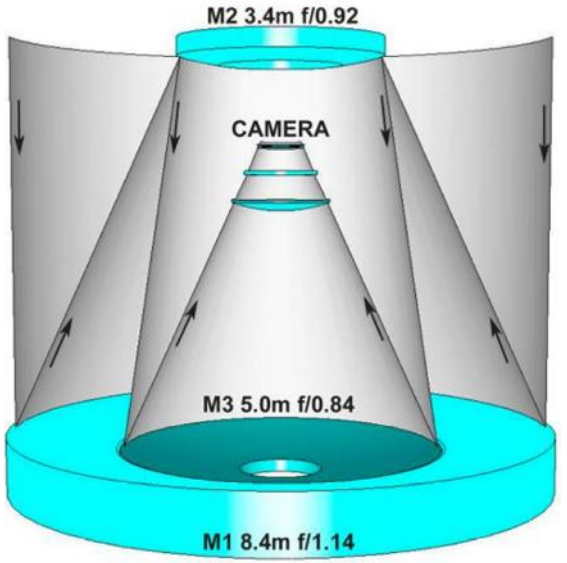


Surrogate M1M3 dynamic tests

SITCOM = System Integration, Test and Commissioning

D.Boutigny and A.Jeremie

Within the sitcom performance analysis team (SPA)

M1M3 mirror

17 tons, 8.4-meter primary/tertiary mirror (M1M3) monolithic

Observatory's Plan to complete sky mapping in 3 nights

=> the telescope mount designed to support slews with high velocity and accelerations

=> 5 seconds allowed for a 3.5 degree on sky pointing

Engineering challenge!

First time such a big mirror is subjected to such high velocities and accelerations

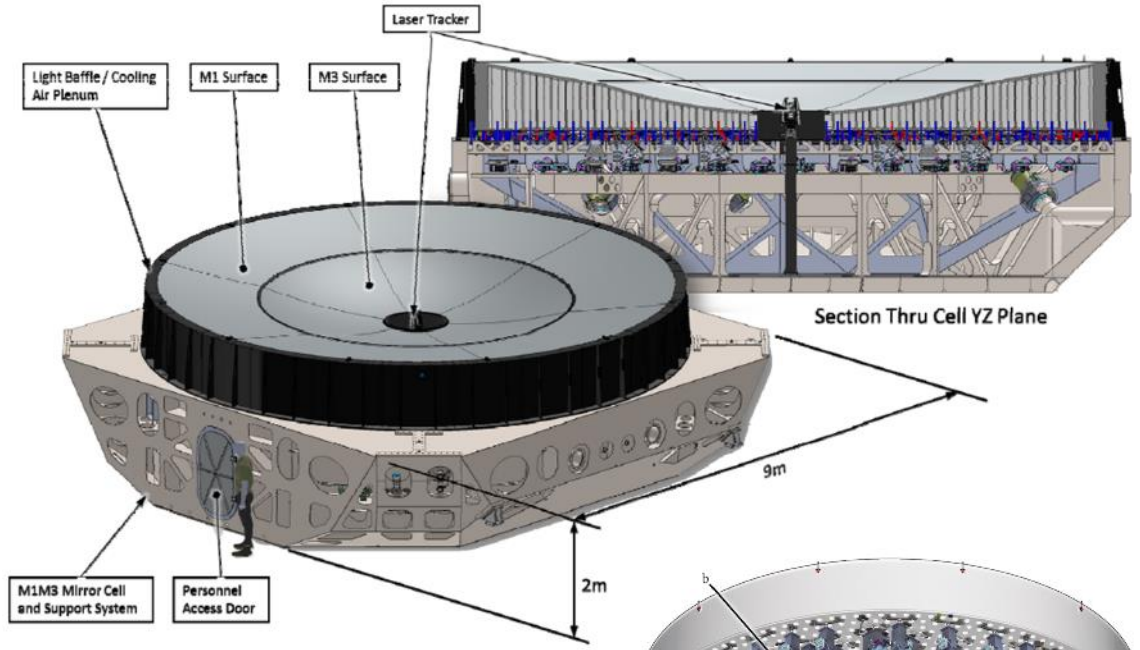
=> inertial forces on mirror

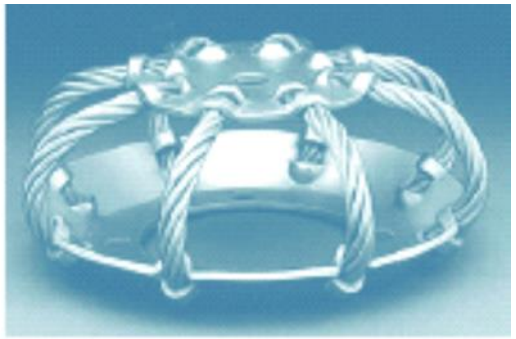
	Velocity (m/s)	Acceleration (m/s^2)	Jerk (m/s^3)
Azimuth	10,5	10,5	42
Elevation	5,75	5,75	21

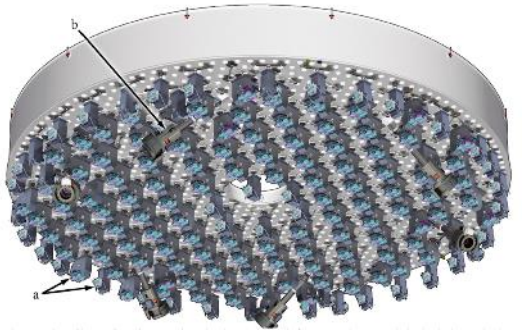
M1M3 Support system has two modes

Active mode:

- **During observation**
- 156 **Actuators** support entire mirror load and control shape => gravity, assembly errors, wind
- Minimise gravitational distortions vs elevation angle => lookup table
- Six axially stiff **Hardpoints in hexapod** configuration define position of M1M3 (6 dof)
- **No force on Hardpoints**, do not support => any force measured compensated by actuators
- If Hardpoints breakaway (reach max load and lose stiffness) => **constant force is maintained to control position vs cell**
- Fine tuning by wavefront error analysis from corner sensors in camera







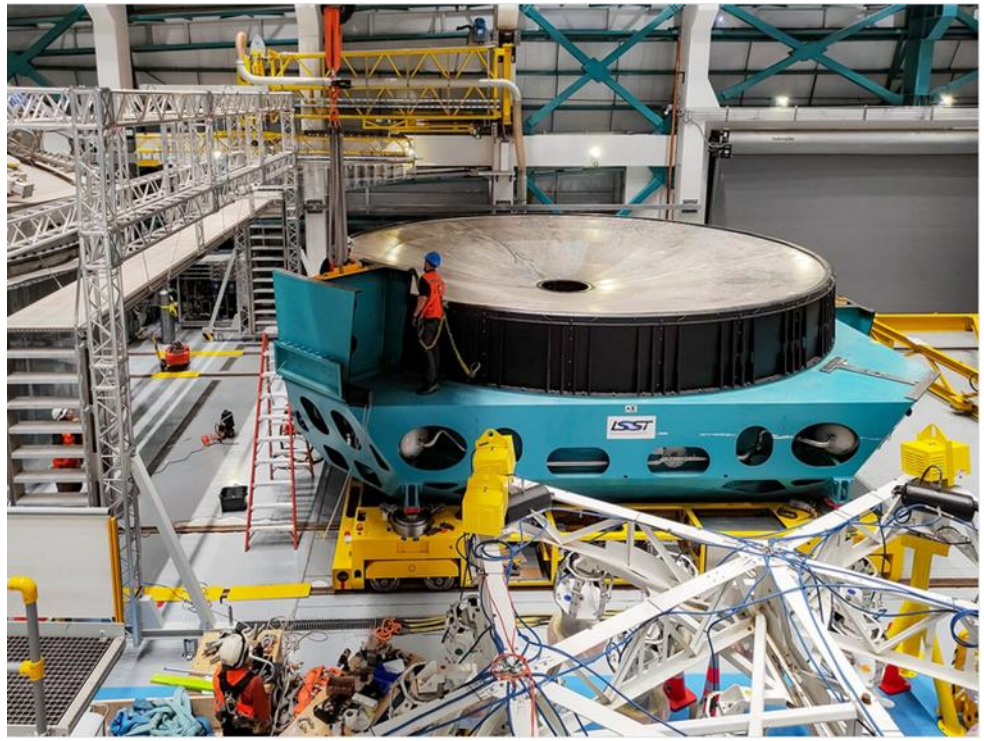
Static mode:

- Whenever active modes no longer support the mirror
- Actuators and hardpoints are depressurised
- **M1M3 rests on static supports**
- Support gravity at any elevation, and seismic acceleration in any direction

Glass safety => Surrogate M1M3

- Before installing the M1M3 glass => confirm glass safety through testing with a steel surrogate
- This surrogate is a mechanical structure used only for tests with similar mechanical properties as glass mirror:
  - mass
  - centre of gravity
  - geometry
- Equipped with:
  - its mirror support system
  - force actuators
  - hardpoints
- Extensive testing of M1M3 Cell system => safe and efficient mirror performance with full dynamic capabilities

Rubin Observatory/NSF/AURA/M. Rivera



- Surrogate M1M3 installed on Cell and Telescope Mount Assembly (TMA) April 2023
- It was dismounted January 2024 to prepare for M1M3 glass mirror

Tests


RubinObs/NSF/AURA /A. Alexov

- The quasi-static tests (<10%)
  - system's safety under controlled conditions,
  - operating at no more than 10% of its maximum velocity, acceleration, and jerk
  - Slowly incrementing from 1% to 10% in 1% steps
  - The primary purpose of these tests was to verify that the mirror's support system could effectively counteract the variations in gravitational orientation as a function of elevation angle.
  - Start by verifying the safety interlock system
  - These tests evaluated the behavior of
    - the hardpoints
    - their breakaway system,
    - the performance of the 156 pneumatic figure control actuators,
    - M1M3 Force Balance System.
- The dynamic tests => Inertia compensation system (10%<DT<max)
  - long slews in the azimuth direction first, the axis most affected by inertial forces
  - telescope operating with a performance ranging from 10%
  - up to its maximum acceleration and velocity

Safety Criteria

Reviews: Dec.11,2023 and Jan.19, 2024

From System Integration Testing/Verification - Before Glass installation

GSCN1 - Bump Tests
GSCN13 - Hardpoint Breakaway
GSCN2A - M1M3 Gravity Look-up Table
GSCN2B - M1M3 Inertia Compensation System
GSCN3 - M1M3 Settling Time
GSCN4 - M1M3 Oscillation and Vibration Criterium
GSCN8 - TMA Oscillations/Vibrations
GSCN5 - M1M3 Position Repeatability
GSCN6 - AOS inputs
GSCN7 - TMA velocity, acceleration, jerk limits
GSCN10 - Emergency Stopping Distance
GSCN11 - M1M3 Mirror Cover
GSCN12 - M1M3 Thermal System Vibrations

GSCN=Glass Safety Criteria Number

Safety Criteria

From System Integration Testing/Verification - Before Glass installation

GSCN1 - Bump Tests
GSCN13 - Hardpoint Breakaway
GSCN2A - M1M3 Gravity Look-up Table
GSCN2B - M1M3 Inertia Compensation System
GSCN3 - M1M3 Settling Time
GSCN4 - M1M3 Oscillation and Vibration Criterium
GSCN8 - TMA Oscillations/Vibrations

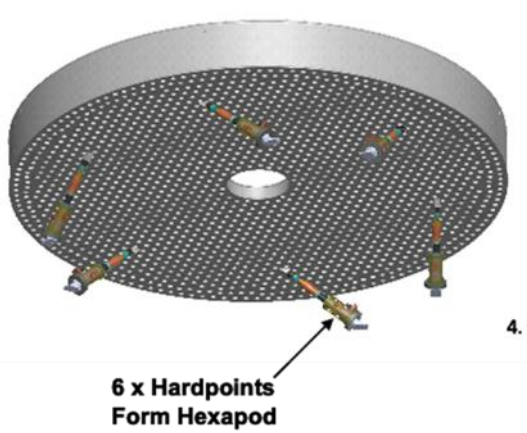
GSCN5 - M1M3 Position Repeatability <= DB+AJ (SITCOMTN-084)
GSCN6 - AOS inputs
GSCN7 - TMA velocity, acceleration, jerk limits
GSCN10 - Emergency Stopping Distance
GSCN11 - M1M3 Mirror Cover
GSCN12 - M1M3 Thermal System Vibrations <= DB+AJ (SITCOMTN-101)

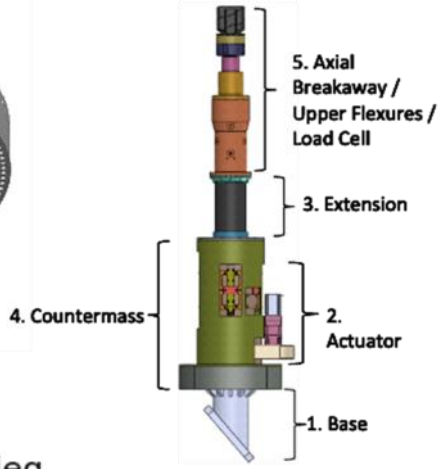
In red critical glass safety items

GSCN13 - Hardpoint Breakaway

Specifications

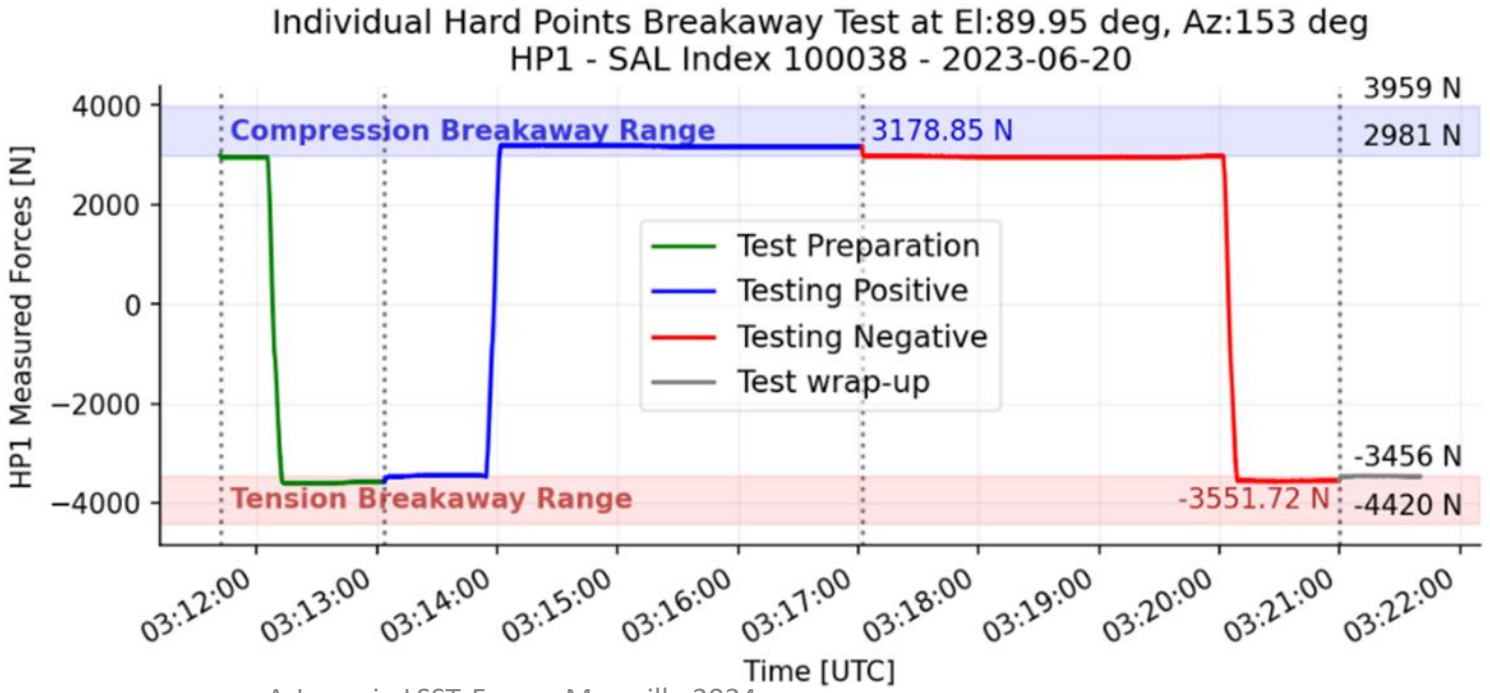
- Measured forces on the hardpoints < breakaway limit
  - -4420N<breakaway limit<-3456N in tension
  - 2981N<breakaway limit<3959N in compression





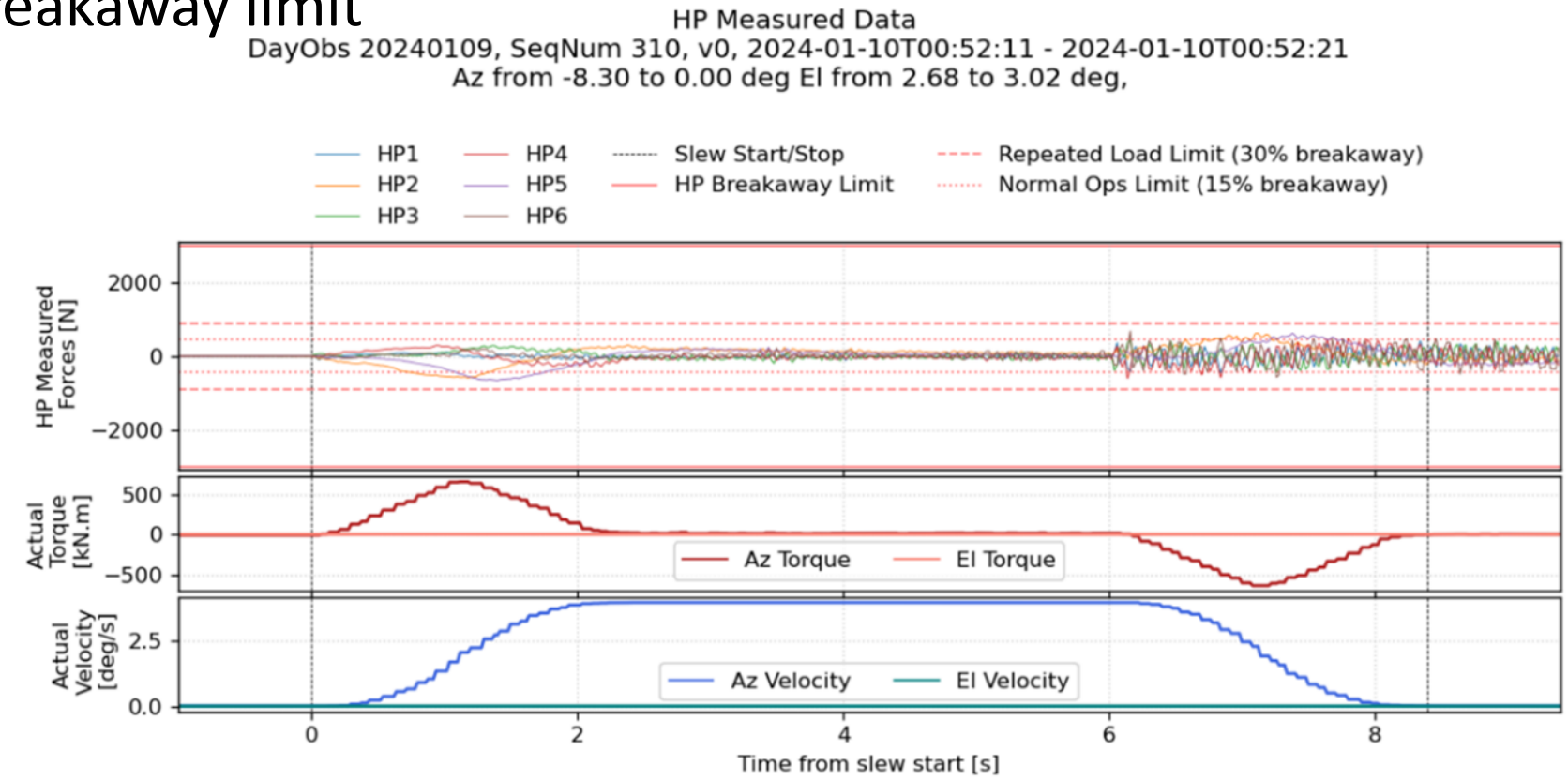
=> -3600N ± 33N in tension

=> 3150N ± 56N in compression



GSCN2B - M1M3 Inertia Compensation System

- => minimize forces applied to hardpoints
- Fatigue failure < 30% of this breakaway limit
- Operation limit < 15% of breakaway limit

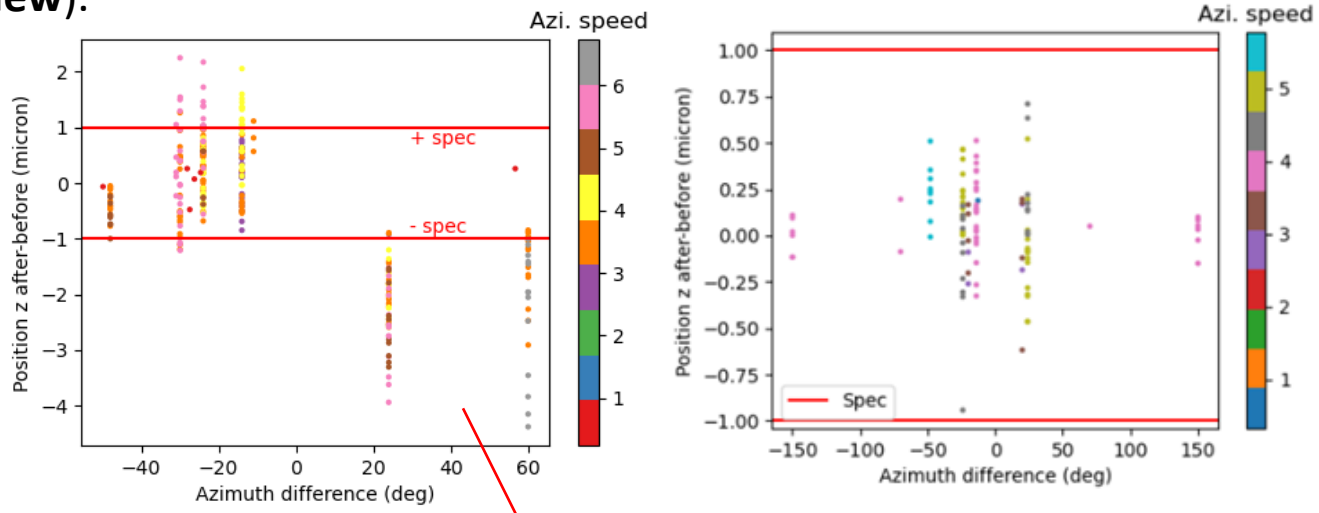


- the measured forces have values below the glass stress limit => glass safe
- However, forces still outside safe operational limit
- Hardpoints still settling after three seconds at the end of the slew

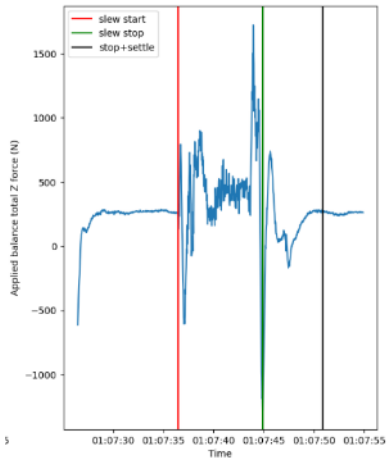
GSCN5 - M1M3 Position Repeatability

The positioning system SHALL maintain mirror decenter less than **+/- 1 micrometer** for piston (z), all relative to the mirror cell, after a slew of 3.5 degrees or less (**short slew**).

- Mirror displacement and rotations as a function of **azimuth difference** when the TMA is moving in **azimuth only**.
- The horizontal red lines indicate the expected tolerances.
- Each data point considers the average of the position 1s before and 1s after slew (left) and 6s after slew (right).



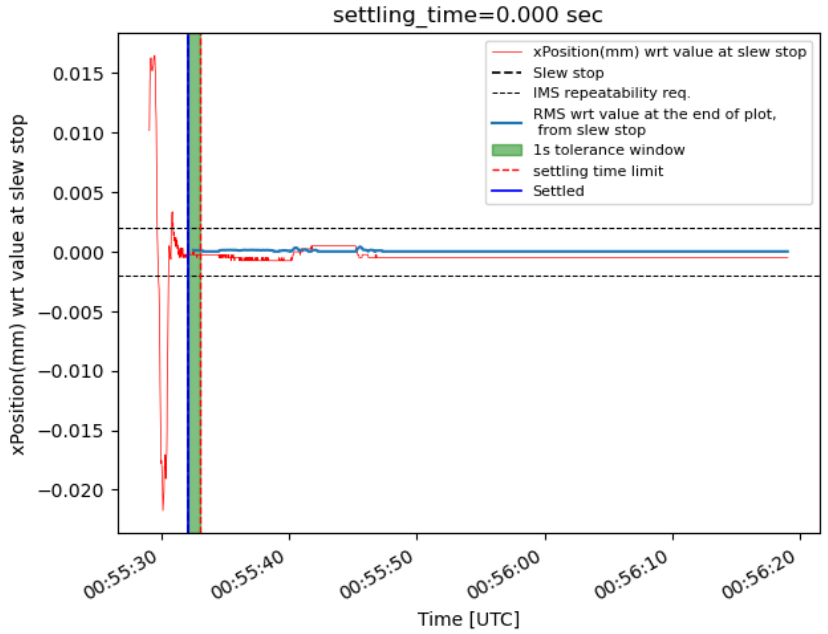
outlier



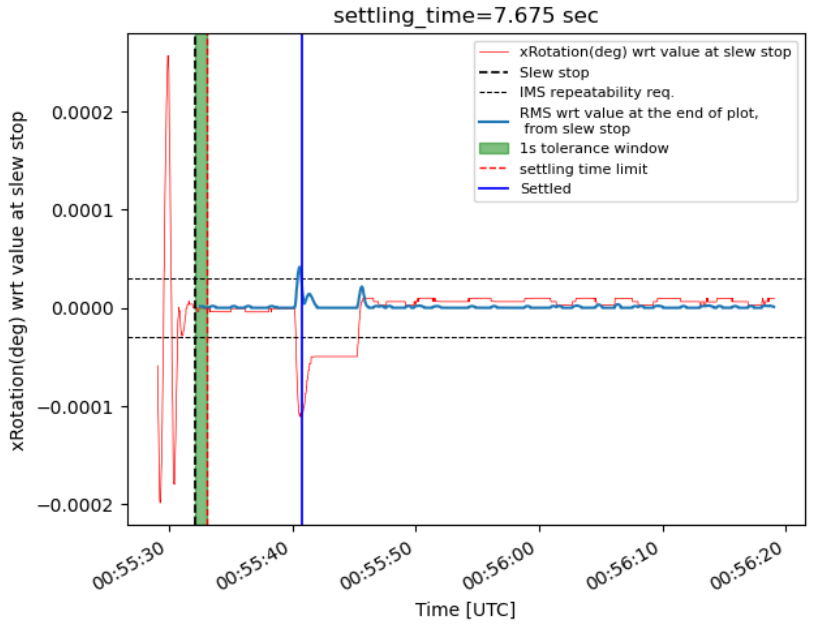
GSCN3 - M1M3 Settling Time

- M1M3 settling time is meeting requirements to settle in 1 sec, but it is failing only with the ‘bump’ feature due to the delay between actuators starting to work and slew flag command sent.
- This is fixed so there’s no delay between two commands, we will see this fix from new data.

pass



fail



Safety Criteria

From System Integration Testing/Verification - Before Glass installation

GSCN1 - Bump Tests ✔

GSCN13 - Hardpoint Breakaway ✘~✔

GSCN2A - M1M3 Gravity Look-up Table ✔

GSCN2B - M1M3 Inertia Compensation System ✔❗
(not all sensors correctly installed yet)

GSCN3 - M1M3 Settling Time ✘~✔

GSCN4 - M1M3 Oscillation and Vibration Criterium ✔

GSCN8 - TMA Oscillations/Vibrations ✔

GSCN5 - M1M3 Position Repeatability ✘~✔

GSCN6 - AOS inputs ❓

GSCN7 - TMA velocity, acceleration, jerk limits ✘❗

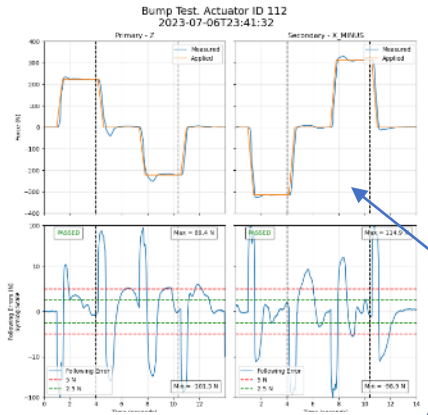
GSCN10 - Emergency Stopping Distance ✘

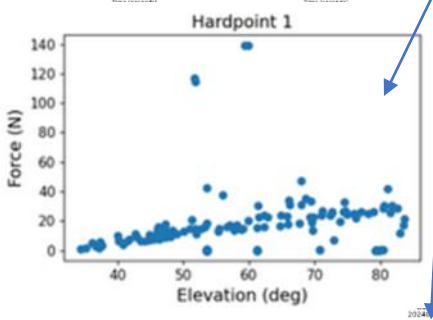
GSCN11 - M1M3 Mirror Cover ❓

GSCN12 - M1M3 Thermal System Vibrations ❓~✔

Safety Criteria

From System Integration Testing/Verification - Before Glass installation





GSCN1 - Bump Tests ✔

GSCN13 - Hardpoint Breakaway ✘~✔

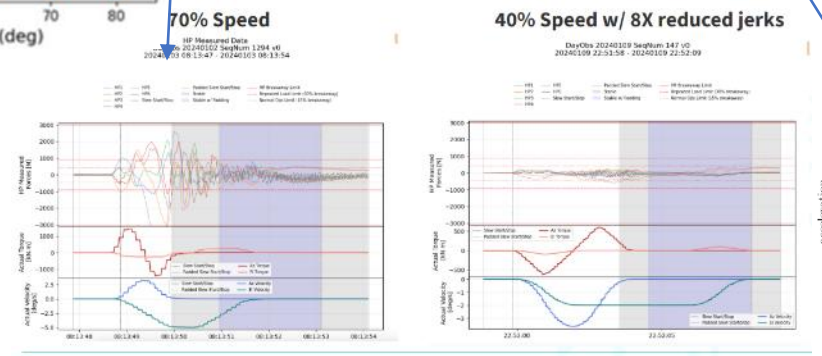
GSCN2A - M1M3 Gravity Look-up Table ✔

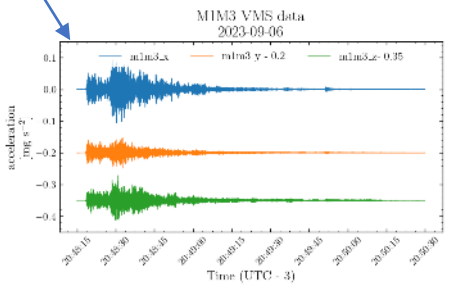
GSCN2B - M1M3 Inertia Compensation System ✔❗
(not all sensors correctly installed yet)

GSCN3 - M1M3 Settling Time ✘~✔

GSCN4 - M1M3 Oscillation and Vibration Criterium ✔

GSCN8 - TMA Oscillations/Vibrations ✔





GSCN5 - M1M3 Position Repeatability ✘~✔

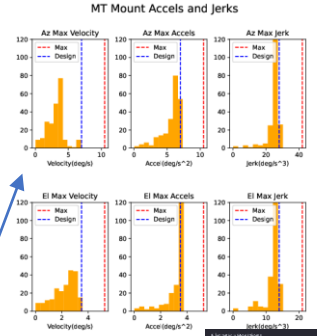
GSCN6 - AOS inputs ❓

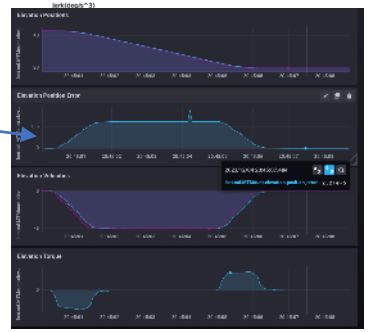
GSCN7 - TMA velocity, acceleration, jerk limits ✘❗

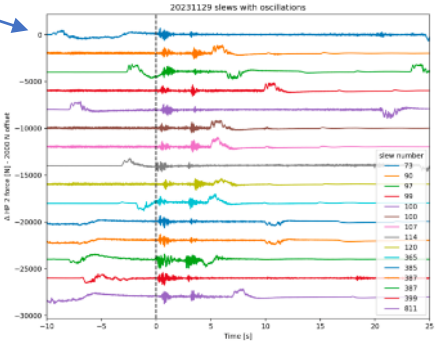
GSCN10 - Emergency Stopping Distance ✘

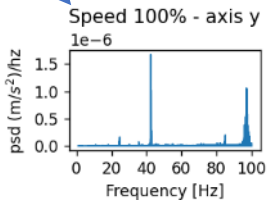
GSCN11 - M1M3 Mirror Cover ❓

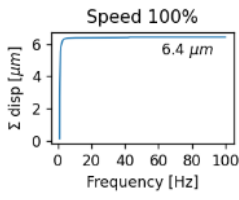
GSCN12 - M1M3 Thermal System Vibrations ❓~✔











Conclusion

- M1M3 Cell provides a safe system for handling mirror (at low speeds)
- Operate the telescope at up to 40% of its maximum capacity
  - The integration of the FBS (Force Balance System) to counteract acceleration and velocity forces was crucial
- The maximum slew performance allowed by the ICS (Inertia Compensation System) is still below the minimum required performance of 70% of the maximum velocity, acceleration, and jerk
- SPIE article in preparation

Reviews: Dec.11,2023 and Jan.19, 2024
The reviewers recommended to go ahead with glass M1M3 installation

RubinObs/NSF/AURA/T. Vučina

June 25, 2024: Observatory readiness for Glass Installation review
End of July, 2024: M1M3 installation on TMA
August 2024: On sky!

extras

GSCN2A - Look-up Table (LUT) - Glass safety

Success Criteria:

The Force Balance System responds to different gravity vectors, minimizing the forces applied to the hardpoints.

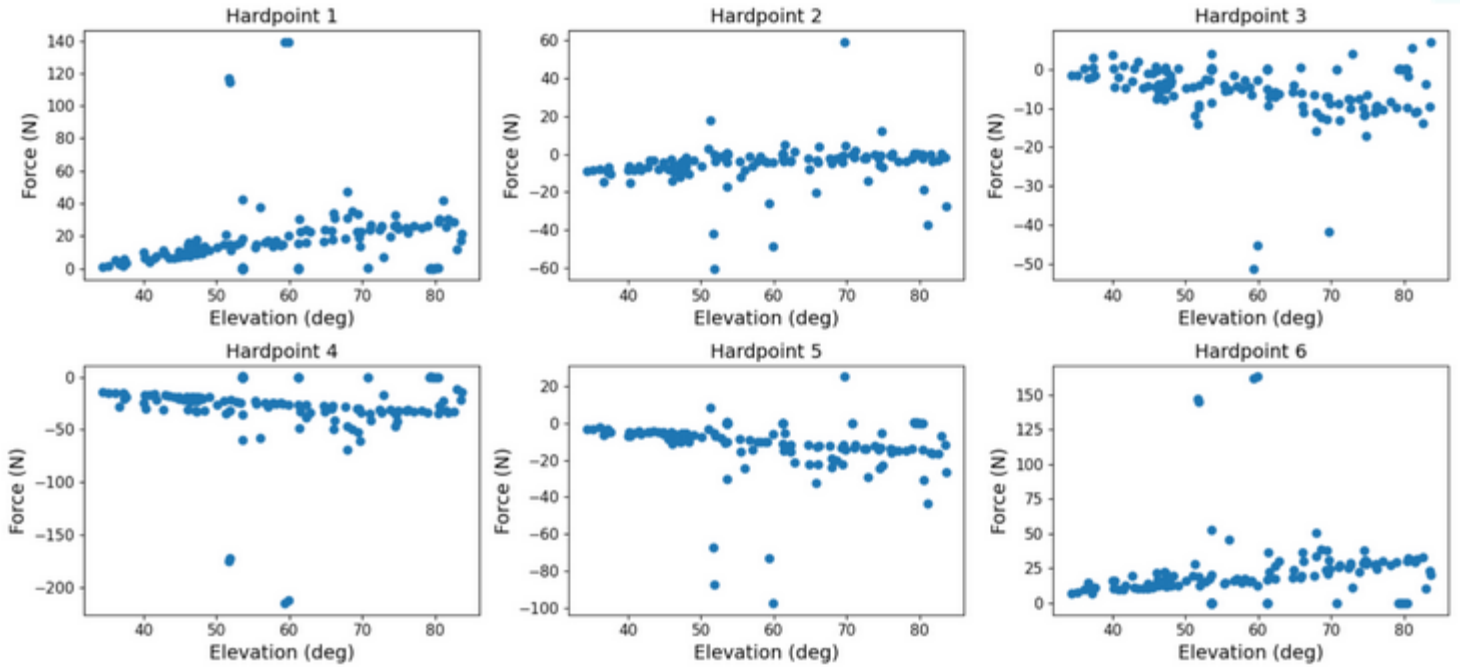
Test case:

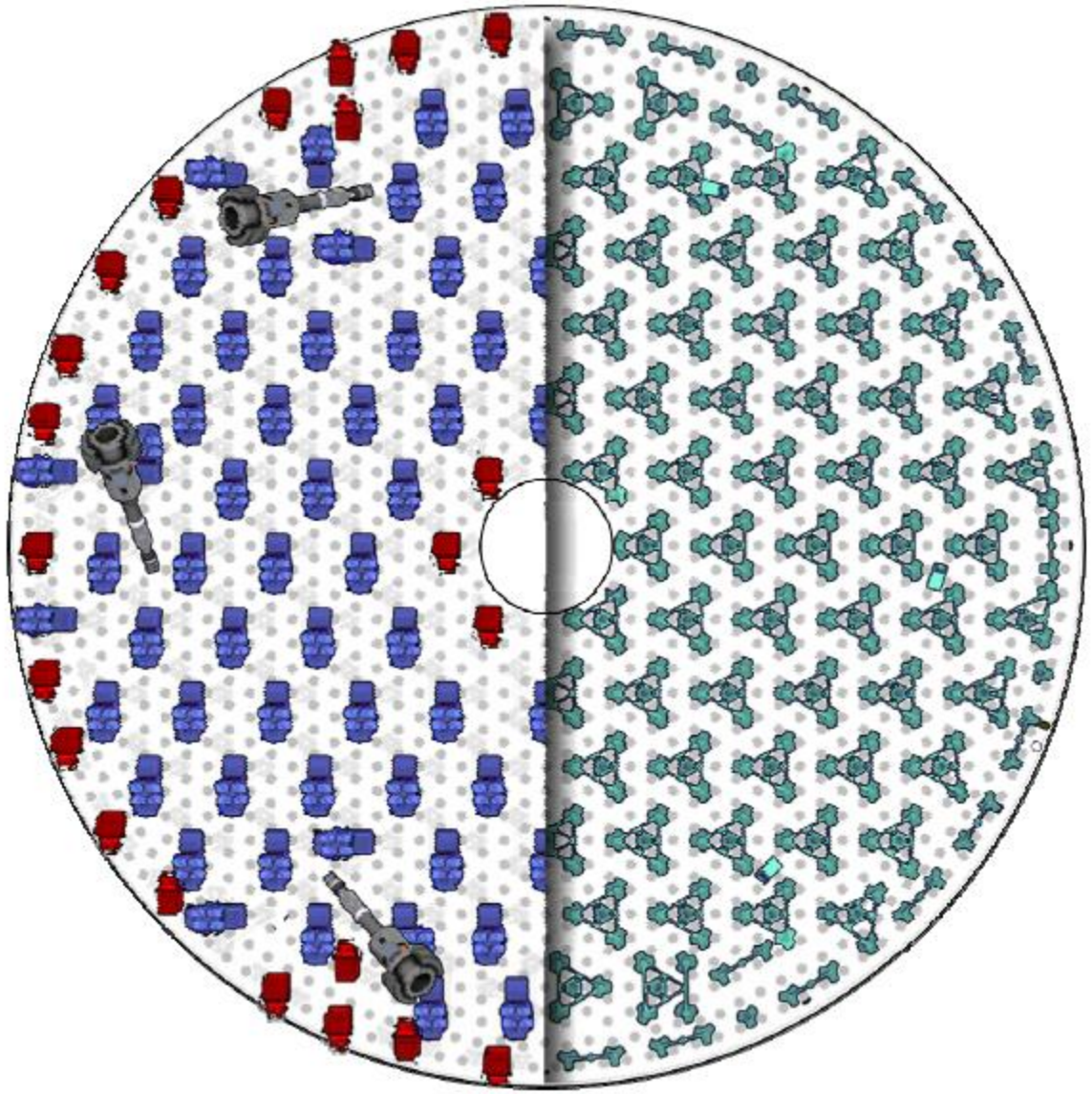
Technote:

SITCOMTN-079: M1M3 Look-up Table

Comments:

After the improvements made in July to the LUT, the hardpoint measured forces have been minimized. The “rule of thumb” for the LUT is that we should expect about 1/1000 correction. Our mirror weighs 170,000 N. We should expect to get within 170N. It looks like we are within this range.





SINGLE AXIS ACTUATORS	QUAN
1 puck	8
2 puck	30
3 puck	6
Total SAA	**44**
DUAL AXIS ACTUATORS	
3 puck	
Y lateral	96
X lateral	12
4 puck	
Y lateral	4
Total DAA Y lateral	**100**
Total DAA X lateral	**12**
TOTAL PNEUMATIC ACTUATORS	**156**

Figure 5. Load spreader and Axial Actuator layout, Right side is load spreaders only, Left side shows associated actuators.

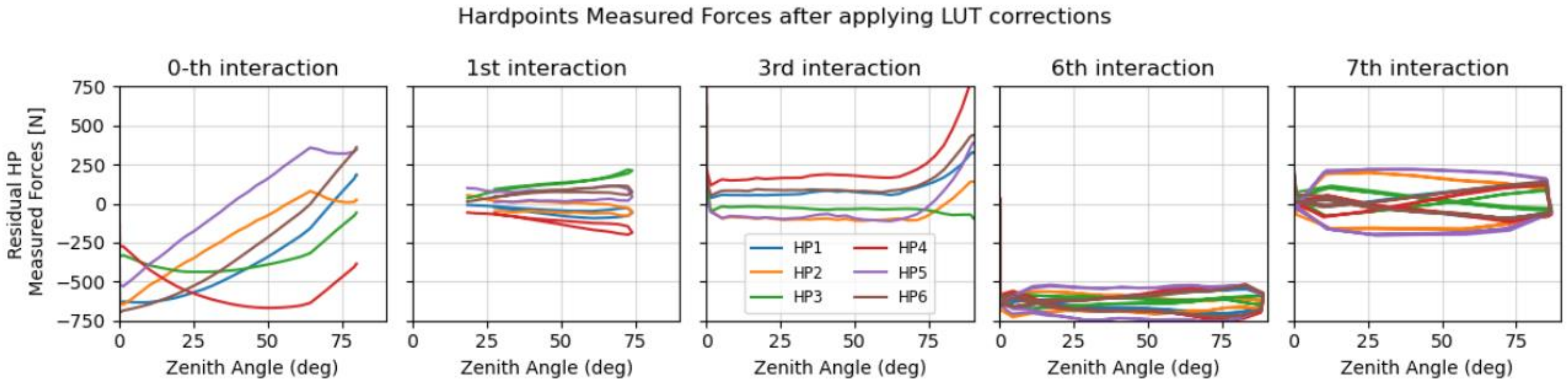


Figure 5. Look-up table evolution shown as different interactions. The first plot on the left shows the initial condition.

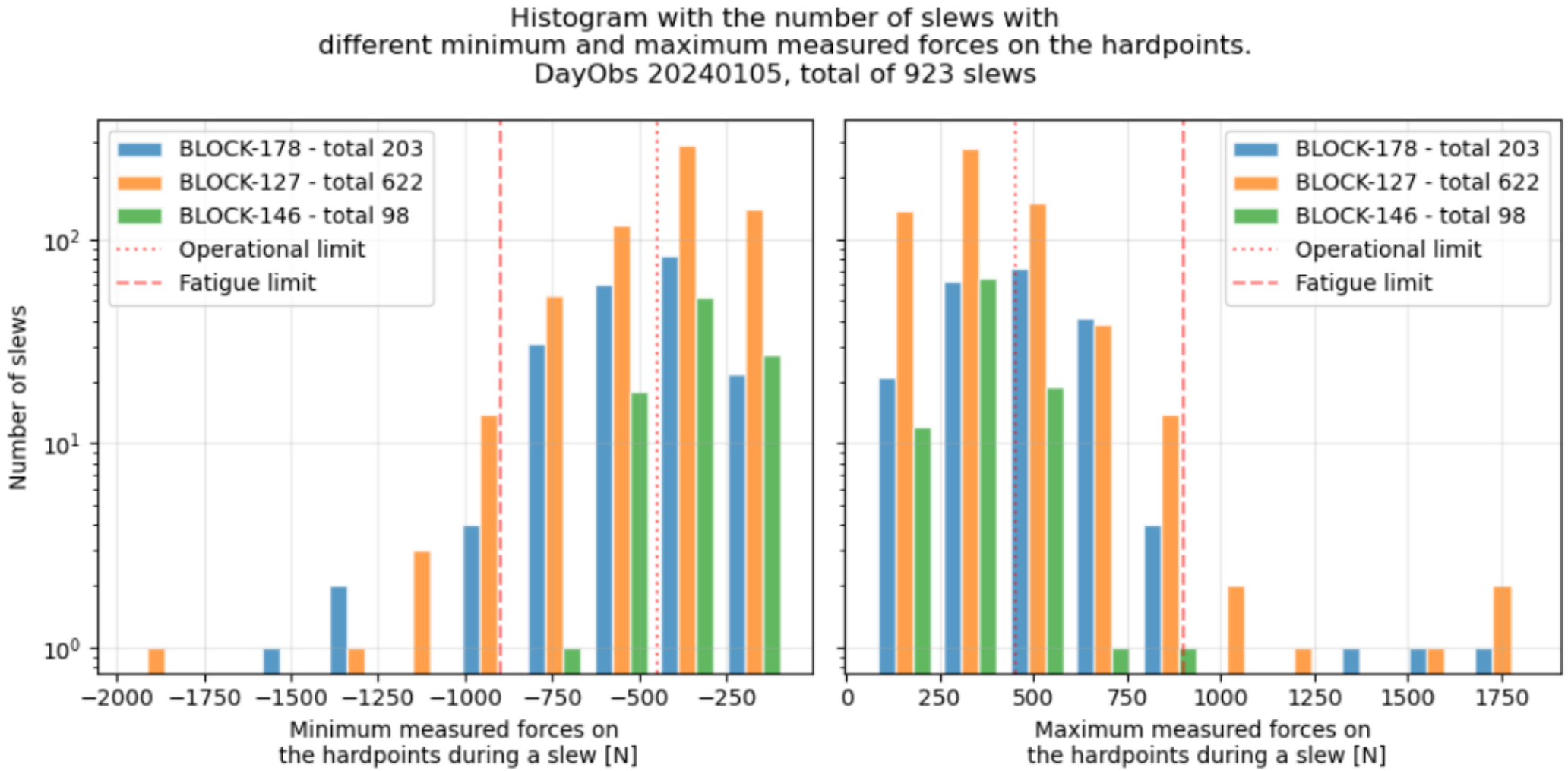
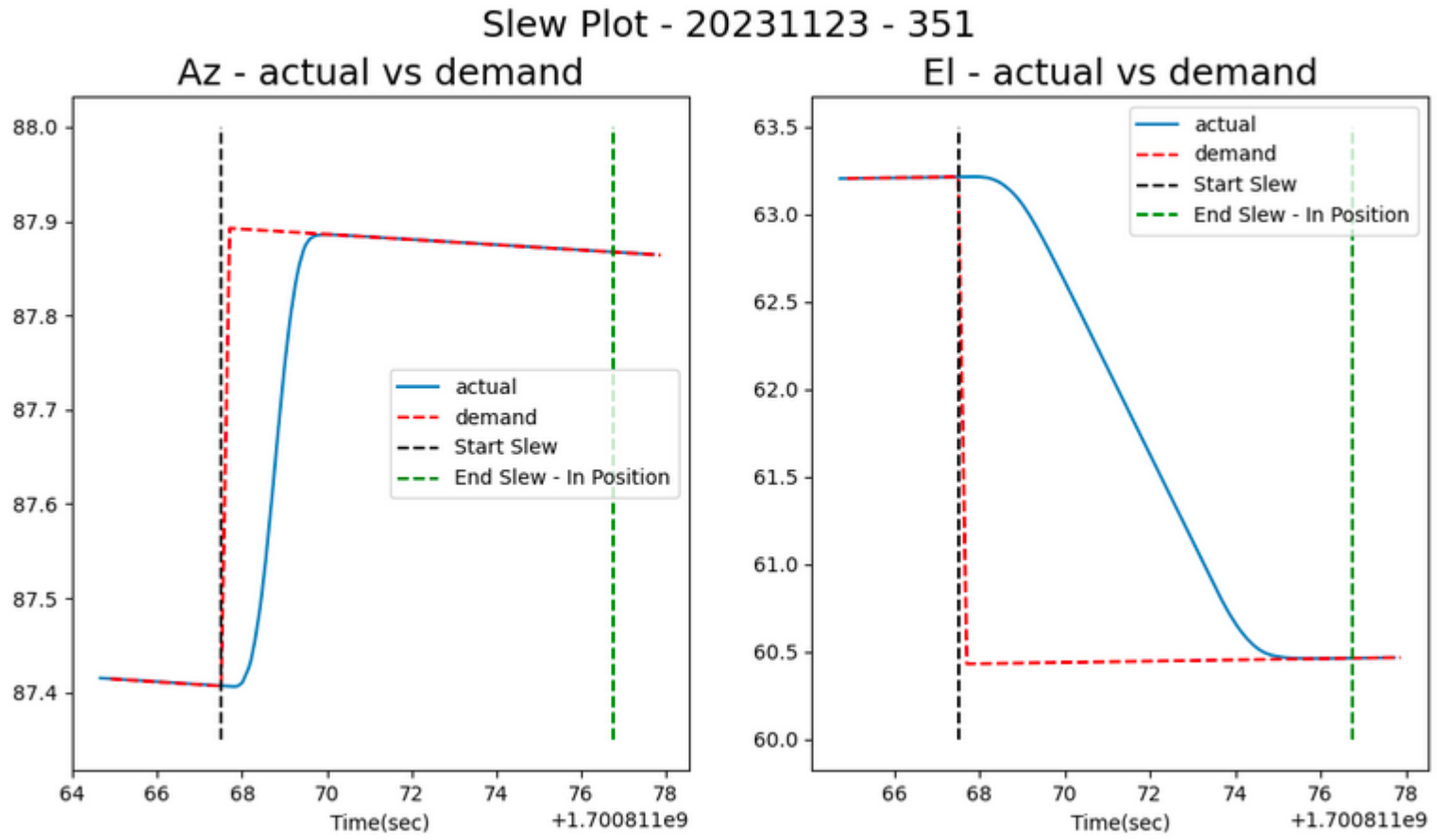


Figure 7. Histogram showing the number of slews that reached certain minimum and maximum measured forces on the hardpoints on three different tests. Please refer to the text in subsection 4.2 for more details.

Position repeatability after slew

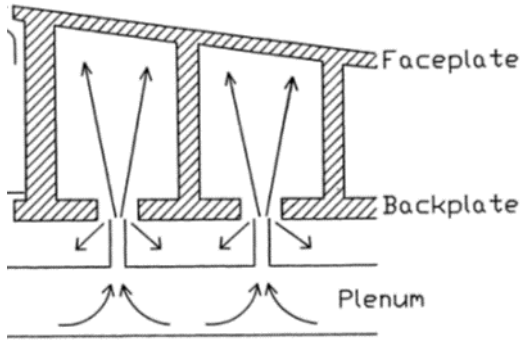
- What is a slew

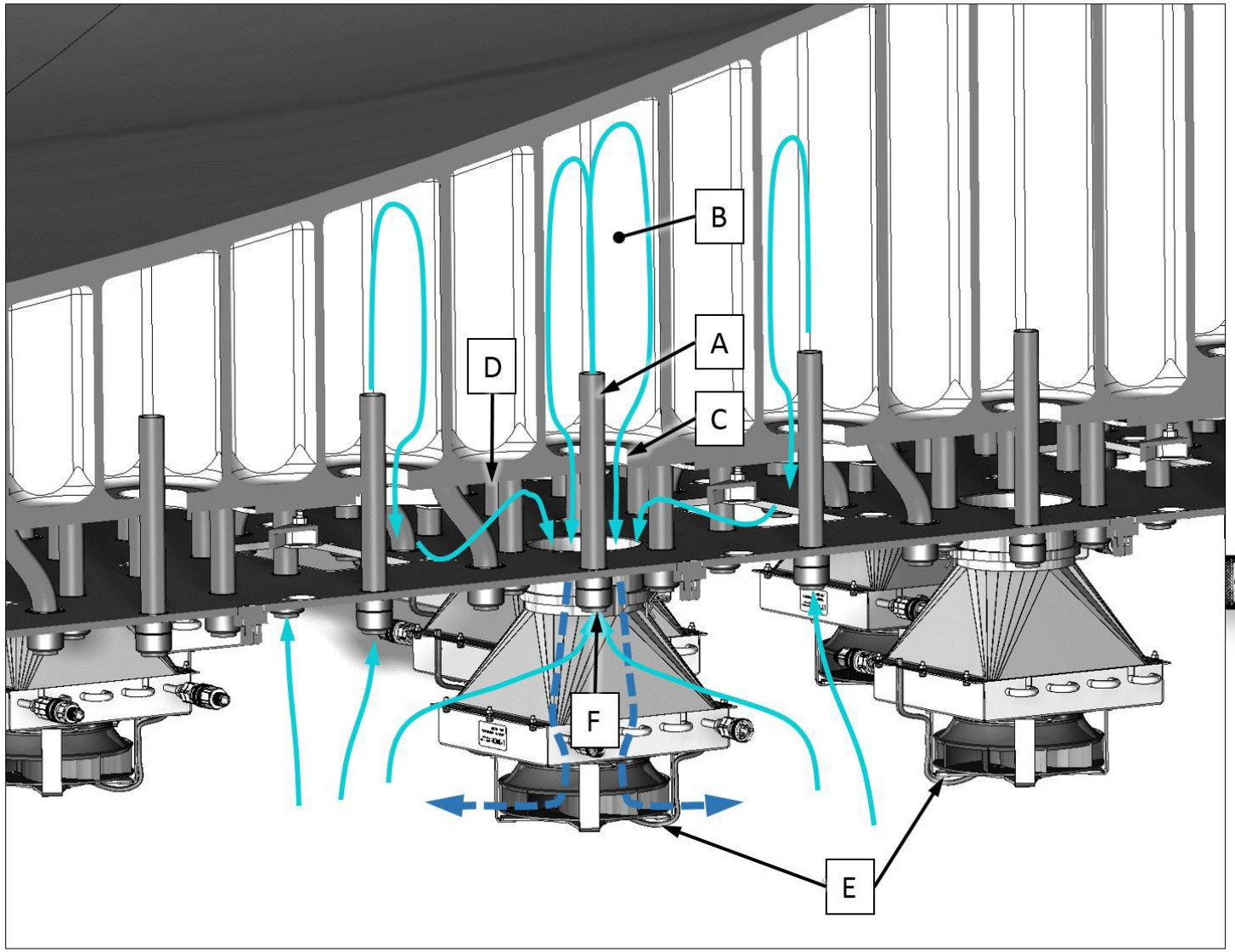
Requirement:
Repeatability of the M1M3 position measurement is as follows :
<+/- 5 microns in X/Y
<+/- 2arcsec in tilt

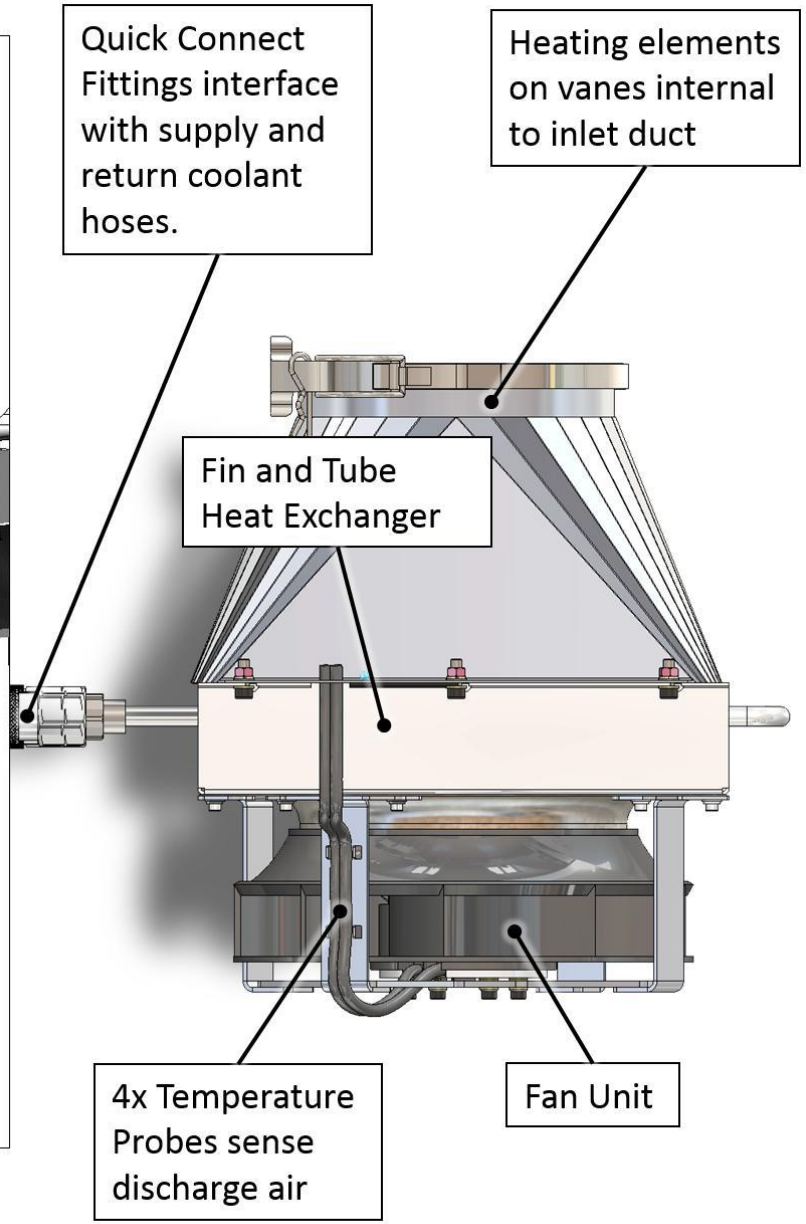


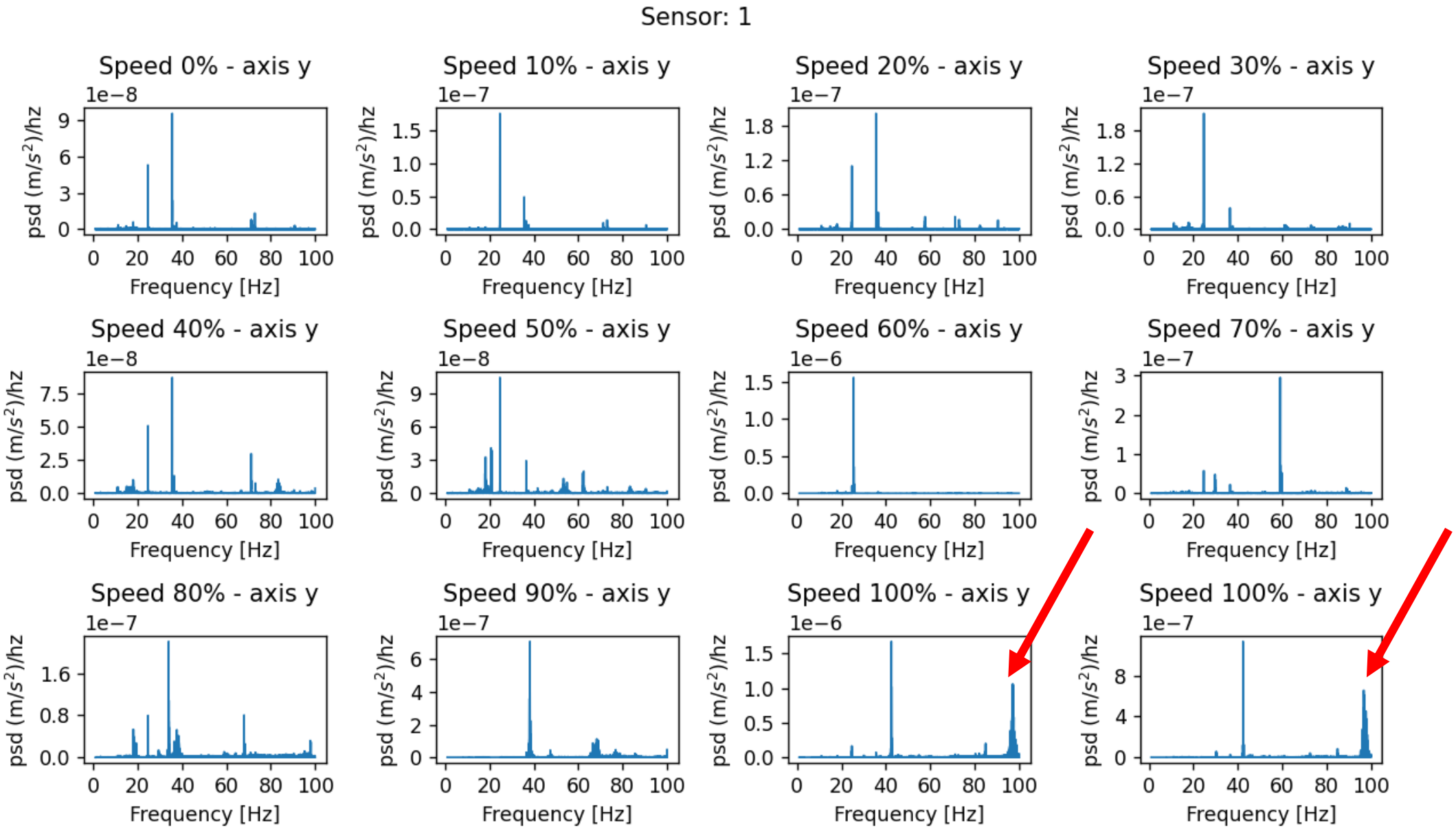
Investigation into vibrations in the M1M3 surrogate on the TMA due to the Fan Coil Units

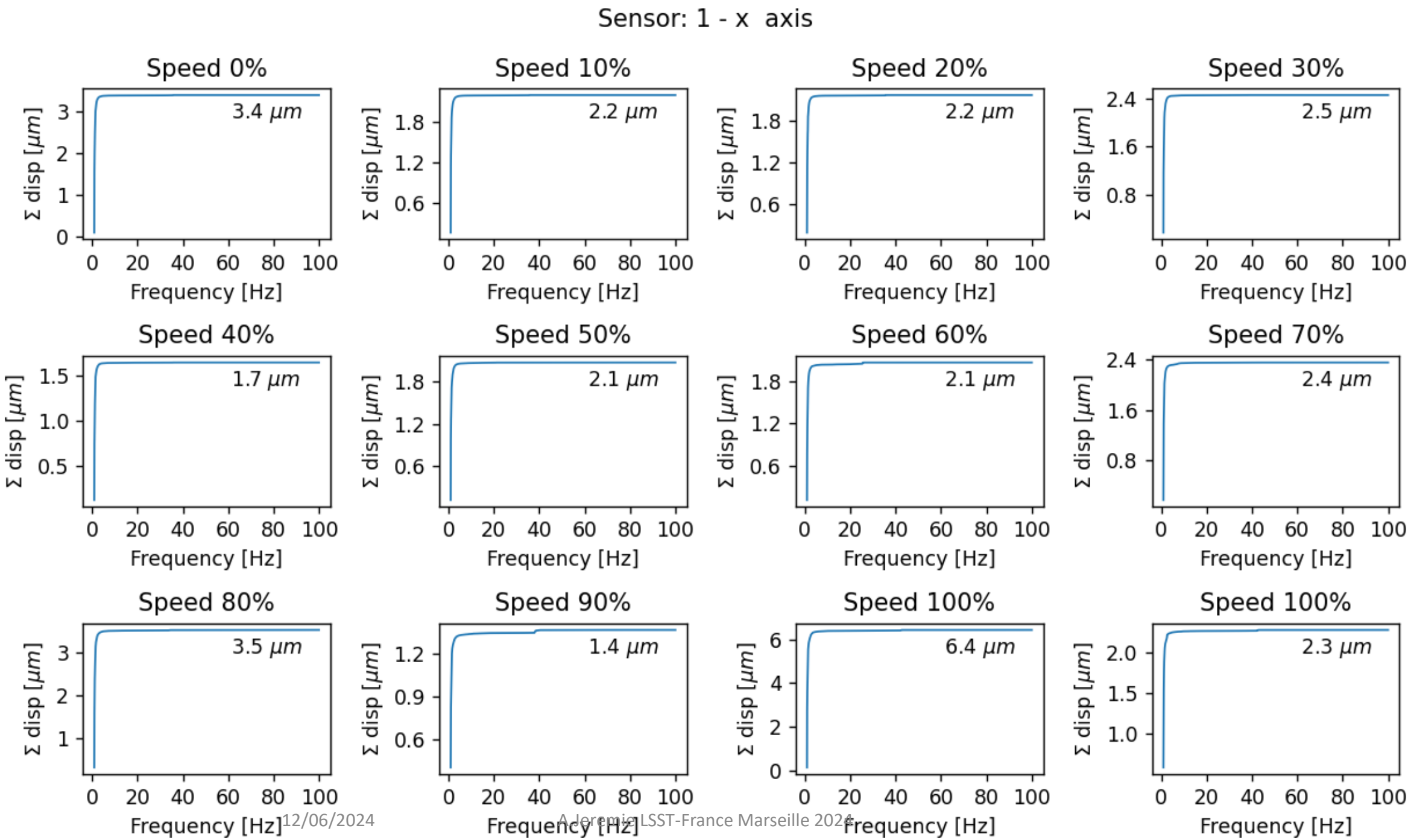
- Analysis of data from the Vibration Monitoring System (VMS), dc accelerometers, and the Independent Measurement System (IMS) to assess how the operation of Fan Coil Units (FCUs) might impact image quality.




B
A
C
D
F
E


Quick Connect Fittings interface with supply and return coolant hoses.
Heating elements on vanes internal to inlet duct
Fin and Tube Heat Exchanger
4x Temperature Probes sense discharge air
Fan Unit


Sensor: 1
Speed 0% - axis y
Speed 10% - axis y
Speed 20% - axis y
Speed 30% - axis y
Speed 40% - axis y
Speed 50% - axis y
Speed 60% - axis y
Speed 70% - axis y
Speed 80% - axis y
Speed 90% - axis y
Speed 100% - axis y
Speed 100% - axis y
psd (m/s²)/hz
Frequency [Hz]


Sensor: 1 - x axis
Speed 0%
3.4 μm
Speed 10%
2.2 μm
Speed 20%
2.2 μm
Speed 30%
2.5 μm
Speed 40%
1.7 μm
Speed 50%
2.1 μm
Speed 60%
2.1 μm
Speed 70%
2.4 μm
Speed 80%
3.5 μm
Speed 90%
1.4 μm
Speed 100%
6.4 μm
Speed 100%
2.3 μm
Σ disp [μm]
Frequency [Hz]

- The measurements will have to be repeated when the glass mirror is in place.