Computer generated hologram (CGH) education kit for hands-on learning of optical metrology for complex optics and systems

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ABSTRACT

Arizona Optical Metrology supplies Computer Generated Holograms (CGHs) that are used around the world for projects in industry, research, and defense. CGHs enable high-accuracy snapshot measurements of complex optical surfaces, such as cylinders, rotationally symmetric aspheres, conic sections and freeforms. The growing markets that use such high-performance optics, along with technical advances in CGH capabilities, have created a demand for technical training in CGH metrology. AOM has produced a CGH education kit for the expressed purpose of donation to colleges and university optics programs for training students and faculty in the capabilities and usability that CGH metrology offers.

Keywords: Interferometry, computer-generated hologram, CGH, metrology, asphere, freeform, cylinder, acylinder, conic, education, optics, optics lab, optical testing

1. INTRODUCTION

Using the principles of diffraction, optical elements can be designed to create a specific wavefront of nearly any shape. Diffraction is a well understood optical phenomenon and can be controlled by design and manufacture to extremely tight tolerances using lithographic writing techniques. A Computer-Generated Hologram (CGH) is a diffractive optical element designed to produce a diffracted wavefront of a particular shape, often to match the shape of a particular optic. A CGH enables interferometric measurement of an optic's Surface Figure Error (SFE) or Transmitted Wavefront Error (TWFE).

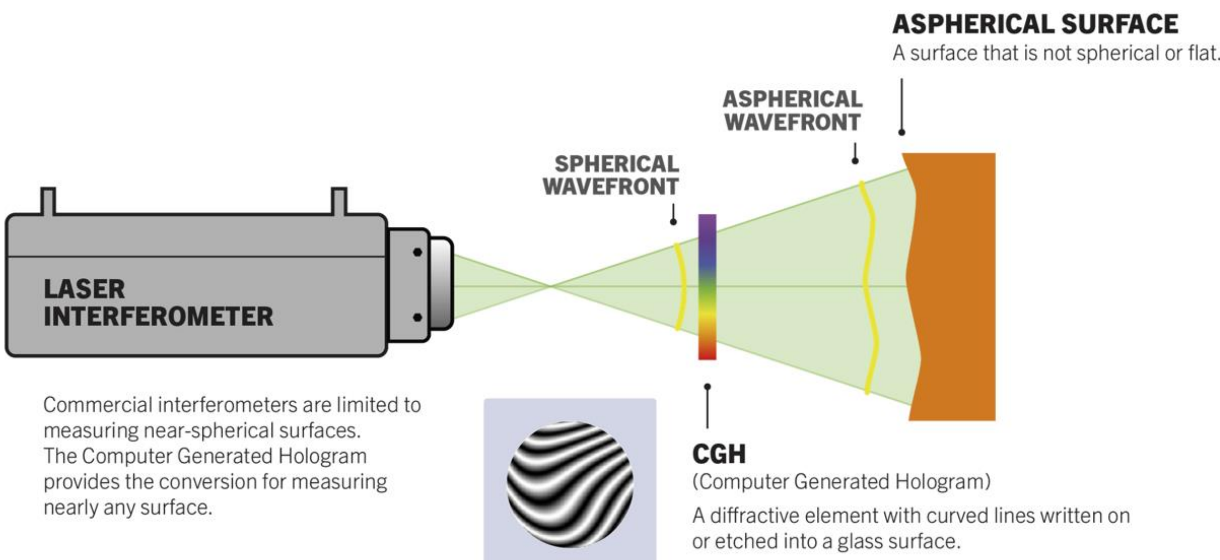

Fig. 1 Interferometric test layout of aspheric optical surface enabled by CGH null element

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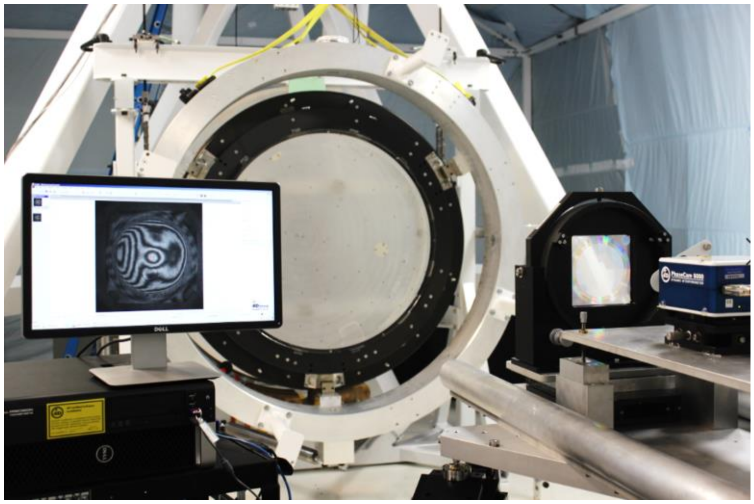

Fig 2. AOM CGHs were used for surface measurement, alignment, and final verification of the world's largest lenses for the Rubin Observatory (LSST)

The CGH Education Kit from Arizona Optical Metrology (AOM) walks the user through several examples of how CGHs work and how they can be applied, from the basics of diffraction to alignment features, and finally to measurements of optical surfaces like cylinders, aspheres and even a custom transmitted wavefront. The principles demonstrated by the CGH Education Kit can extend further to freeform and other complex optical shapes and alignment features that enable optical components or multi-element optical systems to be tested quickly and easily.

2. CGH EDUCATION KIT

The CGH Education Kit was developed by AOM to build understanding and provide hands-on experience for a variety of applications of CGH metrology. Combined with a standard interferometer, the kit includes everything needed to become a pro at CGH metrology.

2.1 Educational goals

The CGH education kit gives optics students and educators the tools to develop interferometric tests for complex and high-performance optics and systems and improve understanding of a critical optical engineering and fabrication skill. The CGH Introductory Metrology Kit includes educational materials, holograms, and complete hardware to teach the following:

1. Functional and mathematical understanding of diffraction and its application to CGHs and ultimately metrology
2. How to design a successful CGH test for optical components and systems
3. How to set up a CGH test and use features in the CGH for alignment
4. How to measure an aspheric surface, cylinder, and transmissive optical element
    a. Set up and align the test
    b. Collect the data
    c. Process the data
5. How to build an error budget to understand the accuracy of the measurement

2.2 Education kit contents

Combined with a standard commercial interferometer, the CGH Education Kit includes everything a user needs to create multiple CGH test setups and explore concepts in alignment and diffraction.

1. Computer Generated Holograms with interfaces for mounting into the FP3 stage

a. Diffraction Demo CGH (part number 7VM-P-S2-C3-BC): Has simple binary gratings to explore the effect of grating period, duty cycle, and phase vs. amplitude on diffraction efficiency.

b. Alignment Pattern CGH: (X3Q-A-S2-C3-BC): Illustrates three principles of optical alignment – 1) Coarse visual alignment of a focal spot, 2) Fine interferometric alignment from confocal reflection on a metal tooling ball, and 3) optical Line Focus Reference (Patent Pending) used with a corner cube. These patterns can be added to any CGH to aid in alignment of the test optic.

c. Cylinder CGH (QKU-P-S2-C3-BC): CGH for measuring a variety of cylindrical surfaces, much like a transmission sphere.

d. Asphere Surface CGH (C8N-A-S2-C3-BC): Used to measure Surface Figure Error (SFE) of an aspheric surface.

e. Asphere TWE CGH (O3P-A-S2-C3-BC): Used to measure Transmitted Wavefront Error (TWE) of an aspheric lens element, including surface-to-surface alignment.

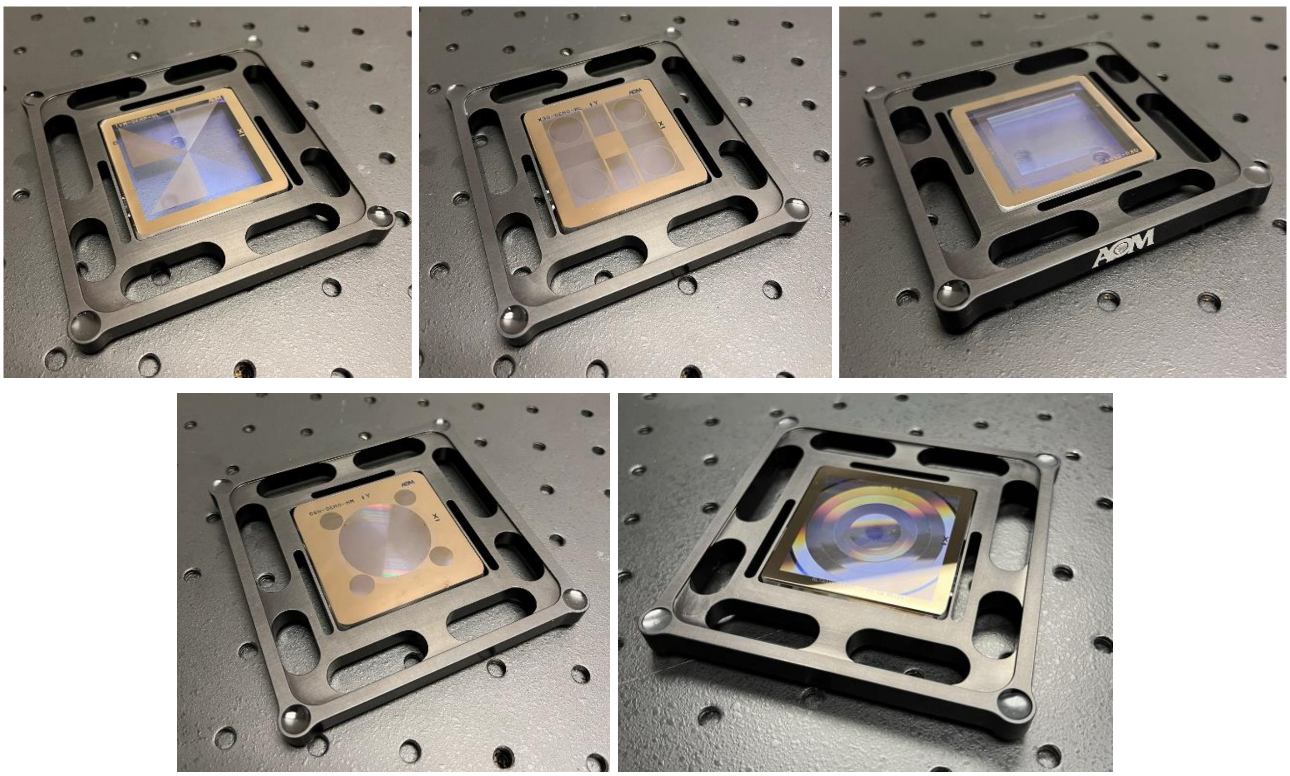

Fig 3. CGHs included in the CGH Education Kit – Diffraction Demo CGH (top left), Alignment Pattern CGH (top middle), Cylinder CGH (top right), Asphere Surface CGH (bottom left), and Asphere TWE CGH (bottom right)

2. Optical components for each CGH demonstration, each mounted in a cell for easy assembly and alignment using a provided 6 DoF alignment stage

   a. Alignment targets plate including photogrammetry target for coarse visual alignment of a point focus, corner cube retroreflector for return of a set of GuideStar™ line focus references providing independent alignment feedback, and a tooling ball for traditional confocal CGH alignment feedback, all mounted on an AOM C3 cell. The C3 cell mounts directly to the AOM FP3 stage for 6 DoF fine alignment.

   b. Aspheric lens mounted in a C3 cell.

   c. Convex cylinder and concave cylinder lenses, each mounted in a C3 cell.

3. FP3 6-DOF adjustment stage (Qty. 2) for mounting CGHs and test optics and providing 6 degree-of-freedom fine alignment and positioning CGHs and test optics at the nominal centerline height of the interferometer. Shown here with 6” centerline height riser.

4. Other included items

   a. Comprehensive user manual with step-by-step instructions for setting up each CGH test, and insights into the details of alignment and interpretation of data.

   b. Laser pointer for demonstration of the diffraction effects of monochromatic light through the Diffraction Demo CGH.

   c. Padded Pelican™ brand case for storage and transport of the entire kit

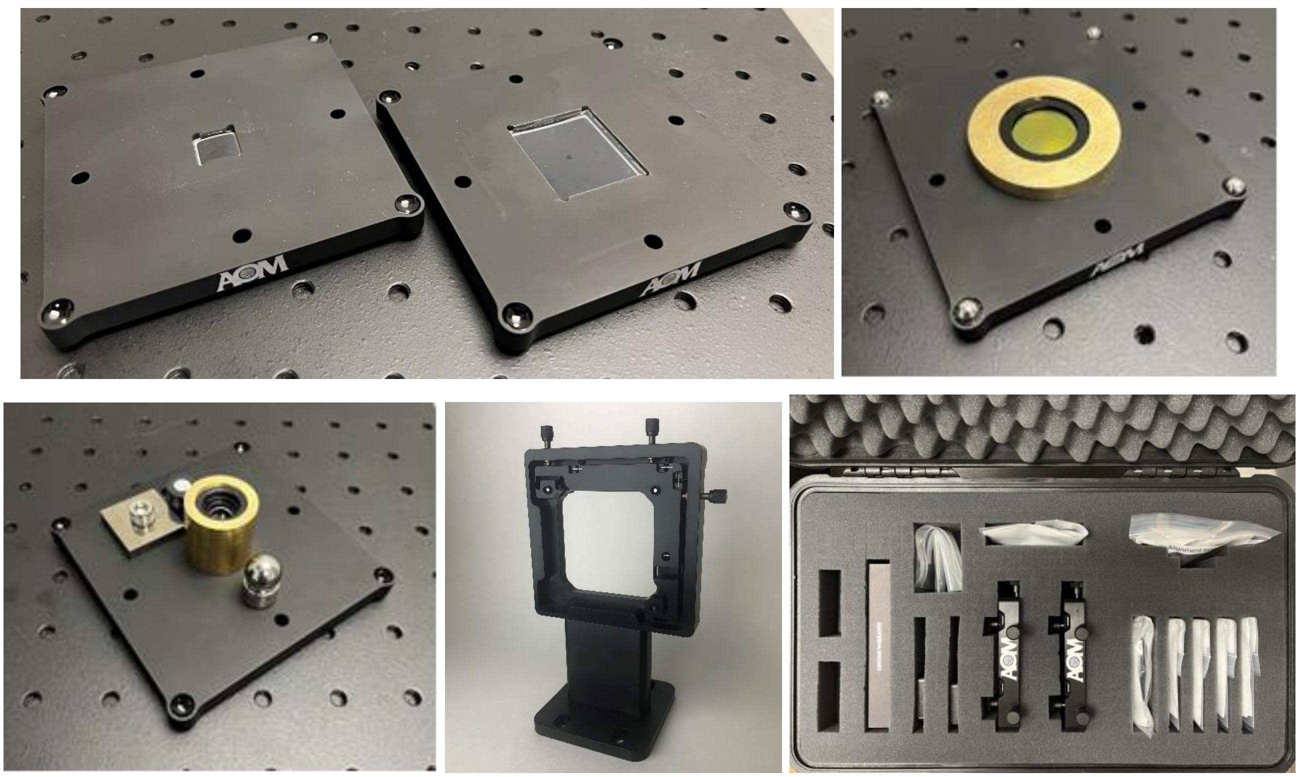

Fig 4. Test optics and hardware included in the CGH Education Kit – Convex and concave cylinder lenses (top left), plano-convex asphere (top right), alignment targets plate (bottom left), and FP3 alignment stage (bottom middle), Pelican™ brand case with complete kit installed (bottom right).

To effectively deploy the CGH Education Kit, the user should provide:

1. 4” or larger Fizeau interferometer on a suitable optical table with available space for setup of the hardware in front of the interferometer. Standard centerline height of the stages in the kit are 4.25”, but other centerline heights can be accommodated upon request.

2. Transmission Flat of proper size for Fizeau interferometer – 4” or 6”

3. Good quality flat mirror (> 2”) on tip/tilt stage, mounted at the centerline height of the interferometer.

4. Screen (white paper works!)

5. Table clamps for fixing stages to optical table as needed

3. CGH EDUCATION KIT DEPLOYMENT

3.1 Setup instructions

Each CGH test setup includes step-by-step instructions that guide the user to set up the test. A common CGH test setup in industry is a cylinder GCH.

Measuring a cylinder optic with a CGH is similar to measuring a spherical optic with a transmission sphere. A spherical optic surface can be measured by placing it at the confocal spherical wavefront produced by a transmission sphere. A cylinder measurement is similar, except that the CGH creates a cylindrical wavefront instead of spherical, and the cylinder is placed at the confocal cylindrical wavefront. One additional alignment parameter needs to be controlled too: theta rotation (clocking) of the cylinder lens relative to the CGH.

The demo kit contains two cylinder optics – one convex, and one concave. Both can be measured with the same cylinder CGH. Each cylinder lens is mounted in a plate which mounts directly to the FP3 stage.

Cylinder Lens	ROC (mm)	Length (mm)	Height (mm)
Concave	-103.4	32.0	30.0
Convex	25.84	12.7	12.7

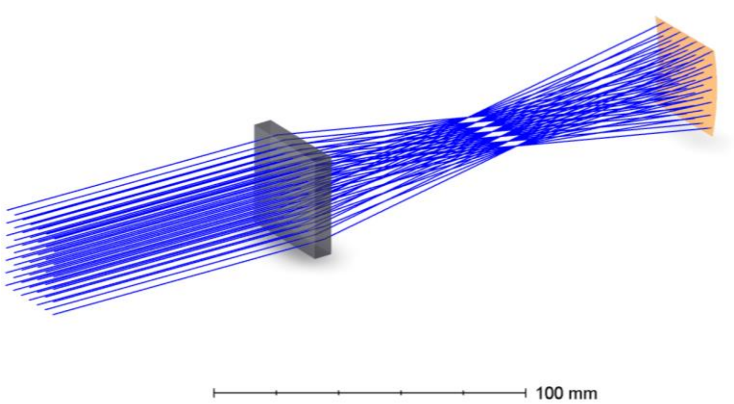

Fig 5. Cylinder CGH ray layout with concave cylinder test optic.

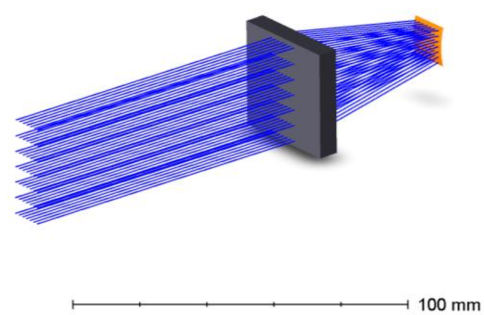

Fig 6. Cylinder CGH ray layout with convex cylinder test optic.

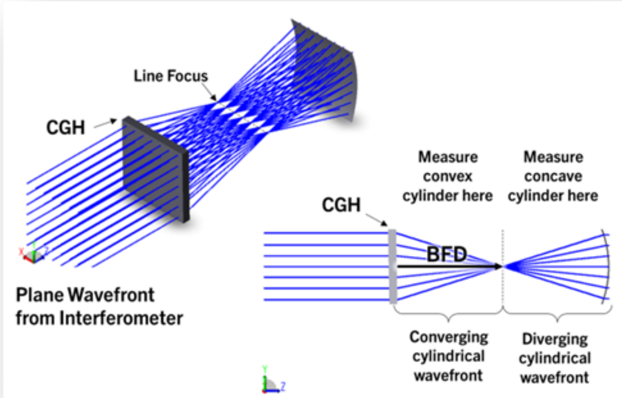

Fig 7. Cylinder CGH ray layout indicating convex and concave test regions within the cylinder converging or diverging wavefronts.

3.2 Cylinder CGH Test Setup Procedures

1. Set up the interferometer with a transmission flat and align it.
2. Set up a rail to register CGH and test optic FP3 stages so that it is easy to slide the test optic along Z behind the CGH.
3. Set up the stage and CGH:
    a. Set the FP3 mount on the optical table in front of the interferometer.
    b. Mount the CGH on the FP3 stage with pattern side facing away from the interferometer (the side with the AOM logo in the upper right). Clock the CGH in the FP3 mount so that the serial number and logo are on the top. Ensure 3 of the 4 balls seat in the 3 magnetic cones on the mount.

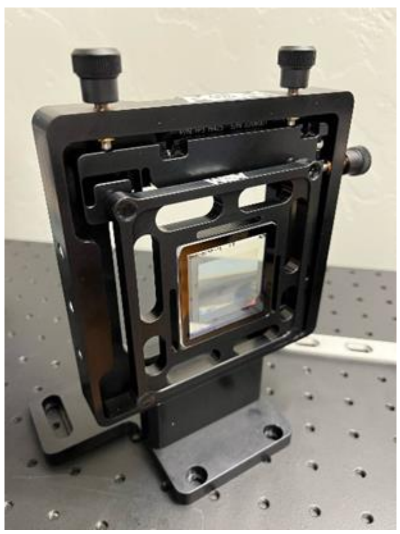

Fig 8. Cylinder CGH mounted in FP3 stage.

4. Align the CGH to the interferometer.
    a. With the interferometer in "align" mode, tip/tilt the CGH to find the 0-order return spot. This is the brightest spot.
    b. Next, tilt the CGH about X so that the top (label) side is tilted *toward* the interferometer. While looking in align mode, adjust tilt of the CGH mount to move first order diffraction spot to (the next-brightest spot) aligned to the crosshairs.

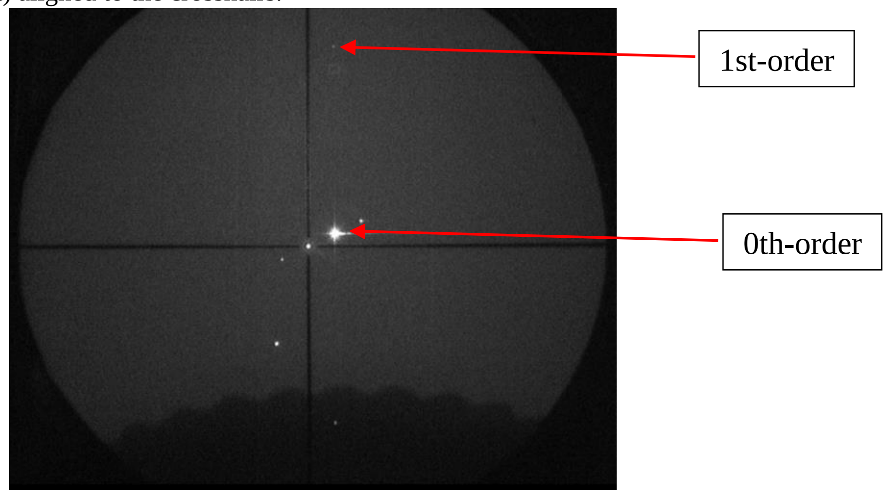

Fig 9. Interferometer align mode with cylinder CGH retroreflection alignment spots visible

    c. Switch to "view" mode and notice the interferogram in a square annular region. Tip and tilt the CGH to null tilt fringes in this pattern. The CGH is now aligned to the interferometer.

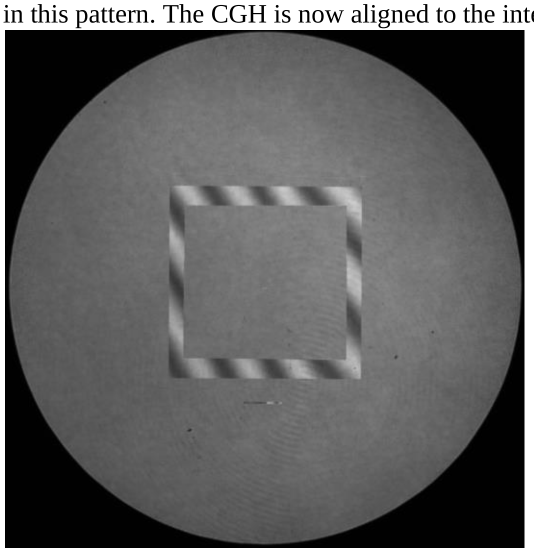

Fig 10. Interferometer view mode with cylinder CGH retroreflection alignment region aligned to TF

5. Align a cylinder test lens surface to the Catseye line of the CGH. (It is recommended to start with the concave cylinder because it is larger and will produce brighter return spots.)
    a. Mount one of the cylinder test optics to the other FP3 mount, ensuring that curved axis of the cylinder is along Y, and the plano axis of the cylinder is along X.

b. Register the FP3 stage against the rail, then slide the cylinder to the back focal distance of the CGH, 76.16 mm. You should see a bright horizontal line come to focus on the cylinder optic (this is the line focus of the cylinder CGH).

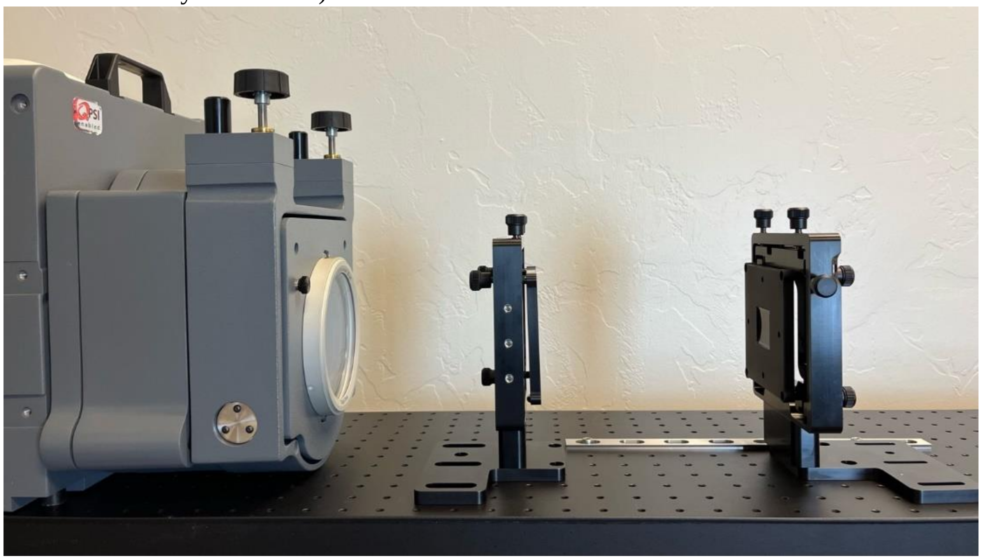

Fig 11. Cylinder CGH and test optic set up in front of interferometer, nominally aligned using a rail to control dX and dRY

c. Look at align mode of the interferometer. Notice the vertical line that shrinks down to a spot as the cylinder translates along the optical axis. Adjust tilt in X and Z translation to focus and center the spot on the crosshairs.
d. Switch to view mode of the interferometer and view the interferogram. This is the catseye alignment of the cylinder. (If the cylinder were mounted on a radial slide, we could use the distance between catseye and confocal to determine its radius of curvature.
e. Adjust dX and dY of the cylinder to center the interferogram in the square alignment pattern.

6. Align the cylinder test lens surface to the confocal beam of the CGH.
    a. With the cylinder aligned to catseye, switch the interferometer to align mode, and adjust tilt of the cylinder optic to decenter the spot along X slightly so it is viewable. Place your computer arrow on this spot for reference.
    b. Slide the cylinder a distance equal to its radius of curvature towards (for convex) or away (for concave) from the CGH.
    c. In align mode, you will notice several vertical lines come to focus at different X positions. Near the distance corresponding to the cylinder ROC, watch for a vertical line to form in the *same angular position (same x position)* as the catseye beam.
    d. If the line appears clocked from vertical, use the clocking adjustment of the test optic mount until it is vertical.
    e. Adjust dY or tilt about X to center the line vertically about the horizontal crosshair.
    f. Then, slide the stage along Z until the vertical line focuses to a spot.
    g. Center this spot on the crosshairs.
    h. Switch to view mode. Observe the interferogram.
    i. Fine-align the cylinder:
        i. Adjust tilt about Y to null vertical tilt fringes.
        ii. Adjust Y decenter OR tilt about X to null horizontal fringes.
        iii. Adjust Z to null power fringes in the Y direction.

iv. Adjust clocking to orient the remaining fringes in an x-y orientation (not diagonal). Note that clocking is adjusted by turning the two "dY" screws in at the top of the FP3 mount in opposite directions.

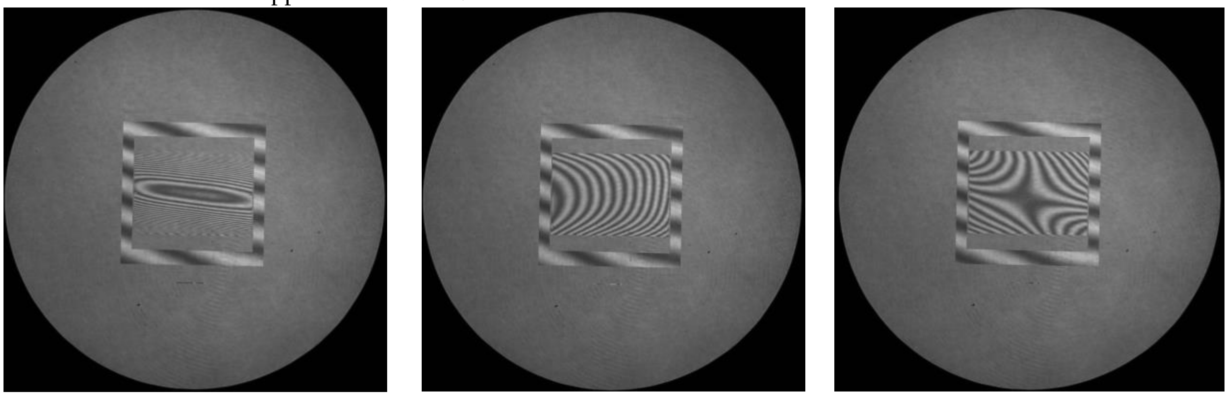

Fig 12. Interferometer view mode with cylinder test optic aligned to CGH in various states of slight misalignment. X/Y/tilt aligned, power (Z) and clocking adjustment needed (left), Y and clocking aligned, X tilt and power (Z) adjustment needed (middle), X/Y/Z/tip/tilt aligned, clocking adjustment needed (right).

4. GOALS AND CONCLUSIONS

A range of ease-of-use features are available that break the paradigm of CGH application of the past. The CGH education kit gives optics students and educators the tools to develop tests and improve understanding of a critical optical engineering and fabrication skill.

AOM is making CGH Education Kits available *at no cost* to optics education programs around the world. The inaugural kit was delivered to The University of Arizona's Wyant College of Optical Sciences for deployment in the OPTI513 Optical Fabrication and Testing Lab and Lecture courses starting in the fall '22 semester.

The CGH Education Kit was developed with optical engineering and fabrication education institutes in mind. Students aiming for nearly any level in their optics career, from technician to engineer, can benefit from the hands-on experience of setting up and aligning interferometric tests using CGHs.