

# Fizeau Interferometer Specification

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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 Fizeau interferometer within this facility.

### **1.2 SCOPE**

This document specifies the requirements for the CLS Optical Metrology Laboratory Fizeau interferometer. 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 Fizeau interferometer 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 3<sup>rd</sup> 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<sup>®</sup> glass ceramic, ultra low expansion glass ceramic- ULE<sup>®</sup>, fused silica, silicon, silicon carbide, Glidcop<sup>®</sup>) and reflection coatings (rhodium, platinum, gold, nickel, graphite, or none). Typical reflectivities for the optics are >80%, both in the visible and xray 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, paraboloids 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  $\mu$ rad rms. Surface roughness is also critical in the x-ray region, so that most mirrors will require smaller than 2  $\text{\AA}$  rms surface roughness. Some supersmooth mirrors will fall below an average surface roughness of even 1  $\text{\AA}$  rms.

**Table 1: Summary of CLS Mirror/Grating Specifications**

Measurement <sup>1</sup>	Minimum	Maximum	Tolerance ( $\pm$ %)
Toroid or Cylinder Mirrors: Radius of curvature- tangential <sup>2</sup>	0.115 x 10 <sup>3</sup> m	10 x 10 <sup>3</sup> m	<0.1 <sup>2</sup>
Radius of curvature- sagittal <sup>2</sup>	0.035 m	0.833 m	<0.1 <sup>2</sup>
Spherical Gratings: Radius of curvature	~2 m	~100 m	<0.1
Slope error- tangential (rms) <sup>3</sup>	1 $\mu$ rad	12 $\mu$ rad	<10
Slope error- sagittal (rms) <sup>3</sup>	5 $\mu$ rad	25 $\mu$ rad	<10
Surface roughness (rms) <sup>4</sup>	1 $\text{\AA}$	15 $\text{\AA}$	<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  $\leq 0.1\%$  can be often be relaxed to  $\leq 1\%$ , 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  $\mu$ rad are sometimes required.
- 4 For measurements on supersmooth planar mirrors, minimum~0.2  $\text{\AA}$ , maximum=1  $\text{\AA}$ , tolerance< $\pm 10\%$ .

## 2.0 REQUIREMENTS

A Fizeau interferometer system takes waveform data by combining the path of light reflecting off the test optic with the path of light reflecting off an internal reference. When the two paths combine, the light waves interfere to produce a pattern of fringes. A piezo-electric transducer (PZT) shifts a series of these fringes by  $\lambda/4$ , and is sometimes referred to as the phase shifter. The computer processes the data to calculate the optical wavefront phase errors. The result of a measurement, after computer analysis of the optical wavefront phase errors (calculated from the optical path difference between the two beams), is a three dimensional plot of the surface topography of the test optic.

The CLS optical metrology laboratory requires a complete high resolution Fizeau interferometer system [switchable between horizontal and vertical (looking down) configurations] to measure the slope profile/slope error, radius of curvature, surface irregularity and power spectral density (PSD) of the optical surface under test. The instrument will be located within a class 10000 cleanroom. Both normal (single pass) and grazing incidence (double pass) measurements will be made. Radius of curvature measurements using an interferometric radius scale and the “cat’s eye/confocal”<sup>[3]</sup> position technique will be required. Surfaces up to 1.5m (length) x 100 mm (width) x 100 mm (height) in dimension and ~134 kg (~295 lbs) in weight will be measured. Surface reflectivities for the test optics are typically quite high in both the visible and x-ray regions (> 80%), so that “coated” transmission and reference flats and an attenuation filter will be required to produce good contrast sinusoidal fringes. A general design goal of the system is to maintain, where possible,  $\geq \lambda/20$  surface error.

### 2.1 FUNCTION

2.1.1 A complete 6 inch Fizeau interferometer system is to be supplied for “horizontal configuration” (with an option for vertical mounting), and operating at the helium-neon laser wavelength of 632.8 nm. This should include the laser beam source and power supply, PZT with amplifier and power supply, CCD camera detector with associated electronics and power supplies,  $\lambda/20$  surface error optics and mounts to carry out normal (single pass) and grazing incidence (double pass) measurements on highly reflective test optics, power supplies, electronics, interface cables, system and power cables for AC power operation, computer and required instrument interface boards, and software for control of the Fizeau interferometer and for data analysis.

An interferometric radius scale with 2 meter precision guide bar, and a 4 inch f/7.2 transmission sphere (standard type,  $\lambda/20$  surface error, 4% reflectance), will be required to measure the radius of curvature of concave optical elements. This should consist of a high-precision

displacement measuring interferometer with fiber optic pickup, stable heterodyne laser head, baseplate, target retroreflector and mount, power supplies, electronics, computer interface boards, interface cables to the control computer, and software to support radius of curvature measurements. Measurements will be taken at the “cat’s eye” position and “confocal” position (manual motion from user), from which the radius of curvature will be calculated from the software supplied.

## Fizeau Interferometer Specifications (Required equipment to be supplied)

### System

Configuration	Horizontal (i.e. Fizeau laser beam output is horizontal)
CCD Camera, Spatial Sampling	$\geq 640 \times 480$ pixels
Digitization	$\geq 8$ bits
Fringe viewing	Live video output should be available, and displayed on a $\geq 9$ inch black and white video monitor.
Remote	Control for zoom, intensity, aperture focus, alignment mode, and new measurement.
Average Modes	Intensity and phase

### Laser

Laser Type	Helium-Neon
Wavelength	632.8 nm
Test beam diameter	6 inch
Coherence Length	$> 100$ m

### Optical

Zoom Range/Encoder	$\geq 6X$ (continuous, operable via remote) Zoom encoder <b>not</b> required- the zoom will be manually calibrated. See section 2.1.4 for a related discussion.
Aperture Focus	$\pm \sim 1$ m
Alignment System	“Twin spot” system with reticle, with $\pm 2$ degrees alignment field of view (FOV) range, and pupil focus range of $\pm \sim 1$ m.
Optical Centerline	$\geq 100$ mm (in height)
Output beam of Mainframe	A two-axis mount (tip/tilt) is required for transmission elements, such as the transmission flat and transmission sphere listed below <sup>s</sup> .

6 inch transmission flat <sup>§</sup>	$\lambda/20$ surface error, ~20% reflectance [Clapham-Dew type reflective coating or equivalent (e.g. Dynaflect™), suitable for highly reflective surfaces with reflectivities from 4-100%]
4 inch transmission sphere <sup>§</sup>	standard type, $\lambda/20$ surface error (f/number of 7.2), 4% reflectance
6 inch reference flat	$\lambda/20$ surface error, 90% reflectance
optical table mounting kit	To mount the Fizeau interferometer to a vibration isolation table [“metric” standard- based on 25 mm hole separation and M6 tapped holes on top surface].
Adapter (6 inch to 4 inch)	To allow mounting of a 4 inch transmission sphere.
Adjustable Mount	6 inch, 2-axis (tip/tilt) to allow mounting and adjusting the 6 inch reference flat, for use in grazing incidence measurements (double pass).
4 inch attenuation filter	( $\lambda/20$ surface error if possible, else $\geq\lambda/10$ surface error), to be used for radius bench measurements using the 4 inch transmission sphere.
Interferometric Radius Slide	This should consist of a high-precision displacement measuring interferometer with fiber optic pickup, stable heterodyne laser head, baseplate, target retroreflector and mount attachments for a 3-axis mount, power supplies, electronics, computer interface boards, interface cables to the control computer, and software to support radius of curvature measurements. Measurements will be taken at the “cat’s eye” position and “confocal” position (manual motion from user), from which the radius of curvature will be calculated from the software supplied.
Guide Bar	2 meter length precision ground bar with attachments for mounting to a vibration isolation optical table [“metric” standard- based on 25 mm hole separation and M6 tapped holes on top surface].

## **Computer and Software**

A minimal computer system would consist of the following components:

1. Pentium IV CPU ( $\geq 2$  GHz speed)
2.  $\geq 17$  inch,  $\geq$ SVGA colour monitor
3. 512 MB RAM
4.  $\geq 20$  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 Fizeau interferometer and interferometer radius scale
14. computer cables and interface cables to the Fizeau interferometer and interferometer radius scale
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 software requirements.

## **Optional Equipment/Service**

reference standards for instrument calibration	Lateral calibration reference or reticle. 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, 12 ft length x 6 ft width x 12 inch thickness, cleanroom standard, with $\geq 6$ isolation legs, compressed air interconnects and filtering].
Vertical orientation mounting kit	For vertical (looking down) configuration. This may be useful to test certain vertically deflecting optical elements. The kit should mount to a vibration isolation table ["metric" standard- based on 25 mm hole separation and M6 tapped holes on top surface].
4 inch transmission sphere	standard type, $\lambda/20$ surface error (f/number of 3.3)
6 inch reference flat	$\lambda/20$ surface error, 4% reflectance
6 inch transmission flat	$\lambda/20$ surface error, 4% reflectance
Mount for test optic	<p>This will be used for initial testing purposes on small optical elements— CLS will eventually have to build/purchase a custom mount to support optical surfaces up to 1.5m (length) x 100 mm (width) x 100 mm (height) in dimension and ~134 kg (~295 lbs) in weight.</p> <p>A standard high accuracy 5-axis mount with x, y, z, and tip/tilt adjustments will be required for initial test purposes, with <math>\pm \sim 6.25</math> mm (x,y) adjustment and <math>\pm \sim 25</math> mm z adjustment. The tip-tilt adapter should be capable of <math>\sim 1.5</math> degrees adjustment range, with <math>\sim 1</math> arcsecond resolution. A 6 inch self-centering three-jaw mount is to be supplied, with all attachments required to attach it to the</p>

	5-axis mount. The 5-axis mount should be capable of being upgraded to add a rotation mount (6 <sup>th</sup> axis).
Rotation mount	A 6 <sup>th</sup> axis for the test optic mount used for 3-flat test with detents every 90°.
Alignment fixtures for 3-flat test	Fixturing to enable the alignment of the center of the return flat relative to the optical axis of the interferometer and the point on the transmission flat defining the optical axis. This is necessary for accurately defining the point used as the axis of rotation for the 3-flat test analysis. This can be adjustable crosshairs that can be placed over the transmission and return flats in a semi-kinematic fashion.
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 Fizeau interferometer must be capable of measuring the following test optics: planar and concave/convex aspherics, including cylinders, spheres, elliptical cylinders, ellipsoids, toroids, paraboloids and hyperboloids. The expected variations in the radii of curvature are shown in Table 1. In addition, many of the mirrors will contain mirror-bending mechanisms, to vary the focus by varying the radius of curvature slightly. Measurement of state of the art slope errors will be required, below 1  $\mu$ rad rms.

2.1.3 The manufacturer shall provide the computer hardware and software required for the operation of the Fizeau interferometer. 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 Fizeau interferometer should allow the user to measure the radius of curvature using the interferometric radius scale, surface irregularity, surface and slope profile/error and power spectral density. The software should support manual calibration of the zoom and focus- so that conversion from pixels to actual distance can be performed (i.e. a zoom encoder should not be mandatory). "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.

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 user should be able to filter the data using most of the following:
    1. removal of Seidel aberration terms and polynomials up to 4<sup>th</sup> order
    2. Average, low pass or high pass filters
    3. Zernike polynomial filtering
  - 2.1.4.3 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.
  - 2.1.4.4 A topographic surface map representing the “instrument error” surface needs to be easily generated by the user. This “instrument error” surface needs to be able to be automatically subtracted from subsequent measurements without user prompting.
  - 2.1.4.5 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.
  - 2.1.4.6 Lateral scale factors that can be determined via a simple user procedure are necessary for calibration of any given zoom/focus combination.
  - 2.1.4.7 Ability to determine test surface radius of curvature (ROC) from a least squares fit of surface sag data.

## 2.2 PERFORMANCE

This interferometer will be used to measure surface irregularity and radius of curvature (ROC) in both sagittal and tangential directions of toroidal optical surfaces.

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 lateral scale factors at any zoom and focus position.

No fringe print through in any measurement.

As little sensitivity to fringe adjustment as possible (this is discussed more in the note pertaining to retrace error).<sup>6</sup>

Table 2 summarizes the desired performance specification requirements for the Fizeau interferometer:

**Table 2: Fizeau interferometer Performance Specifications**

Accuracy of PV statistic <sup>1</sup>	$\leq \lambda/200 (2\sigma)$
Repeatability of PV statistic <sup>2</sup>	$\leq \lambda/1000 (2\sigma)$
Repeatability of rms statistic <sup>2</sup>	$\leq \lambda/10,000 (2\sigma)$
Residual rms repeatability <sup>3</sup>	$\leq \lambda/1000 (2\sigma)$
Interferometric Radius Slide Resolution	$\leq 20 \text{ nm}$
Optical Resolution	$\geq 210$ fringes across the clear aperture at 1X Zoom
CCD Camera, spatial sampling	$\geq 640 \times 480$ pixels
Digitization	$\geq 8$ bits
Radius of Curvature (ROC) Measurement: ROC's: 35mm to 2m <sup>4</sup>  ROC's: 2m to 10km <sup>5</sup> Repeatability of ROC: 2m to 10km <sup>5</sup>	Desired performance (see notes)  $\pm 0.1\%$ with the aid of an interferometric radius slide  $\pm 1\%$ from a measurement of surface sag  $\pm 1\%$ from a measurement of surface sag
Retrace Error <sup>6</sup>	$\leq \lambda/100 (2\sigma)$ PV preferable (see note below)
Imaging system distortion <sup>7</sup>	Documented and defined by vendor

1 Value for peak-to-valley (PV) accuracy that reflects the overall system accuracy for absolute testing, as demonstrated by the repeatability of the three-flat test. Flat 'A' is tested six times using the three-flat test, using the six available pairs of flats B, C, D, and E to complete six three-flat combinations, with 16 phase averages per data set. The specification represents the  $2\sigma$  value of the variation of the P-V statistic. System accuracy for relative testing is dependent on the quality of the reference optics and system retrace error.

2

3 Repeatability of the quoted statistic is for 100 measurements of the same part; with 16 phase averages per data set. The specification represents the  $2\sigma$  value of each statistic.

4 Residual rms error of the point-by-point difference of two consecutive measurements, each consisting of an average of 16 sets of data. The

specification is derived from a sample of 100 measurements, and represents the  $2\sigma$  value from the mean value. Assuming measurement of differential distance between the confocal and cat's eye positions using an interferometric radius slide and an appropriate transmission sphere. It is assumed that this can be tested versus a known radius surface.

- 5 ROC's longer than 2m will be determined from surface sag data. This will be dependent upon retrace error (note 6) as well as distortion of the optical imaging system and calibration of lateral image scale. If this performance is not possible with a catalog instrument, the vendor will provide information on how well they can determine ROC from sag data using a catalog system. The repeatability of the ROC value determined from sag data needs to meet the performance specification.
- 6 This is of concern because CLS needs to measure long ROC's using surface sag data. Retrace errors can occur due to not being able to null the fringe pattern when measuring a toroidal surface. They are dependent upon alignment of the optics inside the system as well as the design of the optical system. Retrace error will be measured over a 6 inch aperture with 4 fringes of sample tilt using a transmission flat at 1X zoom with a return flat 1 cm from transmission flat. To remove errors due to the reference optics a measurement made with the fringes nulled will be subtracted point-by-point from this measurement. The retrace error is represented by residual PV after tilt is removed from this difference. Averaging can be used. The focus and zoom are not adjusted between measurements. This value needs to be characterized by vendor. If this result depends upon quality of the transmission flat and user alignment procedure, the vendor needs to specify what quality transmission flat is necessary and the procedure for alignment to minimize retrace error. CLS is willing to work with the vendor on this specification. Knowing how much correction is necessary is more important than meeting a specific performance specification.
- 7 Determination of long ROC's from sag data is dependent upon field distortion caused by the imaging system. This will depend upon the focus and zoom. The vendor should provide information estimating the distortion of their imaging system at 1X zoom for a fixed focal distance and give an idea of how this varies with focus position. Ray trace data are acceptable. This will enable the determination of correction factors to determine ROC from sag data.

## 2.3 SAFETY AND ENVIRONMENTAL

The temperature in the Optical Metrology Laboratory Facility will be  $23^{\circ}\text{C} \pm 1^{\circ}\text{C}$ . 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<sup>[1]</sup>, 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 Fizeau interferometer has been installed at CLS. The manufacturer is responsible for setting up, commissioning and acceptance testing the Fizeau interferometer 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 Fizeau interferometer, including electrical drawings/wiring diagrams and AutoCAD or Visio drawings, as outlined in the CLS documentation specification<sup>[2]</sup>. Hard copies<sup>[2]</sup> of a spare parts list should be provided, with the manufacturer part numbers and current prices. The manufacturer shall also provide hard copies<sup>[2]</sup> 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.

## **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 Fizeau interferometer. 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 <sup>[2]</sup>.
- 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.
- 3 Lars A. Selberg, "Radius Measurement by Interferometry", Optical Engineering 31(9), 1961-1966 (September 1992).

## 4.0 APPENDIX A:

### **Fizeau Interferometer Acceptance Tests:**

The following tests will be performed using either reference and transmission optics supplied with the instrument by the manufacturer or using CLS supplied optics that meet the vendor specifications. If the vendor prefers they can use their own optics for the acceptance tests at both locations.

These tests can be affected by environmental and operator conditions and should be performed at both the vendor and customer sites. CLS will provide an appropriate test environment to perform these tests.

#### 1. Lateral Calibration

This test can use a known reticle or calibration pattern. A scale factor to adjust the magnification at any zoom or focus position needs to be determined.

#### 2. Lateral Resolution

This test will be performed at 1X zoom.

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) measurable will be used to determine the effective lateral resolution.

#### 3. 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.

#### 4. 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 residual rms of the difference will be an indicator of how much electronic noise is present.

#### 5. Focus Sensitivity

It is understood that high precision measurements depend upon good focus adjustment. The instrument will be focused before each of 2 measurements. A point-by-point difference will be taken between the two measurements. The residual rms of the difference measurements should meet the residual rms repeatability specification.

#### 6. Determination of Sufficient 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 residual rms for a difference measurement 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 (usually environmentally dependent) and this test will determine that point. Using a return 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 residual rms of the point-by-point difference is monitored as a function of the number of averages.

#### 7. 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 residual rms 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

#### 8. Residual rms repeatability

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

Residual rms repeatability for this purpose is defined as taking 2 consecutive measurements without moving any optics. Each measurement can include as many averages as necessary. The two measurements are subtracted point-by-point and the residual rms of this difference shall be less than  $\lambda/1000$  ( $2\sigma$ ) (over 16 consecutive measurements).

#### 9. PV statistic repeatability

This is the repeatability in the statistic PV calculated from one averaged measurement. The variation in this statistic from measurement to measurement without moving the sample shall be less than  $\lambda/200$  ( $2\sigma$ ) (over 16 consecutive measurements).

#### 10. Retrace error

Retrace errors can occur due to not being able to null the fringe pattern when measuring a toroidal surface. They are dependent upon alignment of the optics inside the system as well as the design of the optical system. Retrace error will be measured over a 6 inch aperture with 4 fringes of sample tilt using a transmission flat at 1X zoom with a return flat 1 cm from transmission flat. To remove errors due to the reference optics a

measurement made with the fringes nulled will be subtracted point-by-point from this measurement. The retrace error is represented by residual PV after tilt is removed from this difference. Averaging can be used. The focus and zoom are not adjusted between measurements. It is desirable to have the residual PV due to retrace from this test be less than  $\lambda/100$  ( $1\sigma$ ).

11. ROC measurement with interferometric radius slide (IRS)

This will be performed with a known surface or tooling ball. The test surface will be aligned in the cat's eye position and nulled. The IRS will record the start position. The test surface will be moved to the confocal position and the fringes nulled. The IRS will record this end position. The value of the radius of curvature determined by the instrument software should be within  $\pm 0.1\%$  of the known value. The value of the ROC determined this way needs to be repeatable to  $\pm 0.1\%$  ( $1\sigma$ ) over 16 measurements.

12. Repeatability of ROC measurement from surface sag

ROC will be determined from surface sag data using a least squares fit to the data. The variation of the ROC value should be within  $\pm 0.1\%$  ( $1\sigma$ ) over 16 measurements.

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.