In-Process Testing For Cryo-Figuring
1.5 meter Diameter Auto-Collimating Flats

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3 Autocollimating Flats used in Cryo-Optical Test of JWST
Skip Test Used for Cryo-Figuring ACFs

- **Cryo-Vac Skip Test for 32.8 K ACF**
  - 300 mm beam ($\lambda=660$ nm) “skips” across ACF diameter at 8.213°
  - 60 sub-aperture Slices at 6° rotations measure entire surface
  - Cryo Backout computed, applied to slice
  - Slices stitched together compute surface map

- **Requirements**
  - Clear Aperture of 1.520 m
  - 75 nm surface rms (including test uncertainty)
  - Uncertainty requirements on power and astigmatism

22 CFR 125.4(b)(13) Applicable
CAD Model of Skip Test

Translation & Rotation Stage

Forced Convection

Return Window

Return Mirror

Cryo Shroud

Actuators

ACF

Megaphones

Return Mirror on Cart for Cal

Laser Tracker Station 2

Laser Tracker Station 1

FizCam

Trans Flat

Alignment Mirror

Fold Mirror

Fold Window

Forced Convection

22 CFR 125.4(b)(13) Applicable
Photographs of Skip Test Hardware

- Window
- Return Mirror
- ACF
- Rotary Stage
- Shroud
- Transmission Flat
- Window
- Fold Mirror
- FizCam
- Rotary Stage

22 CFR 125.4(b)(13) Applicable
Initial Alignment of Test Set by Laser Tracker

- Align FizCam Transmission Flat and Alignment Mirror (AM)
- Initial alignment by Laser Tracker
  - Align Return Mirror (RM)
  - Coarse align Fold Mirror (FM)

- RM aligned 1 arcmin (0.017°) accuracy per Theodolite
- Laser Tracker shows ACF bias of 12 arcmin (0.2°)
Optical Alignment by FizCam

- Align FizCam’s Transmission Flat
- Align Return Mirror by Laser Tracker
- Align FM by Alignment Monitor
- Null fringes with FM
- Adjust ACF centration by live video
Automated Measurement & Analysis
Make Complex Test Simpler

Stitching software rotates, de-tilts, and measures for 360° rotation

Stitching processes 360° measurement with summary report

22 CFR 125.4(b)(13) Applicable
1. Interferograms Scaled, Stretched and Rotated by Nominal Geometry

2. 1st Subap is Reference for Scale

3. Nth Subap Matched to N-1th Subap in data overlap region & replaced with Match. Matching done by fitting tilt & scale

4. Final Map is Sum of Adjusted Subaps, normalized Pixel-by-Pixel using Sub-Ap Pixel Map

ACF Surface Computed by Stitching 60 Slices (6° Rotations)

\[ W_{M,n} = 2FC + 2TF + 4FM + 2FW + 2RW + 2RM + 4\sin\beta \sqrt{ACF_n} \]

ACF Surface at 32.8 K
2112 nm RMS
Cryo Backout: Test Set + Cryo-Delta

\[ W_B = W_T \bigg|_{WARM} \]

Backout Errors in Test Optics at Warm-Vac

\[ + \frac{1}{2} \left( \frac{W_C}{2} + \frac{W_C^y}{2} \right) \left( W_M - W_M^y \right)_{CRYO} - \frac{1}{2} \left( \frac{W_C}{2} + \frac{W_C^y}{2} \right) \left( W_M - W_M^y \right)_{WARM} \]

Backout Errors in Test Optics due to Cryo Shift

\[ W_B = \]

Subtract Extrapolated Backout from each Slice before Stitching

291 nm RMS

22 CFR 125.4(b)(13) Applicable

Gradient Reconstruction
Backout not used
Backout Improves Stitching Results

No Backout
Clear Stitching Artifacts
Higher Surface Residual

Use Cryo Backout
Smoother Surface
Smaller Surface Residual

ACF Surface at 32.8 K
2112 nm RMS

37-Zernike Fit Residual
95 nm RMS

37-Zernike Fit Residual
77 nm RMS

22 CFR 125.4(b)(13) Applicable
Cryo Testing Successful

- Pre-Ion 1 Skip Test Complete
- Warm Vac
  - Figure agrees with OAGM Probe
- Cryo-Vac (32.8 K)
  - Hitmap: 3 Surface Maps from Feb 10
  - Close to Warm Vac
  - Power is Dominant Aberration

ACF Surface at 32.8 K
2112 nm RMS
Cryo Shift Successfully Measured

- Cryo Shift is 224 nm RMS
  - Power and Stitching Errors
  - Relatively low compared to worst-case predictions of 3000 nm RMS
- ACF2 & ACF3 to benefit from thermal facility improvements
Cryo Surface Progress

Initial Surface
2184 nm RMS

Stitching Artifacts Removed for Hitmap

Current Hitmap
108 nm RMS

22 CFR 125.4(b)(13) Applicable
Summary: ACF1 Nearing Completion

- **ACF Skip Test Fully Functional**
  - Multiple Cryo-Vac Measurements at 32.8 K
  - Multiple Warm-Vac Measurements
  - Complete Backout Measured and Computed for Warm and Cryo
  - Cryo-Shift Computed & Found to be Small

- **ACF #1 Nearing Completion**
  - Final Ion Hit Beginning
  - Final Warm-Vac & Cryo-Vac Testing Planned