S neox S lynx S mart

*Old version

3D Optical Profilers

Objectives Specifications

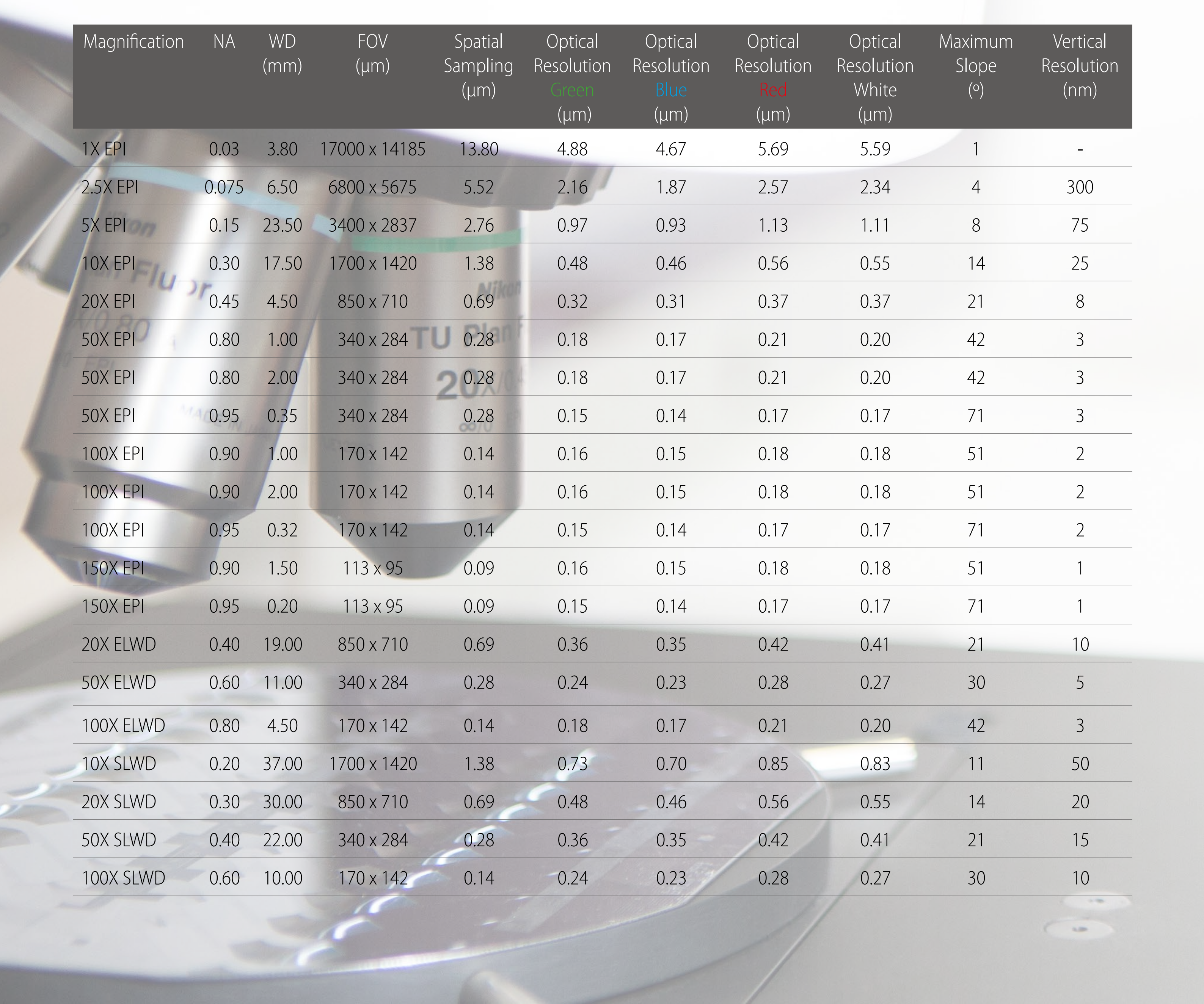
SENSOFAR®
METROLOGY

Objectives Specifications

The S line systems use premium CF60-2 Nikon objectives lenses that have been designed to correct chromatic aberrations and produce sharp, flat and clear images with high contrast and high resolution. Phase Fresnel lenses improve the operability and the working distance, meaning that S line objectives provide the largest available working distance for each NA.

The S line also uses interferometric objectives. The TI series are based on Michelson interferometer. They have an external reference mirror mounted on two tip-tilt screws. The DI series are Mirau objectives that creates the interference internally by dividing the wavefront with a beamsplitter. The TI series are used for low magnification and numerical aperture, being ideal objectives for the measurement of very flat at and thin samples. The DI series can have up to 0.55NA.

Bright field objectives



Magnification	NA	WD (mm)	FOV (µm)	Spatial Sampling (µm)	Optical Resolution Green (µm)	Optical Resolution Blue (µm)	Optical Resolution Red (µm)	Optical Resolution White (µm)	Maximum Slope (º)	Vertical Resolution (nm)
1X EPI	0.03	3.80	17000 x 14185	13.80	4.88	4.67	5.69	5.59	1	-
2.5X EPI	0.075	6.50	6800 x 5675	5.52	2.16	1.87	2.57	2.34	4	300
5X EPI	0.15	23.50	3400 x 2837	2.76	0.97	0.93	1.13	1.11	8	75
10X EPI	0.30	17.50	1700 x 1420	1.38	0.48	0.46	0.56	0.55	14	25
20X EPI	0.45	4.50	850 x 710	0.69	0.32	0.31	0.37	0.37	21	8
50X EPI	0.80	1.00	340 x 284	0.28	0.18	0.17	0.21	0.20	42	3
50X EPI	0.80	2.00	340 x 284	0.28	0.18	0.17	0.21	0.20	42	3
50X EPI	0.95	0.35	340 x 284	0.28	0.15	0.14	0.17	0.17	71	3
100X EPI	0.90	1.00	170 x 142	0.14	0.16	0.15	0.18	0.18	51	2
100X EPI	0.90	2.00	170 x 142	0.14	0.16	0.15	0.18	0.18	51	2
100X EPI	0.95	0.32	170 x 142	0.14	0.15	0.14	0.17	0.17	71	2
150X EPI	0.90	1.50	113 x 95	0.09	0.16	0.15	0.18	0.18	51	1
150X EPI	0.95	0.20	113 x 95	0.09	0.15	0.14	0.17	0.17	71	1
20X ELWD	0.40	19.00	850 x 710	0.69	0.36	0.35	0.42	0.41	21	10
50X ELWD	0.60	11.00	340 x 284	0.28	0.24	0.23	0.28	0.27	30	5
100X ELWD	0.80	4.50	170 x 142	0.14	0.18	0.17	0.21	0.20	42	3
10X SLWD	0.20	37.00	1700 x 1420	1.38	0.73	0.70	0.85	0.83	11	50
20X SLWD	0.30	30.00	850 x 710	0.69	0.48	0.46	0.56	0.55	14	20
50X SLWD	0.40	22.00	340 x 284	0.28	0.36	0.35	0.42	0.41	21	15
100X SLWD	0.60	10.00	170 x 142	0.14	0.24	0.23	0.28	0.27	30	10

The highest quality objectives, the highest quality performance

Water inmersion objectives

Magnification	NA	WD (mm)	FOV (µm)	Spatial Sampling (µm)	Optical Resolution Green (µm)	Optical Resolution Blue (µm)	Optical Resolution Red (µm)	Optical Resolution White (µm)	Maximum Slope (º)
10X WI	0.30	3.50	1700 x 1420	1.38	0.48	0.46	0.56	0.55	14
20X WI	0.50	3.30	850 x 710	0.69	0.29	0.28	0.34	0.33	23
63X WI	1.00	2.00	270 x 225	0.22	0.14	0.14	0.17	0.16	-

Collar ring depth focusing correction objectives

Magnification	NA	WD (mm)	FOV (µm)	Spatial Sampling (µm)	Optical Resolution Green (µm)	Optical Resolution Blue (µm)	Optical Resolution Red (µm)	Optical Resolution White (µm)	Maximum Slope (º)
20X EPI CR	0.45	10.9 – 10.0	850 x 710	0.69	0.32	0.31	0.37	0.37	21
50X EPI CR	0.70	3.9 – 3.0	340 x 284	0.28	0.20	0.20	0.24	0.23	42
100X EPI CRA	0.85	1.2 – 0.85	170 x 142	0.14	0.17	0.16	0.20	0.19	43
100X EPI CRB	0.85	1.3 – 0.95	170 x 142	0.14	0.17	0.16	0.20	0.19	43

Interferometry objectives

Magnification	NA	WD (mm)	FOV (µm)	Spatial Sampling (µm)	Optical Resolution Green (µm)	Optical Resolution Blue (µm)	Optical Resolution Red (µm)	Optical Resolution White (µm)	Maximum Slope (º)
2.5X TI *	0.075	10.30	6800 x 5675	5.52	5.52	5.52	5.52	5.52	3
5X TI	0.13	9.30	3400 x 2837	2.76	2.76	2.76	2.76	2.76	8
10X DI	0.30	7.40	1700 x 1420	1.38	1.38	1.38	1.38	1.38	14
20X DI	0.40	4.70	850 x 710	0.69	0.69	0.69	0.69	0.69	21
50X DI	0.55	3.40	340 x 284	0.28	0.28	0.28	0.31	0.30	25
100X DI	0.70	2.00	170 x 142	0.14	0.20	0.20	0.24	0.23	42
Vertical resolution			**PSI/ePSI** 0.1 nm (0.01 nm with PZT *)				**VSI** 1 nm		

* Not supported by S lynx and S mart

System Performance Specifications

S onix – 3D high-speed sensor

Document purpose

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

S onix

S onix is a high-speed non-contact 3D surface microscope. It measures surface roughness, textures and structure as well as thickness measurements with vertical resolution down to 1 nm.

The system uses Vertical Scanning Interferometry (VSI).

Set-up

In order 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 a tilt stage with and XY translation stage. In order to adjust the position of the sample along the Z-axis without utilizing the microscope's motor, there was also a separate adjustable column.

Figure 1. Set-up.

Objectives

In the performance tests a set of six different objectives was used. This set was formed by 2.5XTI, 5XTI, 10XDI, 20XDI, 50XDI and 100XDI 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 each consist of five cross gratings with heights of 2100, 1200 and 500 nm, respectively, with pitches ranging from 16 to 400 µm (illustrated in Figure 2):

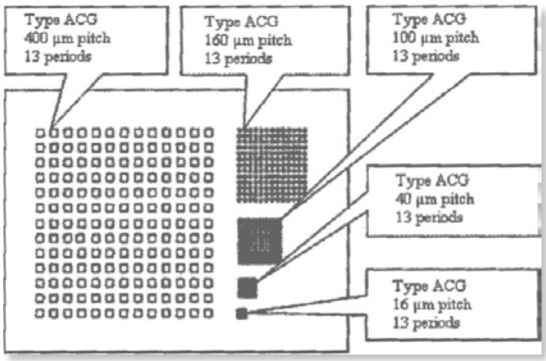


Figure 2. Schematic design of NPL type ACG.

Step height measurements were made on the central mesa of the 160 µm pitch cross grating on all three ACGs. Three measurements were made on each, and the mean height is given in Table 1.

Areal Star Pattern

The ASG includes a combination of two areal star-shaped grooves of 20 and 70 µm radius and thirteen cross gratings with pitches ranging from 20 to 600 µm. The design is shown in Figure 3:

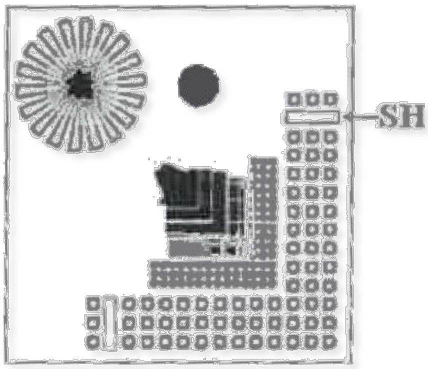


Figure 3. Schematic design of the NPL type ASG-0.2.

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	25 Sept. 2013	2100	2048.2	4.1	2.0
ACG-1.2	24 Sept. 2013	1200	1264.0	4.1	2.0
ACG-0.5	26 Sept. 2013	500	499.7	4.1	2.0
ASP-0.2	27 Sept. 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.

The top random surface, see Figure 4, 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 Table 2:

Figure 4. NPL type B-70.

Model number	Calibration date	Parameter	Mean measured value (nm)	Expanded uncertainty (nm)	Coverage factor (k)
AIR-B40	6 Sept. 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 slope.

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.

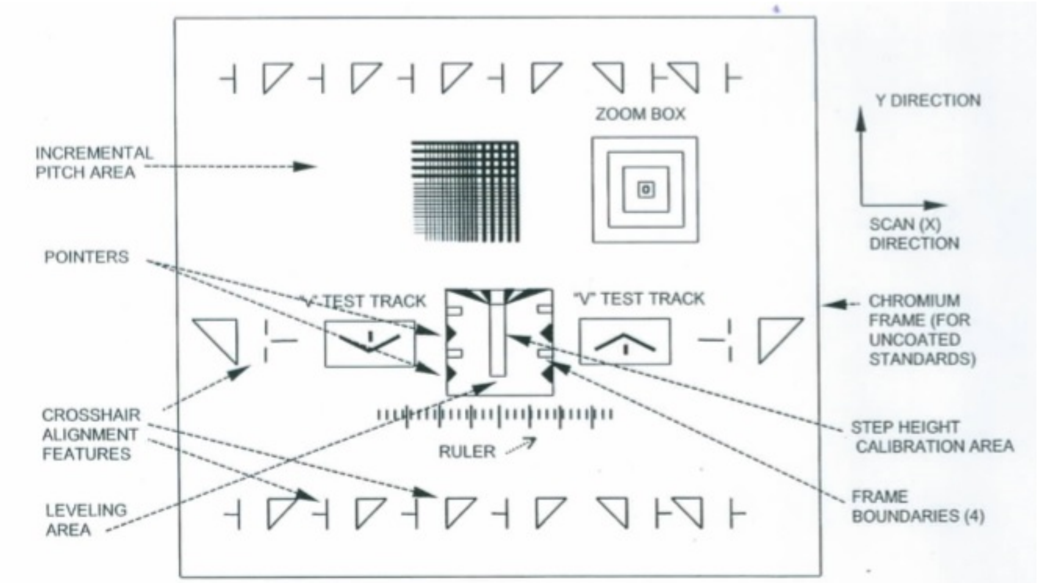


Figure 6. VLSI thin step height configuration.

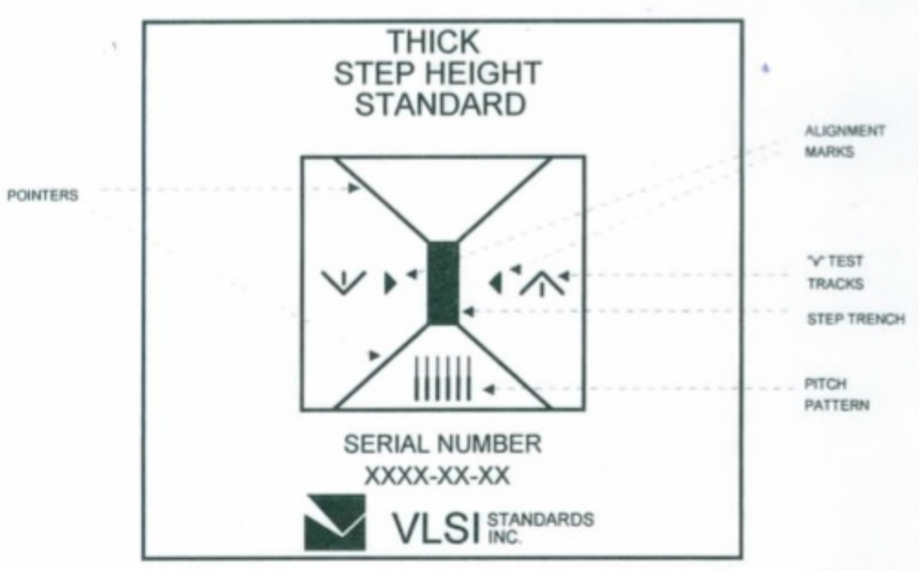


Figure 7. VLSI thick step height configuration.

Tests performed

All measurements were performed using the VSI technique. The following Table summarizes the tests performed:

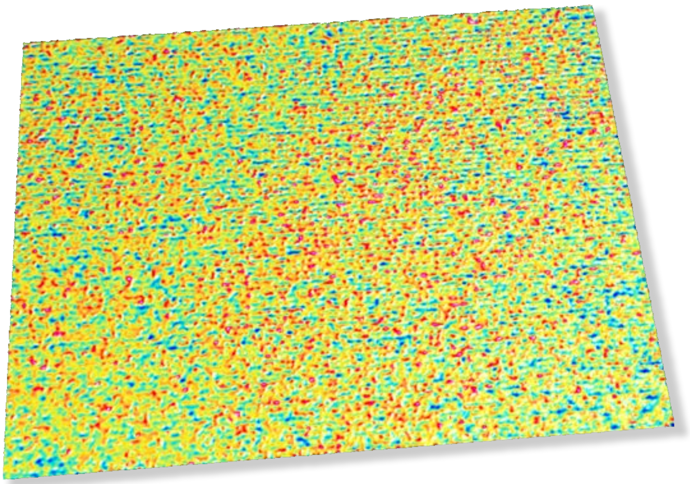
	Specification tested	Standards Used	Objectives	Repetitions
1	Noise Level	SiC Mirror	2.5XTI, 5XTI, 10XDI 20XDI, 50XDI, 100XDI	1
2	Sq Repeatability	Areal Cross Grating (ACG) Areal Star Pattern (ASG)	5XTI, 20XDI	100
		Areal Irregular (AIR)	10XDI, 50XDI	
3	Linearity	Areal Cross Grating Areal Star Patter	5XTI, 20XDI	30
		Areal Cross Grating Areal Star Pattern VLSI standards	20XDI	10
4	Vibration	VLSI standards Areal Irregular	20XDI	30
5	Temperature	VLSI standards	20XDI	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 at the absolute position of -20.0000 mm. Two different studies with all objectives were made.



Test 1.1. Null Fringe

This study was made at null fringes within the FOV. It measured two topographies that were subsequently subtracted, with a different number of averages in each topography.

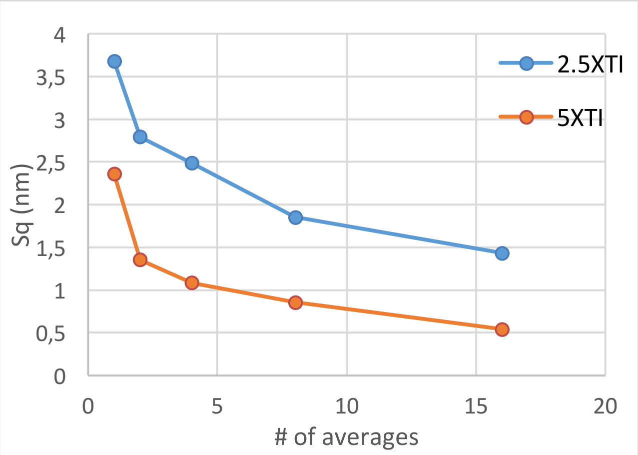


Figure 8. Sq value for 2 topography subtraction of a mirror (2.5XTI and 5XTI objectives).

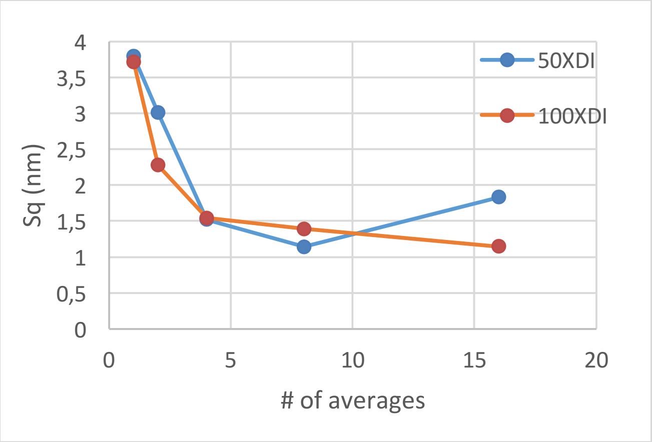


Figure 9. Sq value for 2 topography subtraction of a mirror (10XDI and 20XDI objectives).

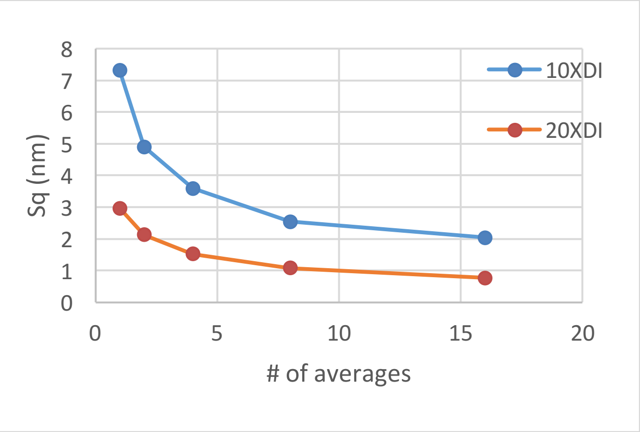


Figure 10. Sq value for 2 topography subtraction of a mirror (50XDI and 100XDI objectives).

Test 1.2. Multiple Fringes

This study measured one topography with a single average, but with a different number of fringes within the FOV.

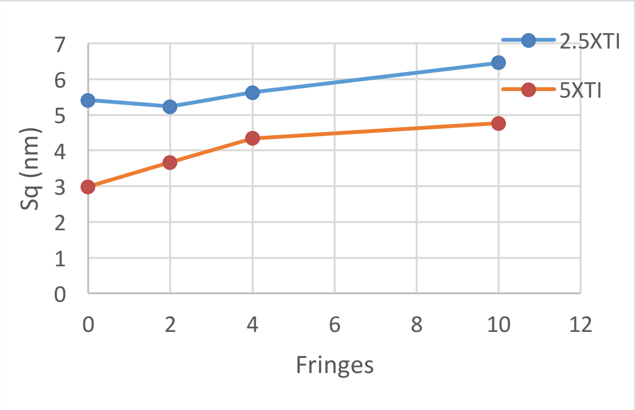


Figure 11. Sq value vs number of fringes (2.5XTI and 5XTI objectives).

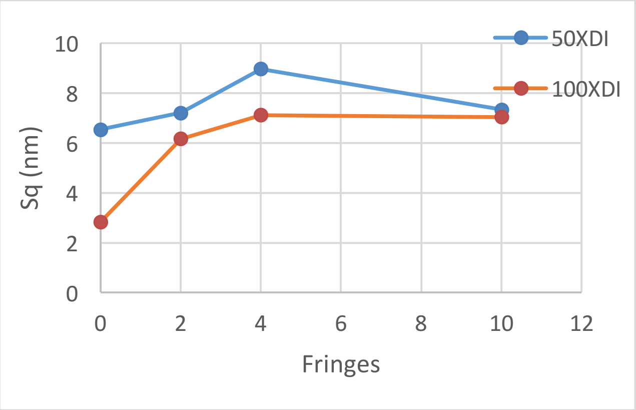


Figure 12. Sq value vs number of fringes (10XDI and 20XDI objectives).

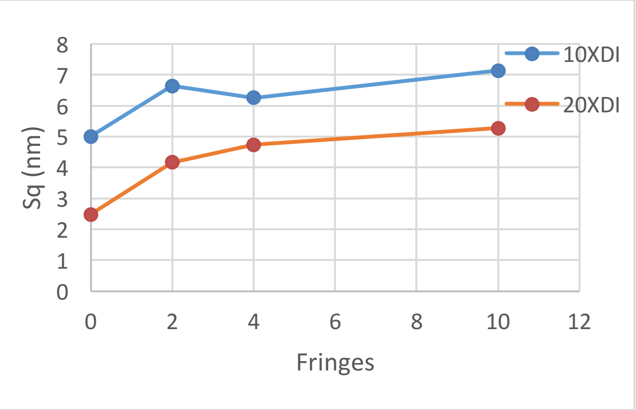


Figure 13. Sq value vs number of fringes (50XDI and 100XDI objectives).

If we compare the values of the Sq parameter at null fringe for the case where we subtract two topographies with the case with one topography, we see that in most objectives (all but 10XDI and 20XDI) the value of Sq is lower in the first scenario. A reasonable explanation is that the measurement shows the result of a sum of two mirrors: the mirror of the sample and the reference mirror. So when we subtract a topography with another one of the same surface, what the system is doing is compensating the topography of the reference mirror, which remains constant among the measurements.

Test 2. Vertical Resolution

This test's aim 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 100. 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, while the objectives used were 5XTI and 20XDI. The measurement time was 5 minutes.

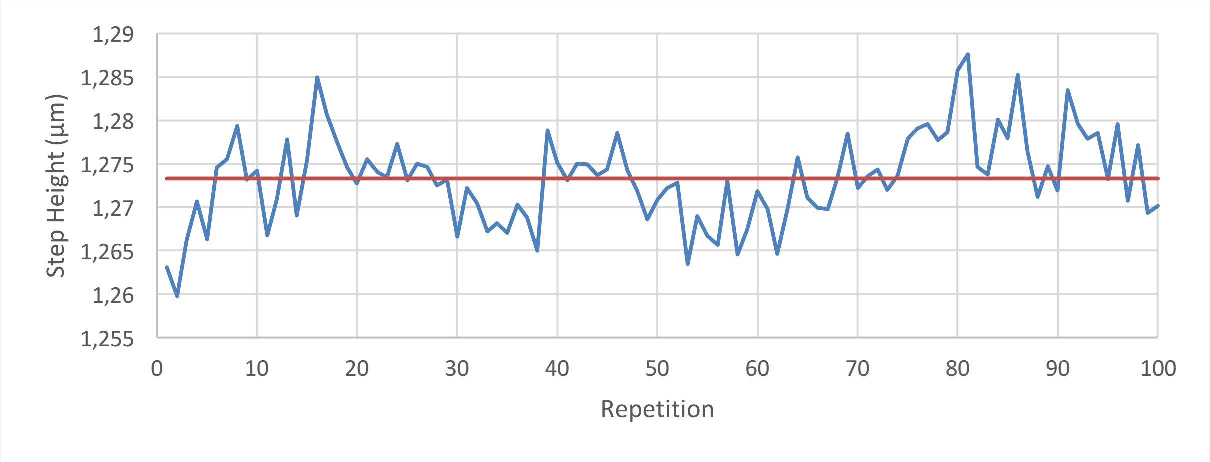


Figure 14. Step Height of ACG-1.2 with 20XDI objective.

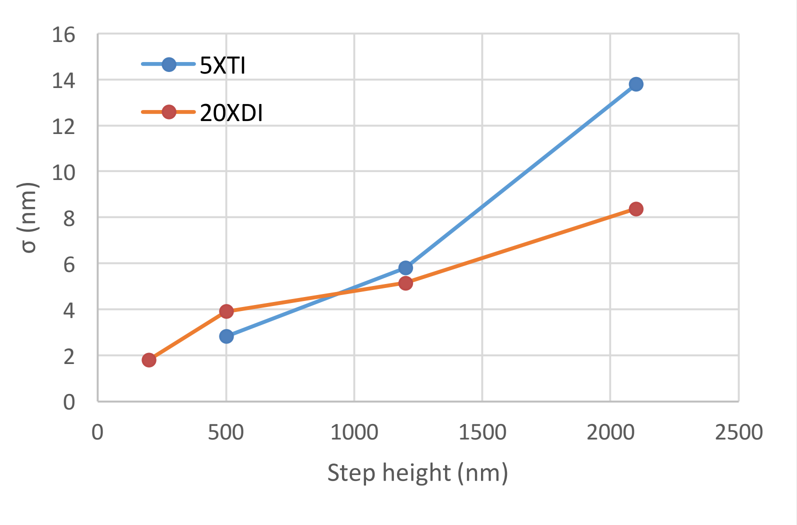


Figure 15. Value of standard deviation vs step height (5XTI and 20XDI objectives).

Test 2.2. Roughness

The standard used in this test was provided by NFL and was AIR-B40, while the objectives used were 10XDI and 50XDI. The random surface was analyzed in the following manner:

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

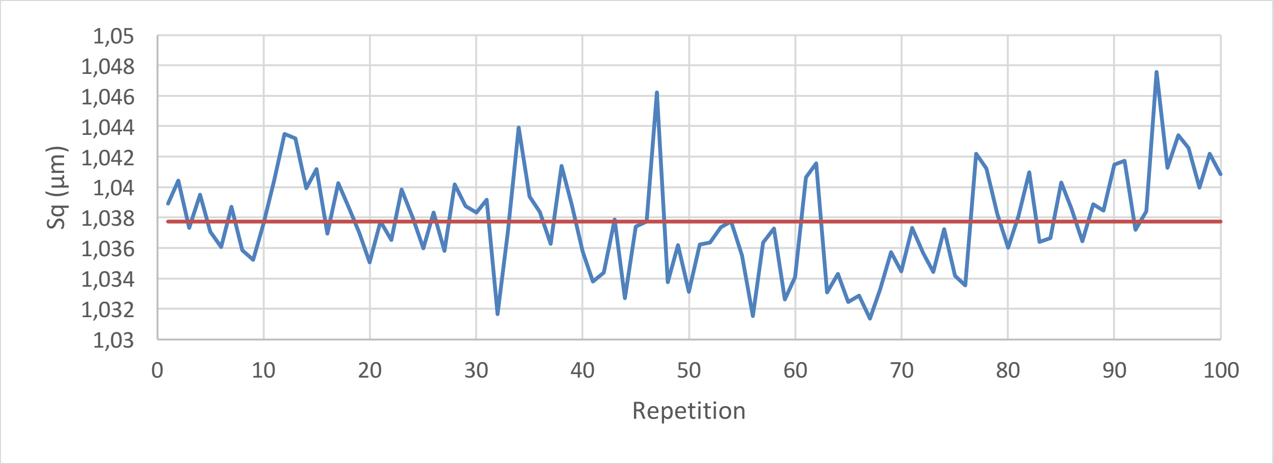


Figure 16. Sq value of a random surface (AIR-B40) with a 10XDI objective.

	Height parameter: Sq	
	Average (nm)	Standard Deviation (nm)
10XDI	1037.7	3.2
50XDI	1060.1	4.3

Table 4. Average repeatability value Sq of 100 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 -18.000 mm and ended at -22.000 mm in steps of 0.1 mm. The standards used in this test were ACG-2.1, ACG-1.2, ACG-0.5 and ASP-0.2. The objectives used were 5XTI and 20XDI. The room's temperature was in the range of 23.5 - 23.9 ºC. The number of measurements made was 30 and the acquisition time was 1 minute and 45 seconds.

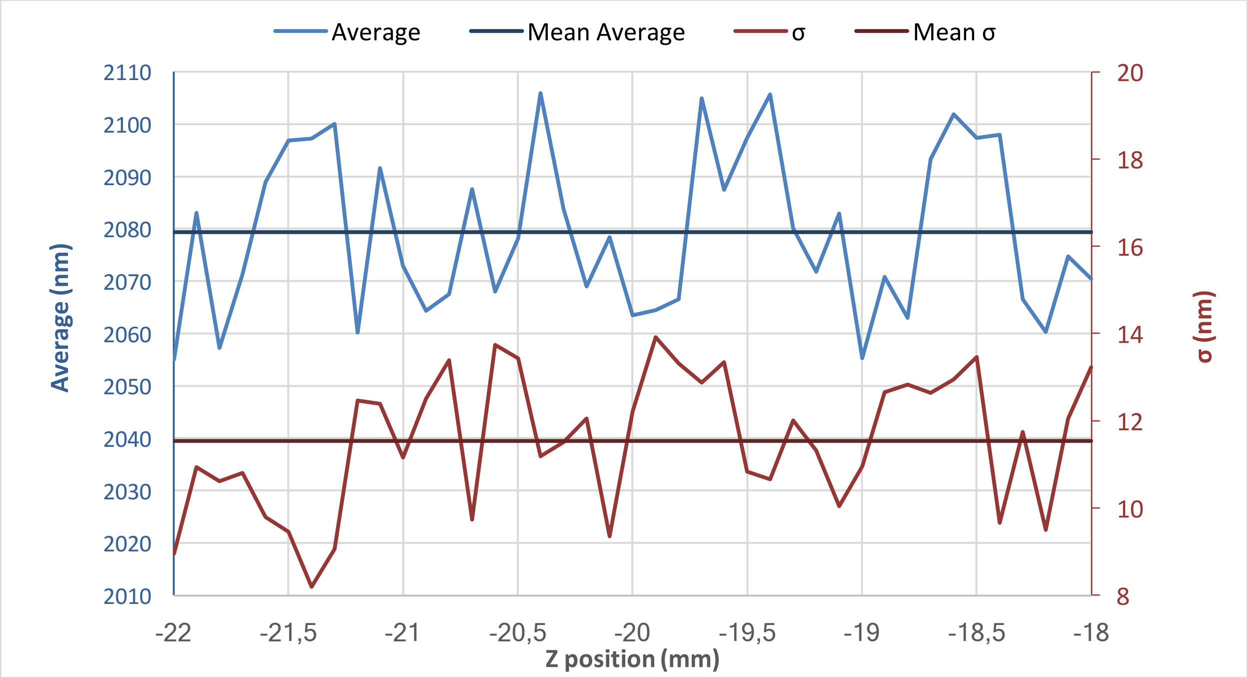


Figure 17. ACG-2.1 with 5XTI objective.

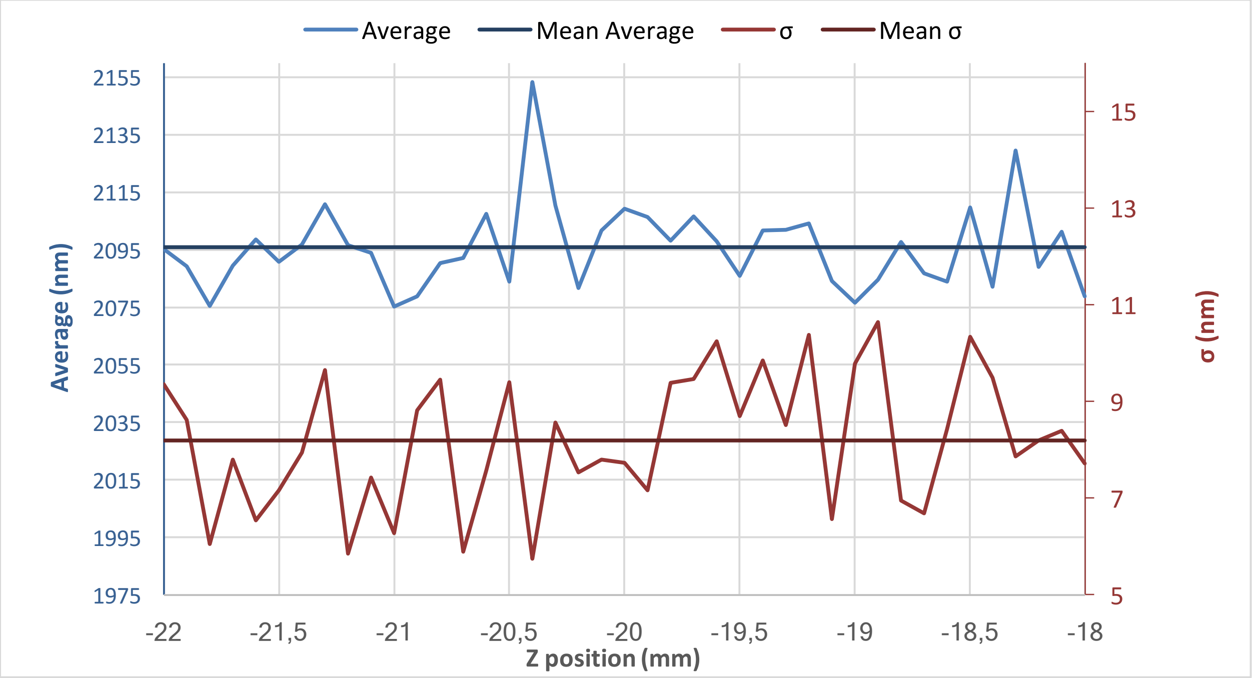


Figure 18. ACG-2.1 with 20XDI objective.

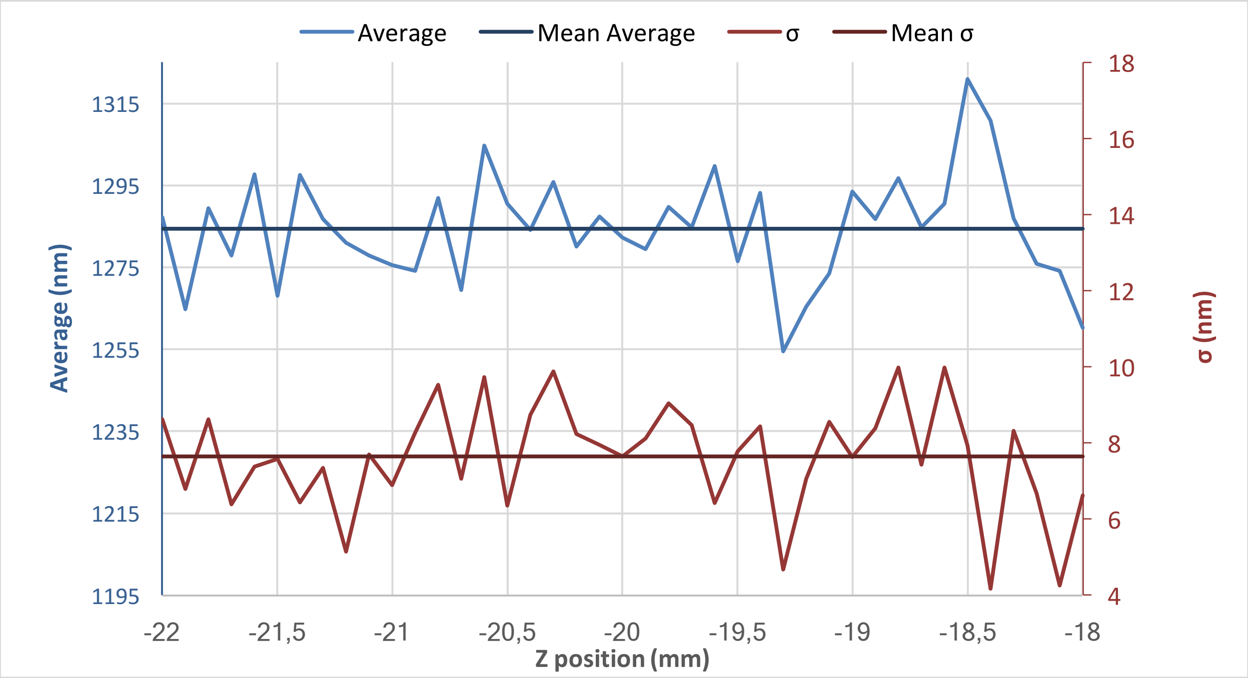


Figure 19. ACG-1.2 with 20XDI objective.

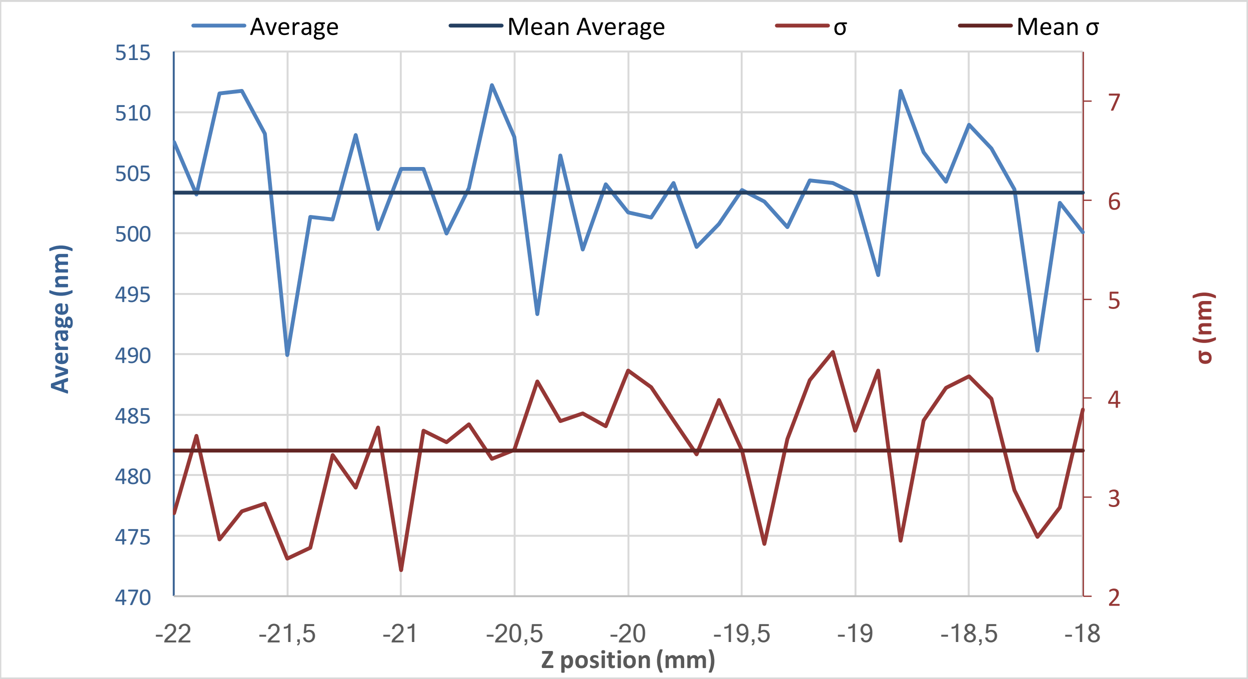


Figure 20. ACG-0.5 with 20XDI objective.

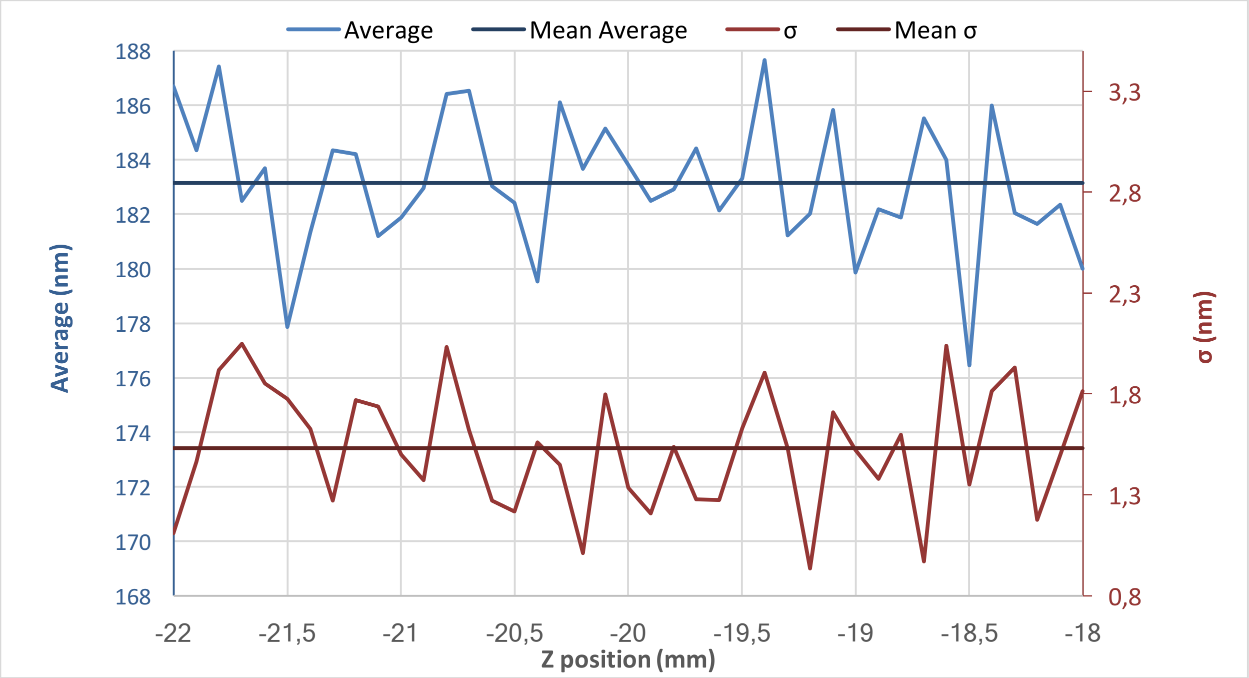


Figure 21. ASP-0.2 with 20XDI objective.

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

	5XTI	20XDI			
	ACG-2.1	ACG-2.1	ACG-1.2	ACG-0.5	ASP-0.2
Mean Average (nm)	2079.4	2095.8	1284.5	503.3	183.1
Standard Deviation of Mean Average (nm)	15.5	14.9	13.3	5.1	2.5
Mean Standard Deviation (nm)	11.5	8.2	7.6	3.5	1.5

Table 5. Summary of linearity test values.

In order to study the behavior in all the Z stroke possible range, a similar less exhaustive test was made. The range was from -39.000 to -1.000 mm in steps of 2 mm.

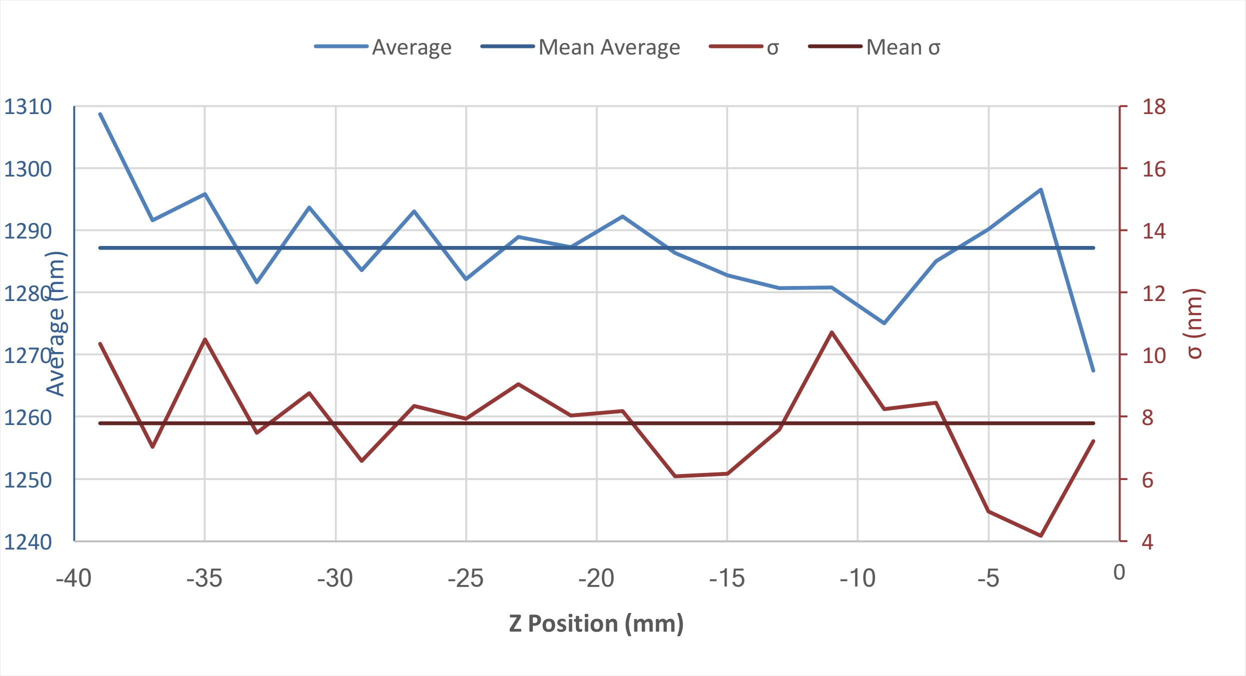


Figure 22. ACG-1.2 full range with 20XDI objective.

Test 3.2. Linearity along Z step height

In this study the Z axis 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 measurements 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 6. Set of step heights.

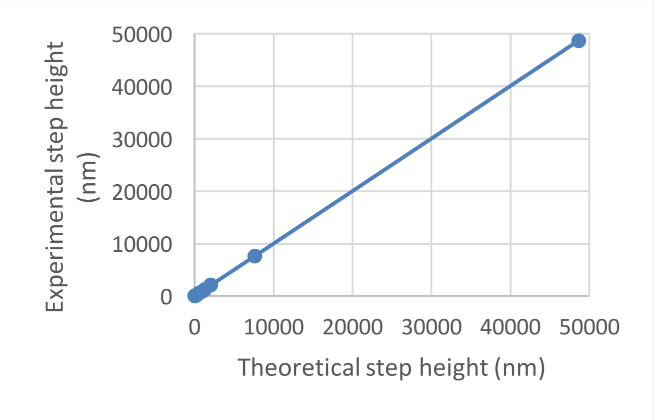


Figure 23. Theoretical vs Experimental step height value.

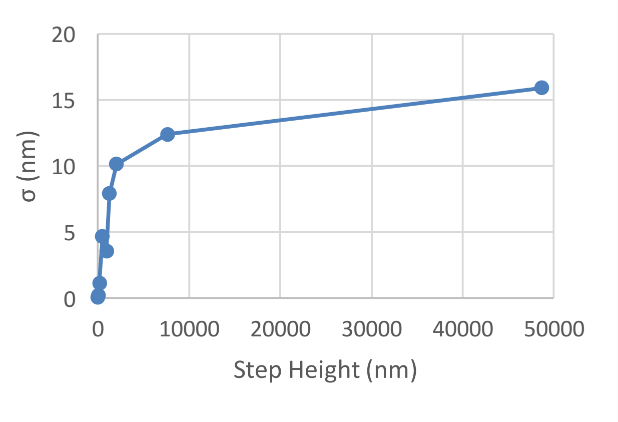


Figure 24. Standard deviation of step heights.

If we plot the theoretical value minus the experimental value versus the theoretical value, we obtain:

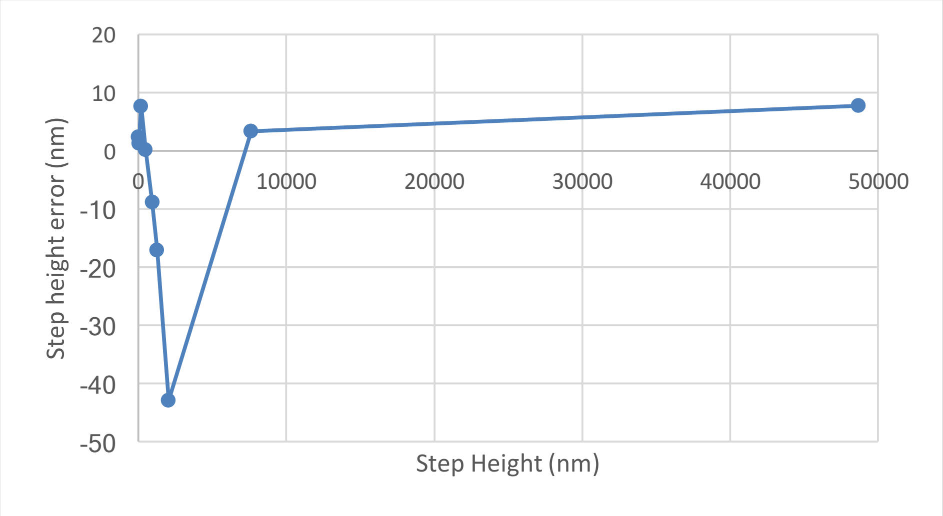


Figure 25. Step height error.

It can be noticed that if the two bigger height steps are excluded the system behaves linearly. In order to minimize the error of the measurements it is necessary to calibrate the system.

Before we do the linear fitting we add the point [0,0] in order 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. We obtain the following Figure:

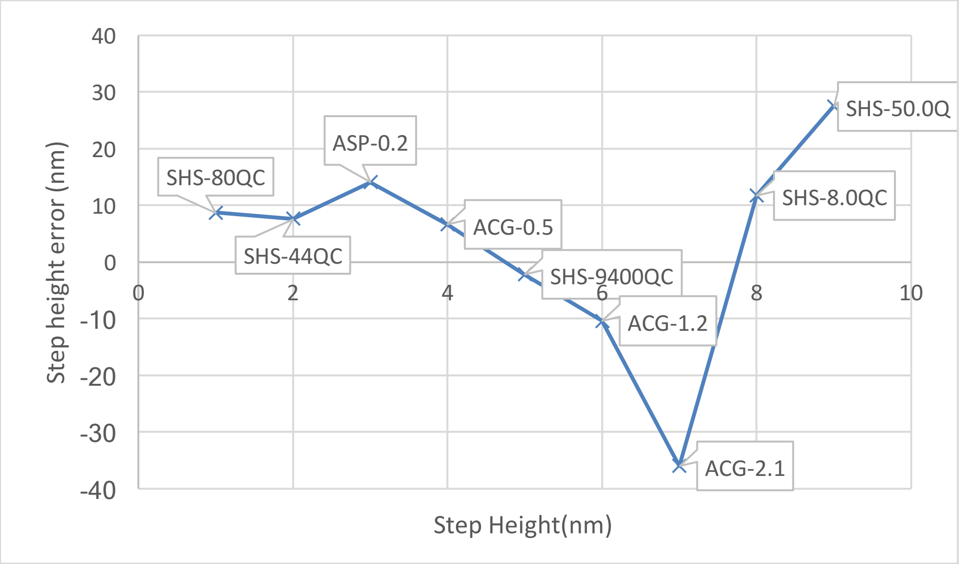


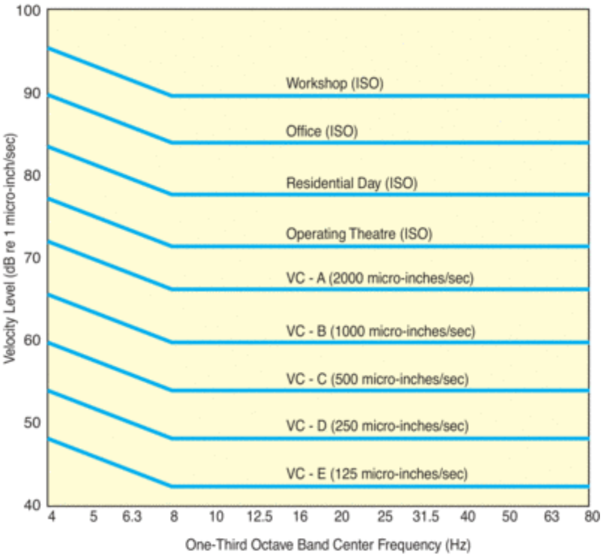
Figure 26. Calibrated step height error.

It can be observed that the range of error is reduced if the system has to work with different step heights. Therefore, it is necessary to do the calibration before taking measurements.

Test 4. Vibrations

On this test an external vibration was introduced while measuring, with frequencies ranging from 4 to 200 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 amplitude of the vibration on the sample, frequencies above 200 Hz were not studied.



A series of 30 measurements at the position of -20.000 mm was taken with the 20XDI objective. The room's temperature was 24.2 ºC. The microscope's camera worked at 299 frames per second.

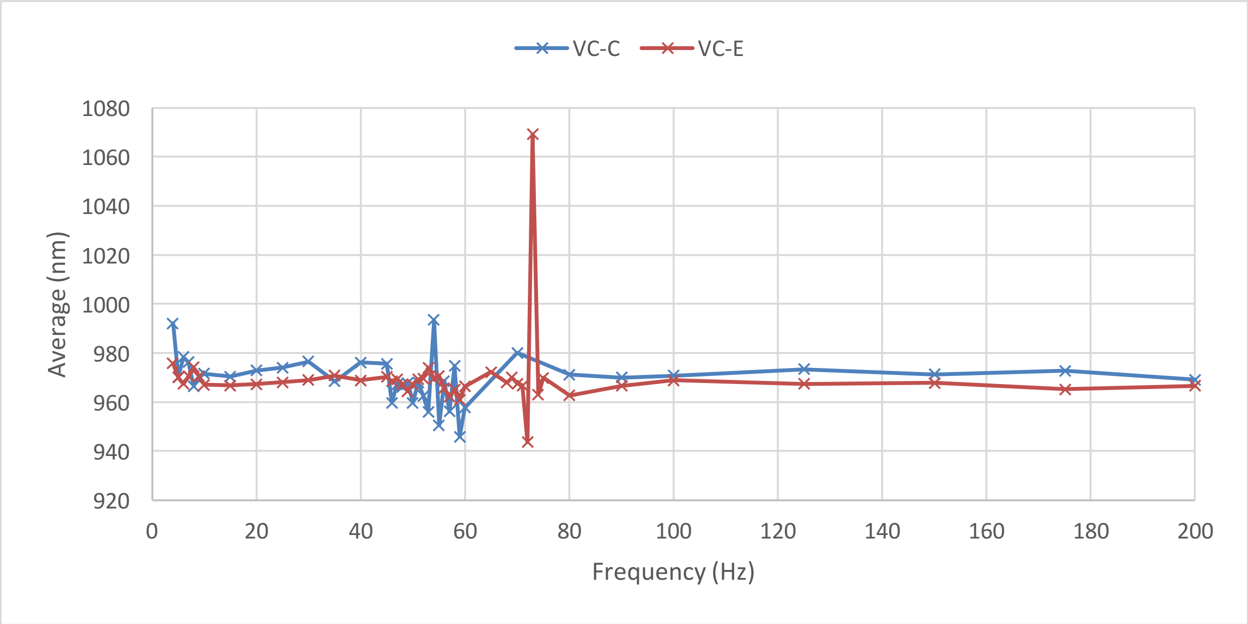


Figure 27. SHS-9400 step height.

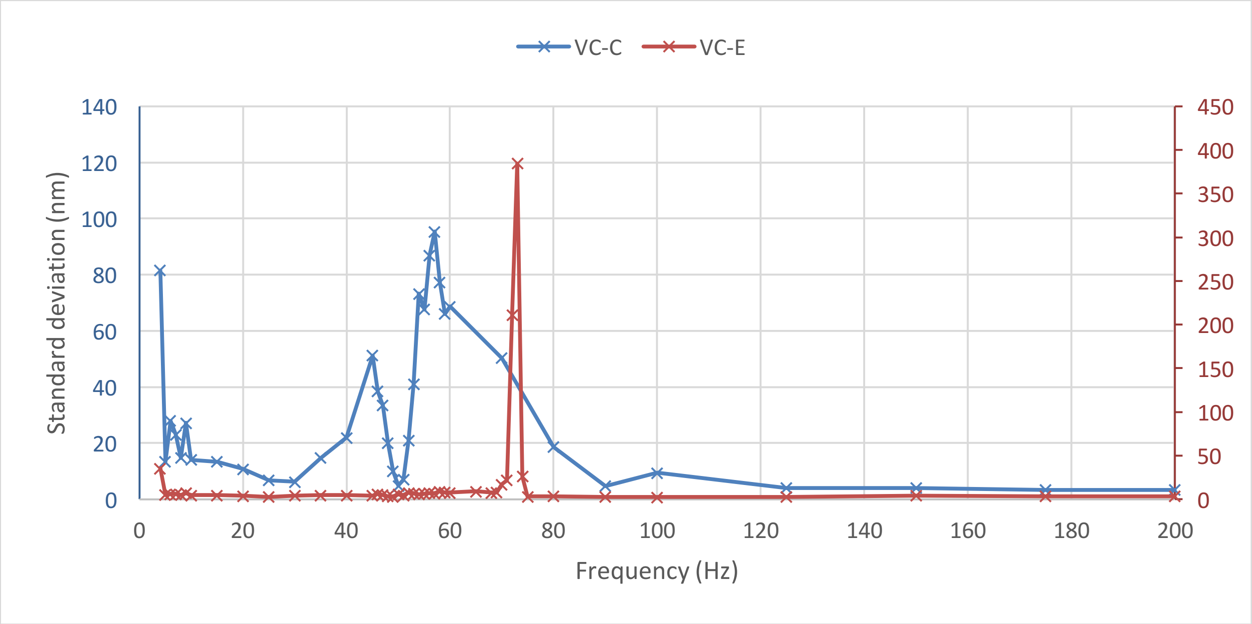


Figure 29. SHS-9400 step height.

In order to understand the 4 Hz peak, it is necessary to state that with this experimental set-up at this exact frequency, the harmonic contributions were the same or higher than the contribution at 4 Hz. At all other frequencies, all harmonics made low contributions compared with the original frequency.

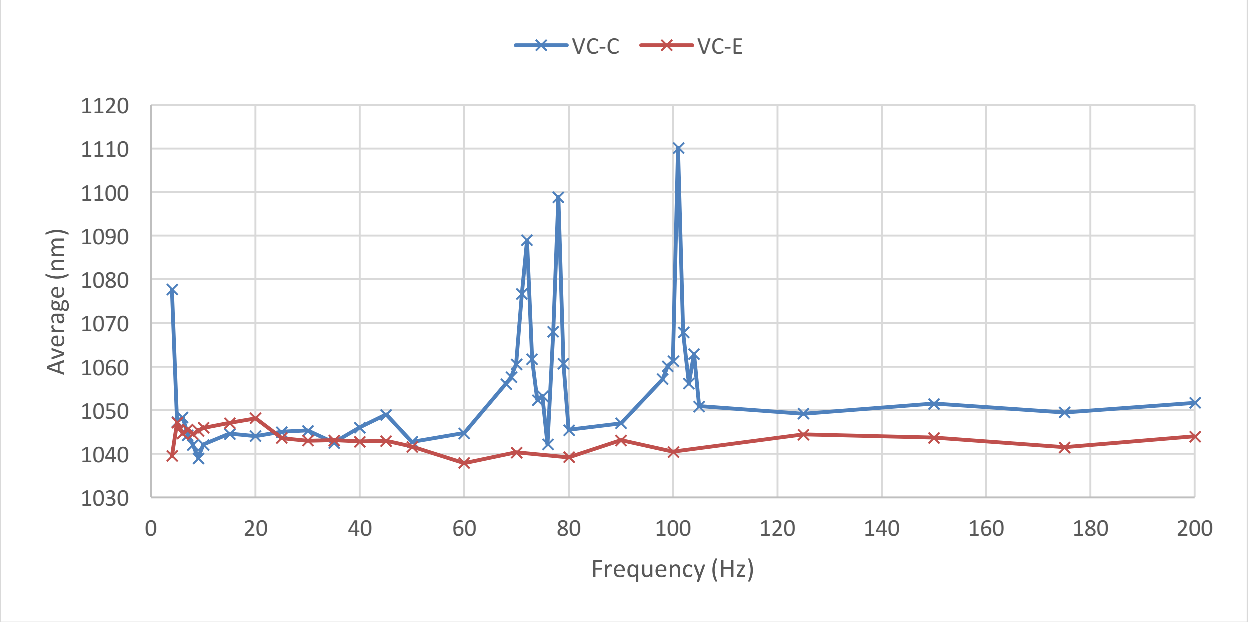


Figure 28. Sq on AIR-B40 standard.

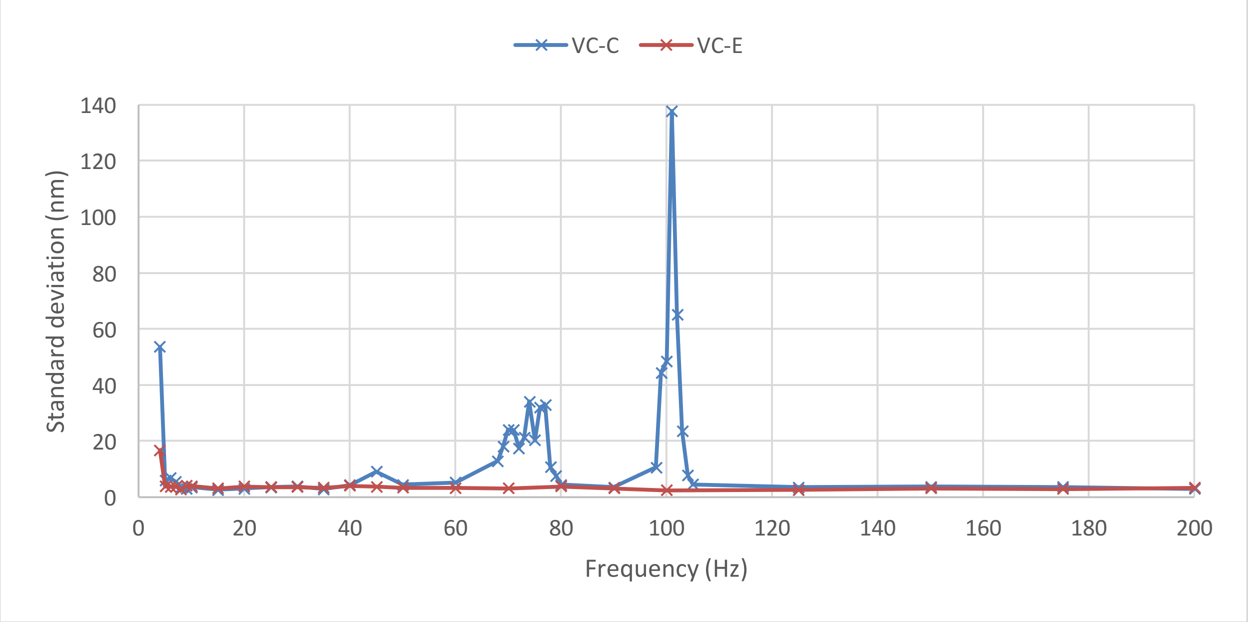


Figure 29. Sq on AIR-B40 standard.

The regions where the vibration curved was showing a peak were studied more in detail, increasing the number of points measured.

Test 5. Temperature

This test was performed at -20.000 mm with the 20XDI objective. Due to temperature changes the focus distance did not remain constant, so at the highest temperature the autofocus finished at the position of -19.9708 mm.

The system was taking measurements during the entire temperature change process, and a series of 10 consecutive measurements was selected for each temperature. The range of temperatures was 25 - 32.5 ºC. Two thermocouples measured temperature; one was glued with thermal grease to the system measuring its temperature and the other thermocouple measured room temperature 1 or 2 cm from the system. This test lasted one entire day.

In order to perform the heating curve, the air conditioning was set at maximum power, but the room's equilibrium was at 24.0 ºC. Then air conditioning was turned off and data acquisition was initiated. 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 temperature over time, noting that the step temperature changes correspond to the mentioned changes in the heating process:

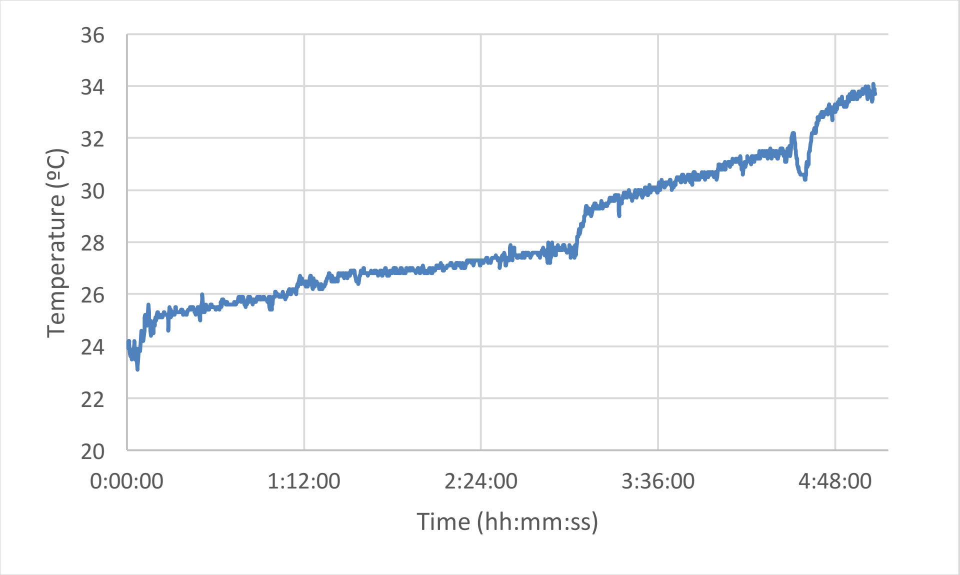


Figure 30. Room's temperature on heating process.

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.

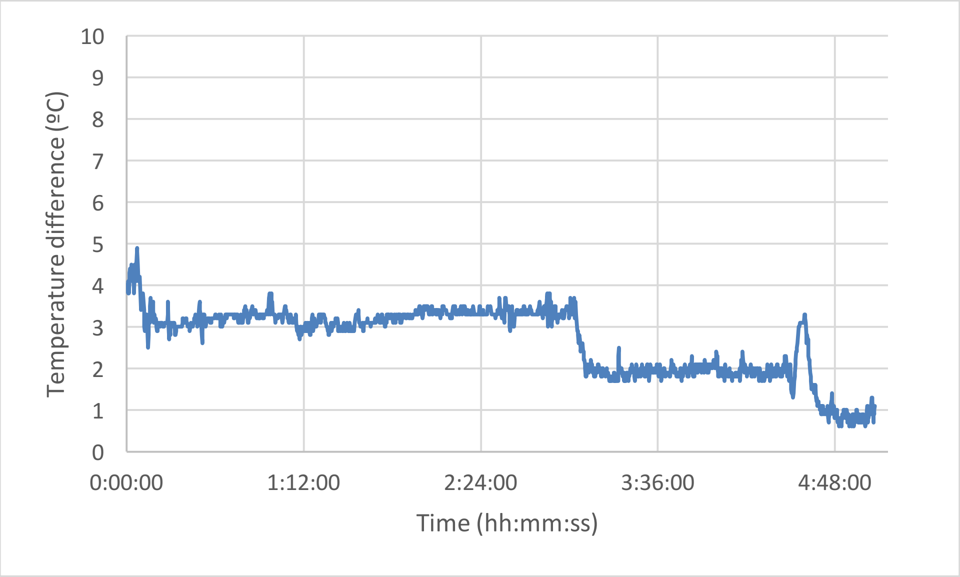


Figure 31. Temperature difference between the system and the room on heating process.

For each linear behavior zone of **¡Error! No se encuentra el origen de la referencia.**, a linear fit is made and with the equation obtained for each 0.5 ºC temperature difference the time of measurement is obtained. Then the series of 10 measurements after this specific time is averaged in order to obtain the following figures:

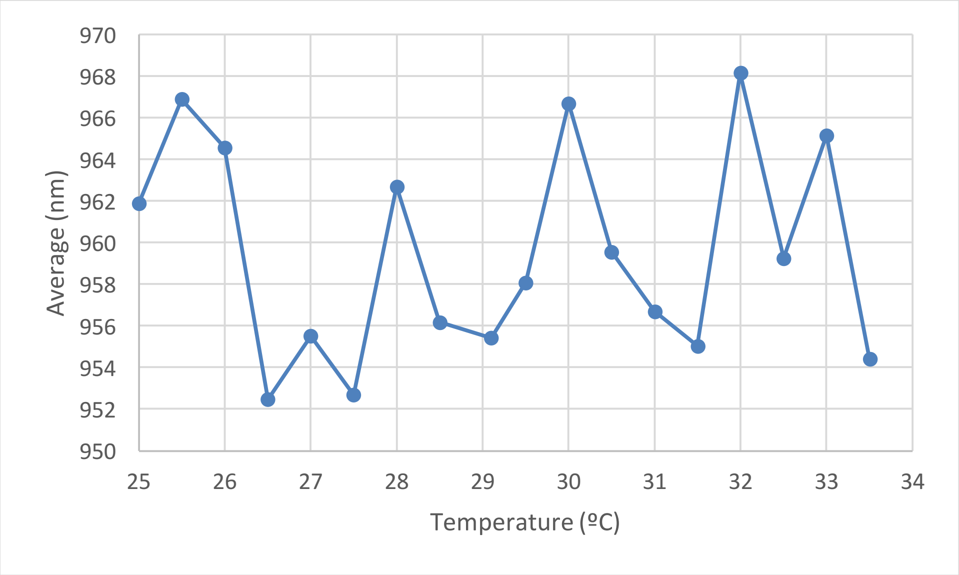


Figure 32. Heating curve on SHS-9400.

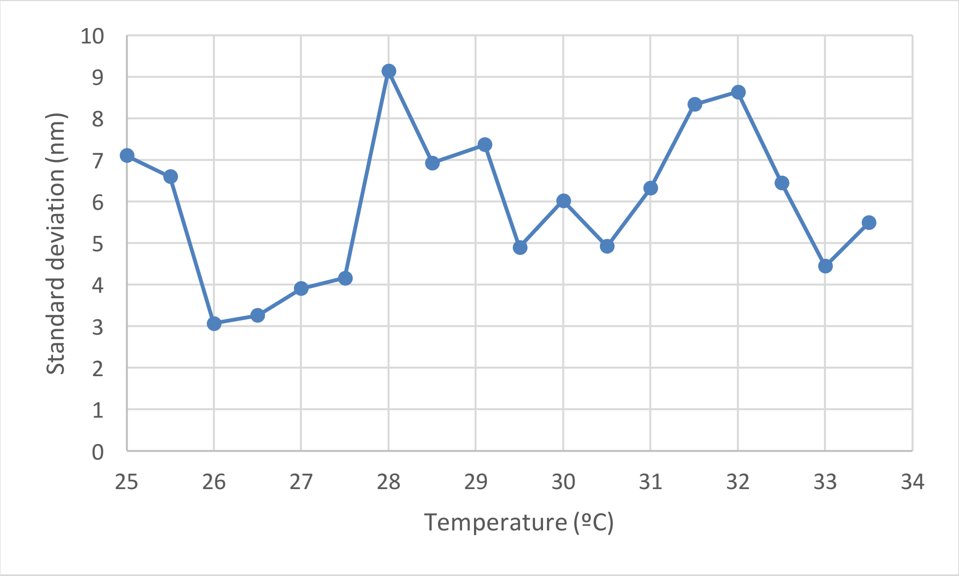


Figure 33. Heating curve on SHS-9400.

It is remarkable that high values of repeatability correspond to fast temperature changes, so when the temperature curve is linear with low slope, repeatability is expected to remain below 7 nm.

The cooling process only consisted on turning off the heater and letting the room reach equilibrium. The following figure shows this process.

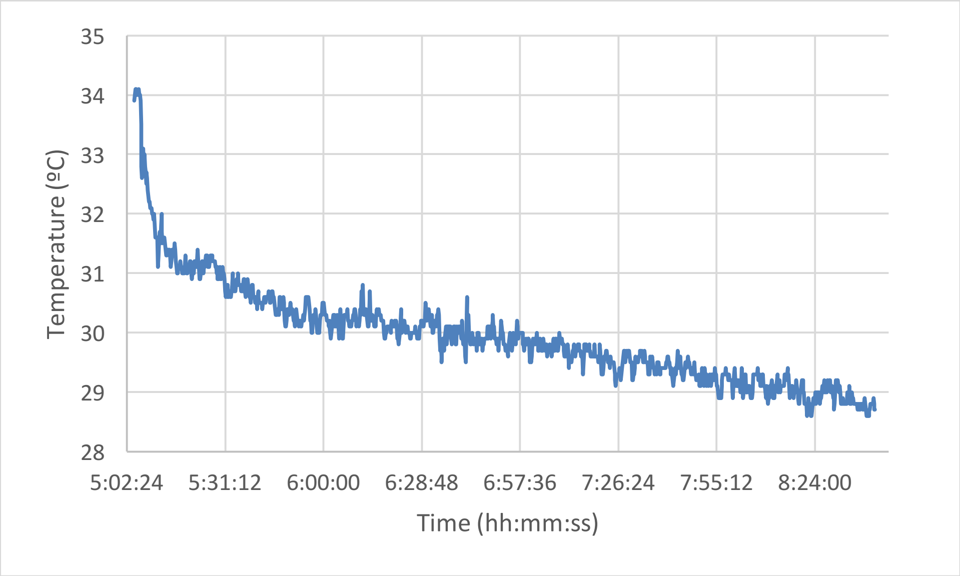


Figure 34. Room temperature on cooling.

The same data processing of the heating was followed on the cooling process. The results are shown in the following figures:

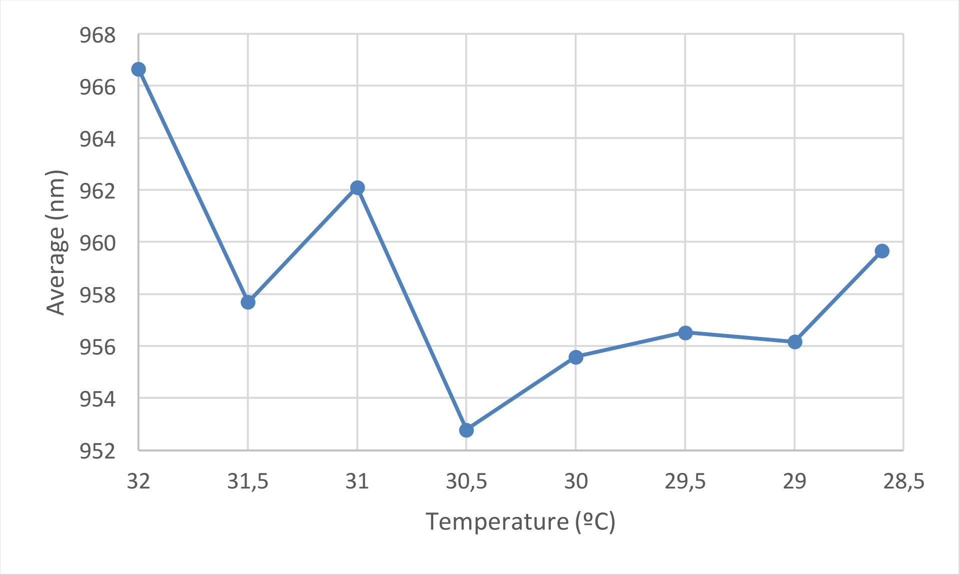


Figure 35. Cooling curve on SHS-9400.

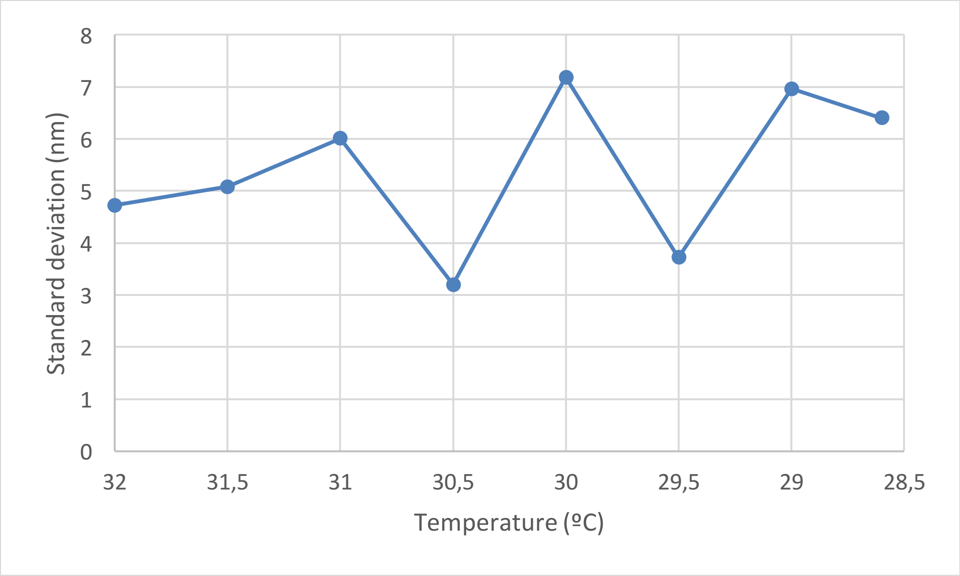


Figure 36. Cooling curve on SHS-9400.

In order to fully understand the behavior of S onix it was necessary to know how much time the system needed to stabilize once it had been turned on. this turned out to be about 40 minutes to fully stabilize with room temperature:

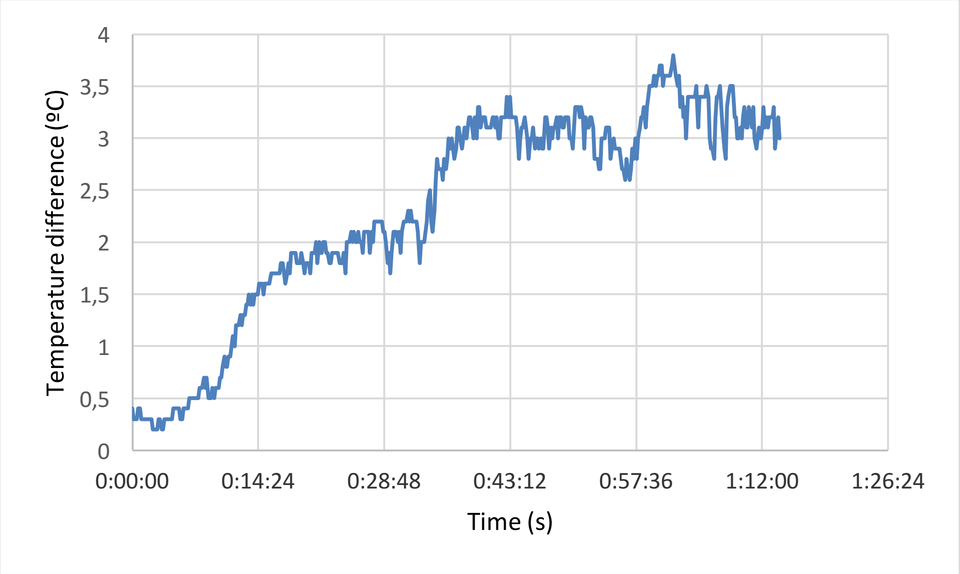


Figure 37. Cooling curve on SHS-9400.