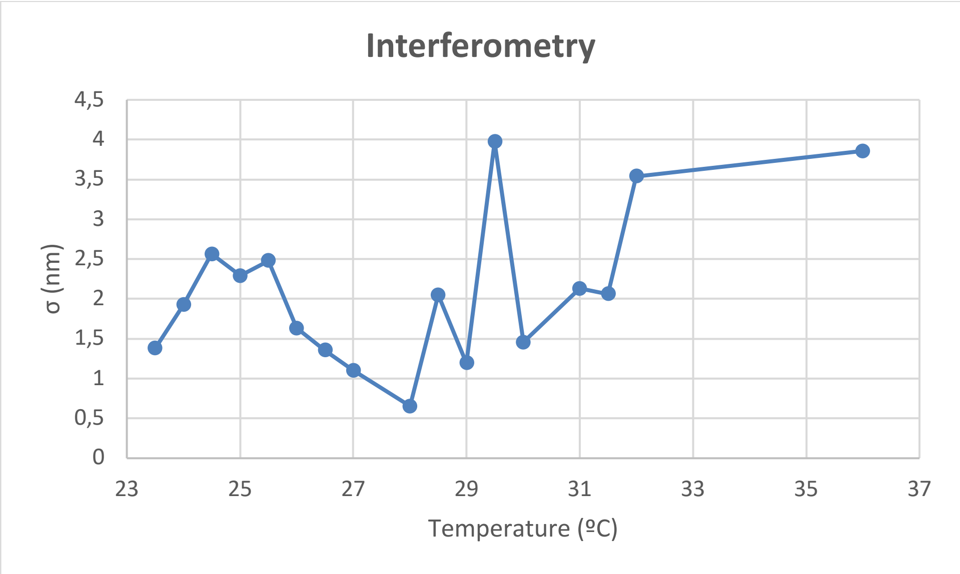


Figure 27. Heating curve on SHS-9400.

The same process was followed to study the confocal performance.

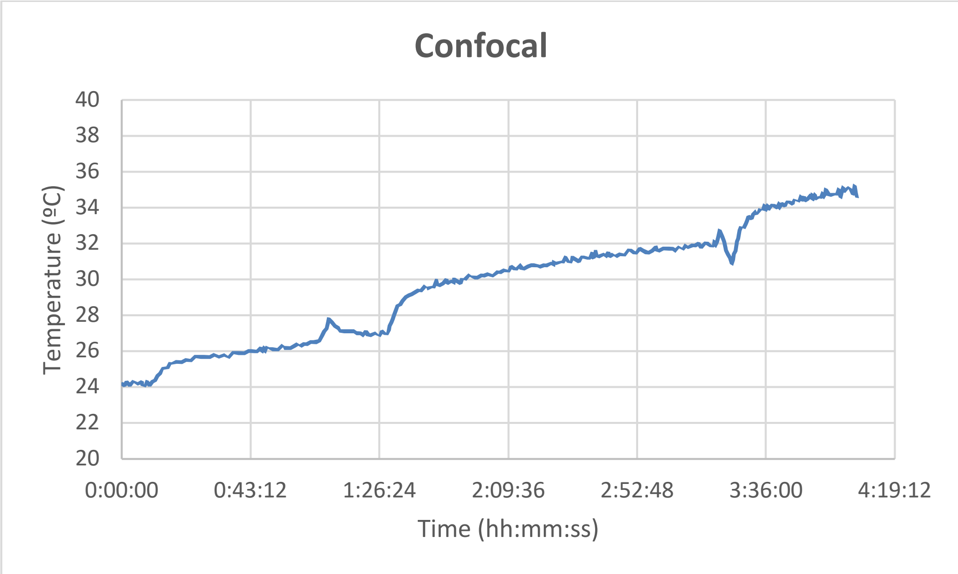


Figure 28. Room's temperature on heating process.

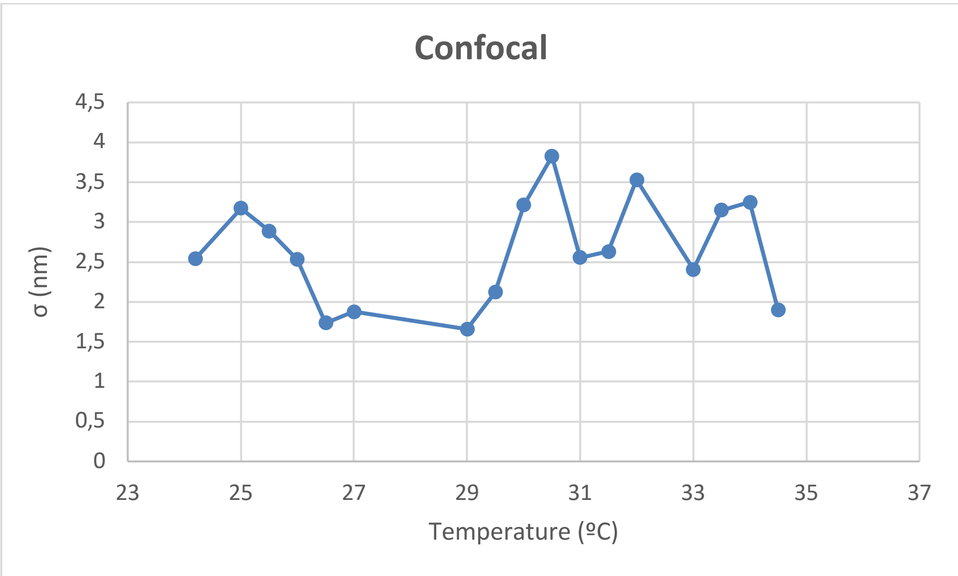


Figure 29. Heating curve on SHS-9400.

Either interferometry and confocal techniques show the best performance in terms of repeatability around the temperature of 27ºC.

To fully understand the behavior of S-lynx it was needed to know how much time did the system need to stabilize once it had been turned on.

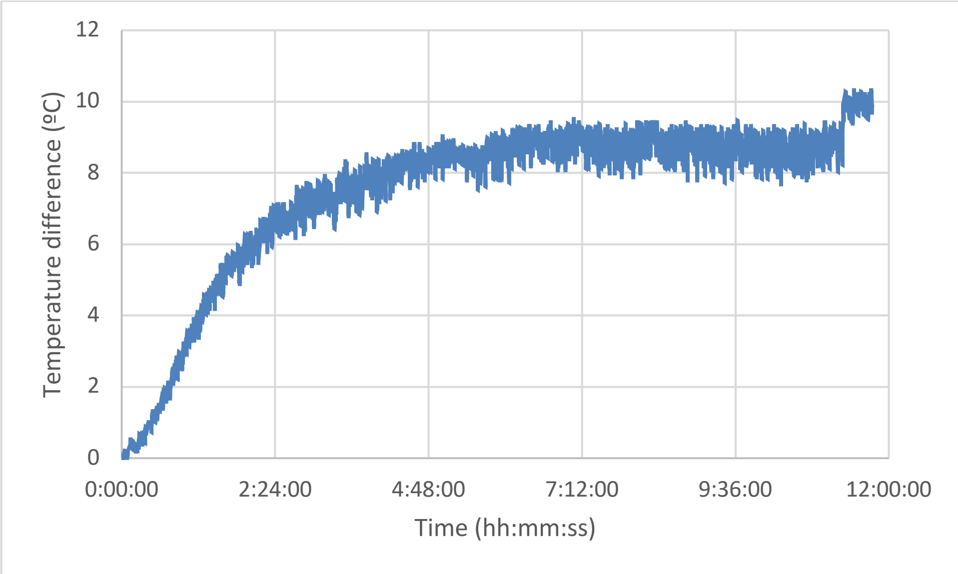


Figure 30. Warm-up curve.

The warm-up curve shows that it is needed to wait at least about 2 hours to have a sufficient stabilization (due to high slope of the temperature difference), but to have a proper stabilization this time increases to 5 hours.