Non-contact Surface Profiler Specification

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REVISION HISTORY

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		Addition of acceptance tests, written by Dr. Kathy Creath (consultant, Optineering Consulting Services).	Kathy Creath
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			Kathy Creath

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1.0 INTRODUCTION

1.1 PURPOSE

An optical metrology laboratory will be set up at the Canadian Light Source, Inc. (CLS) to characterize the figure and the finish of the beamline optics. This document contains the technical specification for the non-contact surface profiler within this facility.

1.2 SCOPE

This document specifies the requirements for the CLS Optical Metrology Laboratory non-contact surface profiler. This work includes, but is not limited to:

- Equipment
- Function and Performance Requirements
- Fabrication
- Testing & Inspections
- QA/QC documentation
- Delivery to the CLS site
- Assistance in setting up the non-contact surface profiler at CLS

1.3 BACKGROUND

The Canadian Light Source is a national scientific research facility under construction at the University of Saskatchewan campus in Saskatoon, Saskatchewan, Canada. The CLS is a 3rd generation synchrotron light source, that will house a variety of scientific beamlines and their associated optics. This synchrotron facility will be a high intensity source of infrared, visible, ultraviolet, and x-ray radiation.

The CLS optics metrology laboratory shall be dedicated to optical surface characterizations in terms of figure, slope errors, and surface roughness. Measurements are generally carried out on the optical surface in non-contact mode, using optical instruments. The beamline mirrors will range in size from ~0.025m to 1.5m in length, and consist of a variety of substrate materials (i.e. Zerodur® glass ceramic, ultra low expansion glass ceramic- ULE®, fused silica, silicon, silicon carbide, Glidcop®) and reflection coatings (rhodium, platinum, gold, nickel, graphite, or none). Typical reflectivities for the optics are >80%, both in the visible and x-ray regions. These optical elements can be quite large and heavy. A typical “long” mirror made of copper alloy may be 1.5 m (length) x

100 mm (width) x 100 mm (height) in dimension, and weigh approximately 134 kg (~295 lbs).

In general the optics will be either planar or concave/convex aspherics, including cylinders, spheres, elliptical cylinders, ellipsoids, toroids, parabaloids and hyperboloids. Table 1 illustrates the current CLS range of mirror/grating specifications, including the expected variations in the radii of curvature. The table does not currently include any supersmooth mirrors, although CLS has a keen interest in their future potential. Many of the mirrors will contain mirror-bending mechanisms, to vary the focus somewhat. Since many of the mirrors will be used in the x-ray regions, state of the art slope errors will be required, often below 1 µrad rms. Surface roughness is also critical in the x-ray region, so that most mirrors will require smaller than 2 Å rms surface roughness. Some supersmooth mirrors will fall below an average surface roughness of even 1 Å rms.

Table 1: Summary of CLS Mirror/Grating Specifications

Measurement[1]	Minimum	Maximum	Tolerance (± %)
Toroid or Cylinder Mirrors:			
Radius of curvature- tangential[2]	0.115×10^3 m	10×10^3 m	<0.1[2]
Radius of curvature- sagittal[2]	0.035 m	0.833 m	<0.1[2]
Spherical Gratings:			
Radius of curvature	~2 m	~100 m	<0.1
Slope error- tangential (rms)[3]	1 µrad	12 µrad	<10
Slope error- sagittal (rms)[3]	5 µrad	25 µrad	<10
Surface roughness (rms)[4]	1 Å	15 Å	<15

1 Clear aperture (width) general ranges from 25-60 mm. Width of optic is larger than this, but <~100 mm. Average clear aperture (width) ~30-40 mm. For these optical elements, the photon beam footprint generally underfills the clear aperture.
Occasionally 2-3 stripes of different reflective metals are put down, for harmonic order rejection and light intensity optimization.
Length of optics varies tremendously, from 25-1500 mm, and generally >90% is clear aperture (length).

2 Desirable tolerances. It is understood that different measurements are required for sagittal and tangential radius of curvatures (ROC's). The tolerance of <±0.1% can be often be relaxed to <±1%, if one has the freedom to alter the angle of incidence on the mirror by a few %.

3 For plane mirrors, slope errors <0.5 µrad are sometimes required.

4 For measurements on supersmooth planar mirrors, minimum~0.2 Å, maximum=1 Å, tolerance<±10%.

2.0 REQUIREMENTS

The CLS optical metrology laboratory requires a complete high resolution non-contact surface profiler to measure the three dimensional surface profile of these beamline optics. Both 2D and 3D surface metrology measurements of the test surface are required. From the surface profile, required parameters like the surface roughness, slope profile/error and power spectral density need to be derived. The instrument will be located within a class 10000 cleanroom.

A surface profiler is an instrument that measures the 3D microscopic topography (finish) of optical surfaces. When operated with a low power objective (i.e. 5X), the field of view can be as wide as ~1 mm^2, while with a high power objective (i.e. 50X) submicron lateral resolution can be obtained. Light from the microscope divides within the interferometric objective; one portion of the light beam reflects from the test surface, while the remaining portion reflects from an internal high quality reference surface in the objective. Both portions are then directed onto a solid-state CCD camera detector. Interference between these two light waves results in an image of light and dark bands, called fringes, that indicates the surface structure of the test optic.

The test part is scanned vertically by moving the objective with a piezoelectric transducer (PZT). In order to accommodate our "large" optics, the phase shifting hardware must be located in the microscope head of the non-contact surface profiler and cannot be located in a support stage. As the objective scans, the camera pixel intensities are captured by a video system and displayed on a video monitor. These intensities can also be processed into colour images representing the three dimensional surface height using the supplied instrument control software, and displayed on a colour monitor. Vertical measurements, normal to the test surface, are performed interferometrically. Lateral measurements, in the plane of the surface, are calculated from the camera pixel size and the objective field of view used.

2.1 FUNCTION

2.1.1 A complete high resolution non-contact surface profiler system is to be supplied. This should include the halogen lamp source (with filters) and controller/power supply, PZT with amplifier and power supply, CCD camera detector with associated controller electronics and power supplies, other necessary electronics and power supplies, interface cables, system and power cables for AC power operation, computer and required instrument interface boards, and software for control of the non-contact surface profiler and for data analysis. A list of required equipment to be supplied is furnished below. In addition, a list of optional equipment/service is supplied.

Non-contact Surface Profiler (Required equipment to be supplied)

System

Measurement capability	3D non-contact surface profile measurements
Measurement techniques	Non-contact three-dimensional interferometric surface topography measurement. Phase measurement mode required for measurement of supersmooth surfaces. Scanning white-light interferometry mode desirable.
Light Source	Halogen lamp with manually operated filter stage is sufficient. "Appropriate" filters should be included to optimize the performance of the instrument, and be well characterized.
Objective Magnifications	5X, 10X, 20X, 50X Parfocal objectives are highly desirable. Objective working distances are to be maximized due to the nature of the test surfaces, and should be ≥3 mm for all objectives.
Zoom	Not required.
Objective Mounting	Manual Turret (5-position), ≤4 inch diameter. A smaller diameter turret is preferred, below approximately 4" diameter, due to the geometry of the test surfaces and a need to access all points on the mirrors. It is highly desirable to have a removable turret in order to use a single objective mount that can access measurements of "hard-to-reach" spots.
CCD Camera, Spatial Sampling	≥ 512 x 480 pixels, user selectable
Digitization	≥ 8 bits
Fringe viewing	Live video output should be available, and displayed on a ≥ 9 inch black and white video monitor.

Phase Shifting and Scanning	The phase shifting (PZT) and scanning hardware must be located in the microscope head. It cannot be located in the support stage due to the size and mass of the test optics.
Sample stage	A manual (tip-tilt and X-Y) stage is required for the initial acceptance testing and "learning how to operate" stage. The stage should be able to hold an ~6 inch square item, have ~ ±50 mm manual motion in the X and Y direction (≤1 µm resolution), ~ ±6° of manual tip-tilt adjustment (≤1 arcsecond resolution), and maximum load capacity of ~6.8 kg (15 lbs.). The stage should be "metric"-i.e. micrometer readings if available should be in mm or µm. **Note:** This manual tip/tilt stage will not be sufficient for testing on our "large" mirrors, for which the CLS will have to purchase or build a more substantial tip/tilt stage, perhaps coupled with (X,Y,Z) motion.
Microscope "Geometry"	Should be able to perform measurements over the entire test optical surface, that is up to 150 mm in height, 150 mm in width, and 1.5 m in length.
Vertical positioning - Microscope head to sample	Manual, ≥150 mm.
Instrument mounting	A mounting kit to rigidly attach the surface profiler to a "metric" vibration isolation table (based on 25 mm hole separation and M6 tapped holes on the top surface) is to be supplied.
Focusing	Manual preferred, but automatic focus will be considered.
Sample reflectivity	Should be able to measure samples with 1% to 100% reflectivity.

Computer and Software

A minimal computer system would consist of the following components:

1. ≥Pentium III CPU (≥1 GHz speed)
2. ≥17 inch, ≥SVGA colour monitor
3. ≥256 MB RAM
4. ≥20 GB Hard Drive
5. CD-RW drive
6. 3.5 inch 1.44 MB Floppy disk drive
7. mouse
8. keyboard
9. RS-232 interface
10. parallel port (minimum of 1)
11. no printer required, but software must support printing to network printer
12. 10/100 Mbps ethernet network card (100BaseT)
13. interface boards required to control the non-contact surface profiler
14. computer cables and interface cables to the non-contact surface profiler
15. computer operator's manuals
16. Microsoft Windows 2000 Professional or XP Professional operating system preferably, supporting TCP/IP for networking (no NetBEUI, netware, etc.)

See sections 2.1.3 and 2.1.4 for additional details on computer/software requirements.

Optional Equipment/Service

reference standards for instrument calibration	1) Lateral calibration standard(s). These are to determine the magnification calibration for the objectives. They should have a useful range for magnifications between 5X-50X. NIST traceable preferred. 2) An approximately 25 mm wide precision reference flat (SiC preferred) with flatness ≤12.5 nm (≤125 Å) and surface roughness ≤0.2 nm (≤2 Å). NIST traceable preferred. 3) A step height standard, to calibrate the Z-direction motion. Since vertical structure in some of our holographic gratings is ≤100 nm, a similar step height to match would be ideal. The step height standard should be composed of a single material, overcoated with a highly reflective metal coating (>80% reflectivity). NIST traceable preferred.
recommended spare parts	A schedule of recommended spare parts should be included, with pricing.
vibration isolation table	Pneumatic (air) vibration isolation table [“metric” standard- based on 25 mm hole separation and M6 tapped holes on top surface, 6 ft length x 4 ft width x 8 inch thickness, cleanroom standard, with ≥4 isolation legs, compressed air interconnects and filtering].
Service Options	List all applicable for the first year, that go beyond the standard warranty (e.g. extended warranty, priority support, etc.).

2.1.2 The non-contact surface profiler needs to be capable of measuring state of the art surface roughnesses [~≤0.05 nm (0.5 Å) Ra], such as that found with supersmooth mirrors.

2.1.3 The manufacturer shall provide the computer hardware and software required for the operation of the Non-contact surface profiler. Since the instrument will be located in a Class 10000 cleanroom, the system should be capable of printing to a network printer. The ethernet network card and software should be configured for DHCP over TCP/IP. Should the control software require an alternate operating system, our preferences are secondly Red Hat Linux 6.2 or higher, or thirdly Microsoft Windows NT.

We **request** that the manufacturer state what permission the control system software requires (i.e. administrator, power user, user, restricted user)- our preference is for user (or restricted user), so that a user cannot accidentally delete system files or alter configurations.

2.1.4 The software supplied by the manufacturer for controlling the non-contact surface profiler should allow the user to measure the surface roughness (using averaging and quasi-absolute measurement techniques), slope profile/error, amplitude/power spectrum, and power spectral density. "Automatic" software features (such as setting the light level on the CCD camera- to provide optimum signal to noise ratio) should be capable of being manually overridden. The software should be able to display the surface as a function of surface heights or spatial frequency, in either 2D or 3D formats.

2.1.4.1 File Specification and file compatibility: CLS needs to be able to compare measurements made on multiple instruments to look at different spatial scales. The ability to read in surface map files from other instruments is a plus. At the very least, the vendor needs to provide a description of their file format sufficient to enable reading of their data into a MathCAD array.

We **request** that the manufacturer outline the following issues with respect to the software supplied –

1. What type of Import/Export data file capabilities exist in the software? List the file formats that are supported for each. (JPEG, ASCII, etc).

   Can the software read/write data files from other instruments, from the same manufacturer? Specify details.

   Can the software read/write data files from other instruments, from different manufacturers? Specify details.

2. What file format conversion routines/programs (other than the Import/Export option) are there available?

3. Are dynamic link libraries (dll) supported for customized data file format input/output?

4. Are the file structures of the data collected by the instrument available in the documentation that will be made available upon purchase? If not, can the file structures required be obtained free of charge from the manufacturer? If not (to both prior questions), is this because the file structures are considered proprietary?

2.1.4.2 The software should support the ANSI 2D “R-values”, and their 3D “S-value” analogs. The following surface statistics are considered minimum requirements:

1. Extreme Amplitude Results - R_p, R_v, R_t, R_{max}
2. Averaged Extreme Amplitude Results - R_{tm}, R_z
3. Averaged Amplitude Results - R_z, R_a, R_q (rms)

2.1.4.3 The following slope results should be available- Peak, Valley, PV, rms, and average, in angular or "pitch" (rise/run) units.

2.1.4.4 In addition, the user should be able to filter the data using most of the following:

1. Average, low pass or high pass filters
2. FFT High Pass, Low Pass, Band Pass, and Band Reject filtering
3. Filtering to remove Plane, Sphere, or Cylinder figure from surfaces, which is of critical importance for our beamline optics. Removal of polynomials up to 4th order is desirable.

2.1.4.5 The software needs to have the capability of subtracting measurements on a point-by-point basis. It is necessary to have this capability at the level of a button or dialog box without having to prompt the user for a filename and manually subtracting files.

2.1.4.6 A topographic surface map representing the “instrument error” surface needs to be easily generated by the user. This surface is generated by averaging 15-30 measurements of a reference surface with randomly distributed roughness as the surface is moved between measurements. This “instrument error” surface will be affected by changes in the tip/tilt of any optical surface in the path so only the test surface should be tilted. Focus can be adjusted between measurements to ensure the best possible estimate of the “instrument error” surface. This “instrument error” surface needs to be able to be automatically subtracted from subsequent measurements without user prompting.

2.1.4.7 It is desirable to have an automatic mode for taking measurements that can be set up by the user. This mode should enable the user to set up measurement times or measurement intervals and save either all the data or save specific statistical and calculated data to a database.

2.1.4.8 Scale factors that can be calibrated are necessary for vertical and lateral calibration as well as scale factors that account for variations due to numerical aperture.

2.2 PERFORMANCE

Table 2 is a summary of the desired performance specification requirements for the non-contact surface profiler:

It is understood that performance specifications will depend upon the amount of averaging, the adjustment of focus and the environment the measurement is made in. CLS will provide a suitable measurement environment.

Ability to calibrate wavelength, magnification, vertical and lateral scale factors at all magnifications.

No fringe print through in any measurement.

As little sensitivity to focus and fringe adjustment as possible.

Table 2: Non-contact surface profiler Performance Specifications

Surface roughness measurements	The profiler should be capable of measuring state of the art surface roughnesses [~0.05 nm (0.5 Å) Ra], such as that found with supersmooth mirrors.
Reflectivity (sample)	Should be able to measure samples with 1% to 100% reflectivity.
Working distance	≥ 3 mm for all objectives Parfocal objectives are highly desirable.
CCD Camera	≥ 512 x 480 pixels
Vertical (Z) range	≥150 µm total range
Vertical (Z) resolution	≤ 0.05 nm (0.5 Å)
Lateral field-of-view on test surface	approximately 1 mm (5X objective) approximately 100 µm (50X objective)
Lateral resolution[1] (optical resolution)	approximately 2 µm (5X objective) approximately 0.5 µm (50X objective)
Ra repeatability[2a]	≤0.05 nm (0.5 Å)
Ra statistic repeatability[2b]	≤0.01 nm (0.1 Å)
Step Height repeatability	≤ 0.1% at 1σ

1 Objective dependent. Sparrow criterion at ~600 nm: point separation=0.5λ/NA

2a These numbers depend upon averaging, instrument stability and focus sensitivity.
Ra repeatability for this purpose is defined as taking 2 consecutive measurements without moving the test sample. Each measurement can include as many averages as necessary. The two measurements (topographic maps) are subtracted point-by-point and the Ra of this difference shall be ≤0.05 nm (0.5 Å).

2b Ra statistic repeatability – this is the repeatability in the statistic Ra calculated from one averaged measurement. The variation in this statistic from measurement to measurement without moving the sample shall be ≤0.01 nm (0.1 Å) (1 sigma over 16 consecutive measurements).

2.3 SAFETY AND ENVIRONMENTAL

2.3.1 The temperature in the Optical Metrology Laboratory Facility will be $23^{o}C \pm 1^{o}C$. The normal relative humidity is expected to vary between 20% and 55%.

2.4 APPLICABLE CODES, STANDARDS AND PROCEDURES

The manufacturer shall comply with the codes, standards, and procedures for the CLS[1], or identify in the quotation how they deviate.

2.5 QUALITY ASSURANCE

The manufacturer shall maintain and apply a quality assurance program compliant with ISO-9001 for the design, manufacture and testing of the equipment.

2.6 INSPECTION, TESTING AND COMMISSIONING

2.6.1 The manufacturer shall perform the acceptance tests outlined in Appendix A, to verify the performance specification requirements listed in Table 2. The acceptance tests and the test equipment used shall be reviewed and accepted by both parties.

2.6.2 The acceptance tests will take place at the manufacturer's plant before shipment, and then repeated after the non-contact surface profiler has been installed at CLS. The manufacturer is responsible for setting up, commissioning and acceptance testing the non-contact surface profiler at the CLS with the assistance of CLS personnel.

2.7 RELIABILITY AND MAINTAINABILITY

The manufacturer shall provide hard copies of an operating and maintenance manual for the non-contact surface profiler, including electrical drawings/wiring diagrams and AutoCAD or Visio drawings, as outlined in the CLS documentation specification[2]. Hard copies[2] of a spare parts list should be provided, with the manufacturer part numbers and current prices. The manufacturer shall also provide hard copies[2] of a detailed parts list, with original manufacturer's part number, name, address, and telephone number. An electronic version of these manuals, diagrams, drawings, and spare/detailed parts lists are to be provided on CD-ROM (in addition to the hard copies). All manuals, documentation and lists are to be written in English. In addition, software source code for the control program should be included on the CD-ROM (if this cannot be provided for proprietary reasons, a statement to that effect **must** be included in the supplied quotation documentation). The original third party component manuals (i.e. computer, {servo,stepping}-motors and controllers/encoders, power supplies, HeNe laser source, CCD array detector, etc.) should also be supplied.

2.8 VIBRATION AND ACOUSTIC NOISE

2.8.1 The vibrations in the main floor of the CLS hall have amplitudes in the sub-micrometer range, and should not affect the measurements. The manufacturer shall state any special requirements that might be required to mount the non-contact surface profiler to a vibration isolation table.

2.8.2 The non-contact surface profiler should be designed and fabricated to be relatively insensitive to vibrations and other environmental influences such as temperature and relative humidity.

2.9 SERVICES

2.9.1 The manufacturer shall state the detailed requirements for all services (for example- water [purity, pressure range, flow rate, recommended temperature range], pressurized air [purity and recommended filter equipment, pressure range], electrical services, etc.), needed for the operation of the non-contact surface profiler. Pressurized air, if required, shall not exceed 80 psi.

2.9.2 The electrical services available are 120 V AC and 208 V AC, 60 Hz. The manufacturer shall state the electrical services needed, including the power requirements for each voltage needed. CLS would prefer 120 V AC, 60 Hz service if possible.

2.10 OTHER REQUIREMENTS AND CONSTRAINTS

2.10.1 All documentation to the CLS shall be in English and conform to the CLS documentation specification [2].

2.10.2 The shipping containers shall be properly labeled in English to ensure proper care during shipment.

2.10.3 Crates shall be designed such that they can be moved using standard handling devices (forklift or pallet jack).

2.10.4 Tolerances and specifications, where not defined or difficult to achieve, are subject to negotiations.

3.0 REFERENCES

1 E. Matias, “Control System Technical Specification”, 7.4.39.1 Rev. 2, April 24, 2002.

2 D.S. Lowe, “CLS Documentation Specification”, 0.4.1.1 Rev. 2, December 14, 2000.

4.0 APPENDIX A:

Non-contact Surface Profiler Acceptance Tests:

The following tests will be performed using either reference surfaces supplied with the instrument by the manufacturer or using CLS supplied reference surfaces.

It is assumed that these tests are performed using a technique that subtracts errors due to the optics of the instrument (i.e. a quasi-absolute test of a statistically random surface) [1]. The "instrument error" surface to be subtracted is generated by averaging 15-30 measurements of a reference surface with randomly distributed roughness as the surface is moved between measurements. This "instrument error" surface will be affected by changes in the tip/tilt of any optical surface in the path so only the test surface should be tilted. Focus can be adjusted between measurements to ensure the best possible estimate of the "instrument error" surface.

Tests 1-4 only need to be done by the vendor.
Tests 5-13 can be affected by environmental and operator conditions and should be performed at both the vendor and customer sites.

1. Wavelength Calibration

   This may be combined with #2 (Vertical Calibration).

   This test will be performed at 5X magnification using a NIST traceable step height standard.

   A step height standard will be measured 10 times moving the step slightly between measurments. The average value of the step height (preferably a 2-sided measurement) will be used to determine a scale factor to adjust the effective wavelength so that the average value for the measured step height equals the certified traceable step height of the reference standard. Focus should be adjusted between measurements.

2. Vertical Calibration

   This test ensures calibration of scaling effects due to numerical aperture. The vendor may choose to provide data rigorously determining this effect (theoretically or empirically). Vertical calibration of scale factors for each magnification objective can use the same procedure as that for wavelength calibration with a step height standard.

3. Lateral Calibration

   This test can use a known reticle, grating or NIST traceable surface topography standard. A scale factor to adjust the magnification of each objective needs to be determined.

4. Lateral Resolution

   This test needs only be done for the 5X objective.

   For this test, the test surface will be tilted until interference fringes are no longer resolvable by the measurement. The maximum number of tilt fringes (or the peak-to-valley of the measurement) and the scaled magnification and wavelength will be used to determine the effective lateral resolution.

5. Fringe Print-through

   It is important that there is no fringe print-through onto surface maps when fringes are present during a single phase measurement.

6. Instrument Electronic Noise

   With the light blocked going to the detector, two frames of data will be registered from the camera. These 2 frames will be subtracted point-by-point. The Ra of the difference will be an indicator of how much electronic noise is present.

7. Focus Sensitivity

   It is understood that high precision measurements depend upon good focus adjustment. If automatic focus before each measurement is not available then this test needs to be performed. A user will focus the instrument before each of 2 measurements. A point-by-point difference will be taken between the two measurements. This will be done 8-10 times. The Ra of the difference measurements should meet the Ra repeatability specification.

8. Determination of Necessary Number of Averages

   This test will determine the number of averages that can be made that increase the performance of the instrument. In an ideal situation the Ra of the difference will be reduced by the square root of the number of measurements following the central limit theorem. However, there will be a point of diminishing returns and this test will determine that.

   Using a reference surface and nulling fringes, a series of difference measurements will be performed. For each difference measurement, 2 consecutive measurements are made by averaging a number of measurements. The Ra of the point-by-point difference is monitored as a function of the number of averages.

9. Measurement Stability

   These tests are preferably done using an automatic measurement mode that can be set up by the user to take measurements at specified intervals. It is a function both of the instrument and the environment.

   At a specified time interval 2 consecutive measurements will be made with averaging without moving the sample or adjusting the instrument. A point-by-point difference will be made of these 2 measurements. The Ra of this difference will be recorded.

a. Short Term – Every 1 minute over 15 minutes.

b. Longer Term – Every 15 minutes over 4-6 hours

10. Ra Repeatability

It is understood this specification will depend upon averaging, measurement stability and focus sensitivity.

Ra repeatability for this purpose is defined as taking 2 consecutive measurements without moving the test sample. Each measurement can include as many averages as necessary. The two measurements (topographic maps) are subtracted point-by-point and the Ra of this difference shall be ≤ 0.05 nm (0.5 Å).

11. Ra statistic Repeatability

This is the repeatability in the statistic Ra calculated from one averaged measurement. The variation in this statistic from measurement to measurement without moving the sample shall be ≤ 0.01 nm (0.1 Å) (1 sigma over 16 consecutive measurements).

12. Step Height Repeatability

This will be measured at 5X using a NIST traceable step height standard. The height of the step as determined by the software (preferably a 2-sided step calculation) will vary by ≤0.1% (1σ) over 16 measurements made without moving the step. Focus may be adjusted between measurements and averaging is assumed.

13. Measurement of CLS Mirror

CLS will provide a sample test surface to ensure that satisfactory measurements can be made of the test surface. The performance specifications and the acceptance tests have been designed to ensure that satisfactory measurements can be made of CLS test surfaces.

Appendix A References:

1. Creath, K and Wyant, JC, “Absolute measurement of surface roughness”, Applied Optics, 29(26) 3823-3837 (1990).