



Advanced LIGO Interferometer for Full Aperture Surface Figure Metrology

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1 Background

LIGO requires a large aperture interferometer to characterize the surface figure and roughness of the coated LIGO optics. The optics are of exceptional quality, of order 0.5nm rms, or better, with piston, tilt and power subtracted. In order to characterize the optics we desire measurement repeatability of order 0.1 nm rms or better. Environment is a significant contributor to measurement stability and repeatability. Seismic data for the laboratory are attached; we welcome recommendations for isolation and mounting equipment.

2 Scope

2.1 LIGO furnished equipment

LIGO will supply the transfer surfaces: All radii of curvature are convex in meters.

Flat (2ea)

34

36

1934

2245

LIGO will supply an optical bench as appropriate, thermal enclosure and mounts for the LIGO optics. The space allocated to measurement is 10' wide by 20' long. Computer control is next door.

2.2 Vendor furnished equipment

The vendor will supply an optical interferometer with a center measurement wavelength of 1064 nm and magnification capability.

Vendor will specify or provide coating for six LIGO supplied transfer flats to measure HR coated optics

Vendor will supply six mounting cells for the reference optics

Vendor will supply one Transfer cell interface so that LIGO can mount the flats to LIGO supplied tooling for three flat tests.

2.3 Vendor furnished services

The Vendor will install the instrument at Caltech and verify performance to this specification after installation.

The Vendor will mount the LIGO supplied transfer flats after coating. Mounting should not distort the surfaces by more than 10 nm peak to valley.

3 Instrument Requirements

Wavelength: 1064 nm

Advanced LIGO Interferometer for Full Aperture Surface Figure Metrology

Contrast: > 80% for each of the test cases; R= 4%, 50% and 100% at 1064 nm

Polarization: Source to be polarized linearly, parallel to the table

Short term repeatability: < 0.1 nm rms over the frequency range of each magnification aperture. Defined as the rms of the point-by-point difference between consecutive measurements taken within 1 minute. These measurements may be an average.

Retrace accuracy: < 1 nm peak to valley for 30 fringes of sample tilt with a flat

Fixed focus: One focal position will be used at all magnifications. The focal position is chosen to provide minimum cavity length, while allowing space for positioning a 370mm diameter optic.

Coarse alignment field of view: of order 2 degrees.

Performance Goals

- < 80 nm total budget for common path wavefront error
- Single pixel imaging, optical resolution is equal to the pixel spacing
- < 1 ppm wavelength knowledge
- < 1 pixel of shear

Focus and astigmatism

Camera:

- Number of pixels: minimum of 1024x1024
- Pixel aspect ratio: prefer square, but other acceptable as long as accounted for in software and instrument transfer function does not limit measurements in one direction.
- Digitization: prefer 10 bits or greater – We want the largest S/N possible. We realize true number of bits, sensor noise levels, and instrument performance are the most important limiting factors.
- Wavelength range: Near IR camera, if it improves the signal to noise ratio by >10%

Intensity (irradiance) control: Should be controlled near the source, not in the imaging side of the interferometer.

Ability to measure distortion and apply a correction mask on a pixel-by-pixel basis

3.1 Magnification

A list of optics to be measured can be found in appendix A. 370 mm is the largest optic diameter to be measured. LIGO optic characterization consists of full aperture measurements, coupled with statistical data from measurements with fine spatial resolution. Nominally, we would do this by applying the full camera detector over smaller apertures of interest.

Frequency range: Full aperture to 10/mm, with the range 0.1/mm to 1/mm covered in a single magnification. Otherwise, the frequency range may be covered by an optional number of fixed magnifications. The different magnifications should have sufficient spatial overlap to provide a consistent PSD of an optic. The ITF must be above 50% for any spatial frequency, or a shift to another magnification is required.

Magnification aperture coincidence: Full aperture is at least 380 mm, each magnification aperture axis is coincident with the axis of the full aperture within ± 2 pixels.



Advanced LIGO Interferometer for Full Aperture Surface Figure Metrology

Magnification aperture position repeatability: The optical axes for each magnification must be repeatable to within a tolerance grid of 3x3 pixels. This is defined as the change in position of an image feature (ie. Crosshair) after switching to a different magnification and back without realignment.

Measurement repeatability requirement: < 0.15 nm rms over the frequency range of each magnification. This is defined as the point-by-point difference between consecutive measurements separated by changing to a different magnification and back immediately. This applies to each magnification aperture.

Measurement repeatability goal: < 0.1 nm rms

4 Support equipment and software

4.1 Support equipment requirements

Due to thermal considerations, the controlling computer will be located in an adjacent room. Electronics should be able to support cabling of roughly 50 feet

Two alignment monitors, one each at the instrument and at the remote control console.

4.2 Required Software functions:

Require access to raw intensity and phase data

Software control of start phase for each measurement if applicable

Ability to apply Caltech algorithms to control phase shifting and calculate phase

4.3 Desired Software functions

Automatic means of rejecting data sets affected by vibration or that have a low signal to noise ratio.

Software to support creation of the distortion map

Ability to apply a pixel-by-pixel distortion map to the data

5 Acceptance test

Acceptance testing is performed at Installation. Demonstrate the following, per section 3:

Contrast: at all magnifications

Short-term repeatability: at all magnifications

Retrace accuracy: at all magnifications

Fixed Focus: at all magnifications

Imaging: at all magnifications

Demonstrate low aberrations.

Demonstrate axis alignment: at all magnifications

Aperture coincidence: at all magnifications

Aperture axis repeatability: at all magnifications

Aperture measurement repeatability: at all magnifications

Advanced LIGO Interferometer for Full Aperture Surface Figure Metrology

Appendix A: Properties of the Optics to be measured

Optic Name	Beam Splitter and Fold Mirror	Compensation Plate	Test Mass	R3 (PR3, F-PR3, SR3)
Size (mm)	370 x 60	340 x 130	340 x 200	265 x 100
ROC (m)	Flat	Flat	2245cc, 1934cc	34cc, 36cc
Reflectivity (%)	50, 100	AR/AR	98.6, 100	100
Special	45° optic, Measure at 0°	Measure in transmission	ROC to <1m, measure ITM in transmission	Measure with Transmission Sphere
Specification*	E080514 E080515	E080513	E080511 E080512	E080516 E080517 E080518
Drawing*	D080660 D080661	D080659	D080657 D080658	D080662 D080663 D080664

Table 1 note: *All specifications and drawings can be accessed at <https://dcc.ligo.org>

choose: Public User

Appendix B: LIGO past experience

Repeatability is highly dependent on environment. With our current environment and instrument (modified WYKO 6000) LIGO has been able to repeat measurements to 0.16 nm rms. We will be installing the new measurement system in a new laboratory, to be ready in early 2010. The new space is in the same building, but on the north side of the building, on grade in the sub basement. We can expect lower acoustic and seismic backgrounds than the current laboratory. A report comparing the seismic backgrounds in the two laboratories is attached in appendix C. Thermal variation in the current measurement space is less than 0.1 C° per day. We expect to achieve similar or better performance in the new laboratory.

Our current measurement philosophy is to average hundreds of data sets in a very stable environment. Adding a tight, conductive enclosure controls the thermal profile of the measurement environment. With this method we have found that alignment is stable to within a few tens of nanometers over hours of operation, so we do not require auto-nulling control. The cavity is aligned, then left for a few hours; there is a final tweak by momentary alignment motors to null the fringes before taking data.

Beam splitters and Fold mirrors will be measured at 0° angle of incidence, because the index of refraction noise induced by a 45° measurement with such large optics is unacceptable. Previous research indicates that coating design and thickness uniformity can be used in conjunction with a zero degree phase map to accurately predict the surface. Caltech is responsible for this analysis.



Advanced LIGO Interferometer for Full Aperture Surface Figure Metrology

Appendix C: Environmental conditions.

April 1st, 2008, comparison of Vertical Seismic noise in current Metrology Lab, new Metrology Rooms

The current lab is 39 Lauritsen, in the sub basement, above the machine shop. Two walls are below grade, two walls are plasterboard. Floor and ceiling are cement, 6" construction.

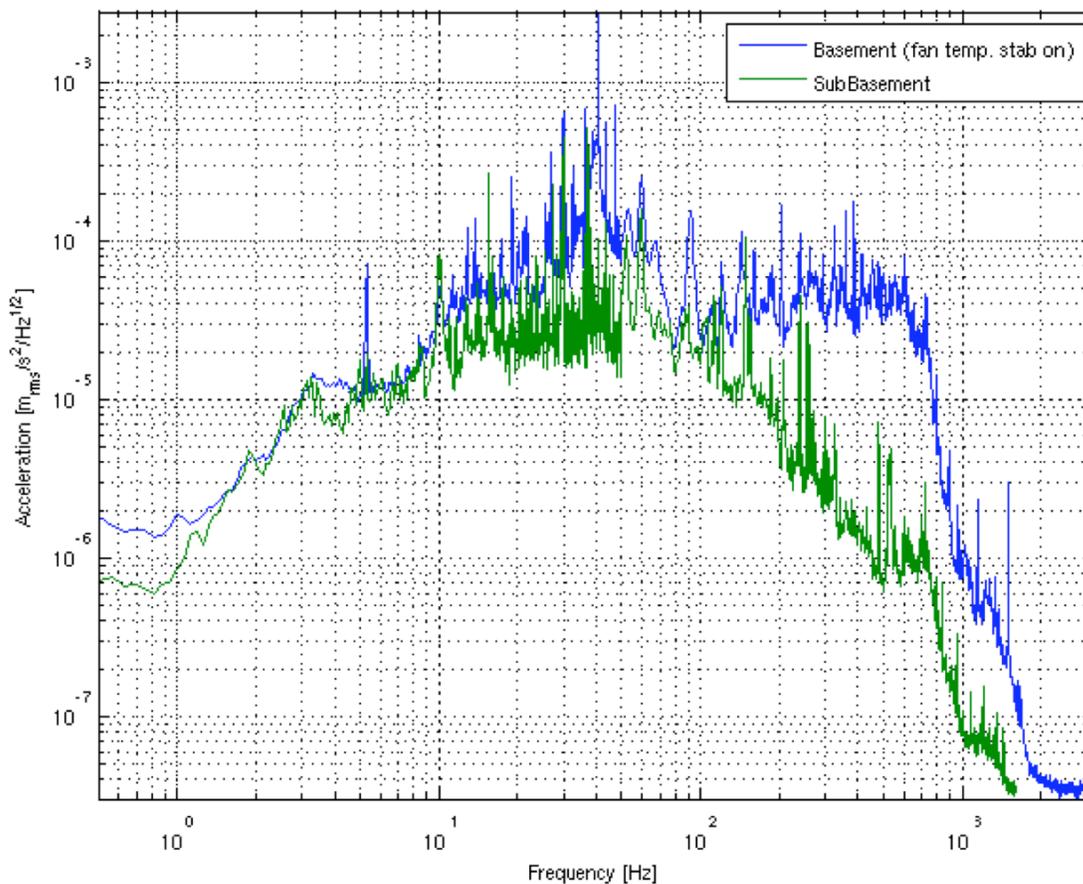
The new lab is 014 Downs, sub basement. The lab is on grade, with 12" concrete on one side, dirt fill on one side and plasterboard on two sides. The ceiling is 4" concrete. Office above.

Accelerometer: Wilcoxon Model 731A Driver: Wilcoxon P31

Driver Setup Gain 1000 V/g Filter 450Hz

Observation: First accelerometer. internal resonance is 1.166kHz, from manufacturer Transfer Function (TF) measurement, it should work well up to 500Hz.

Current (basement) and New (sub-basement) Rooms Vertical Acceleration Noise



Squareroot Power Spectra, calibration reliable from about 1Hz to about 500Hz



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Current (basement) and New (sub-basement) Rooms Vertical Displacement Noise

Squareroot Power Spectra, Calibration reliable from about 1Hz to about 500Hz

