Preliminary Design Review
- Mechanisms Design -
# iSHELL Preliminary Design Review: Mechanisms

- **Mechanisms Overview:**

<table>
<thead>
<tr>
<th>Layout #</th>
<th>Name</th>
<th>Abbrev.</th>
<th>Type</th>
<th># of Discrete Positions</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Image Rotator</td>
<td>IMR</td>
<td>Continuous Angular Position</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>Slit Mechanism</td>
<td>SLM</td>
<td>Discrete Angular Position</td>
<td>5 (10)</td>
</tr>
<tr>
<td></td>
<td>Dekker Mechanism</td>
<td>(DEK)</td>
<td>Discrete Linear Position</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Filter Mechanism</td>
<td>FWM</td>
<td>Discrete Angular Position</td>
<td>15</td>
</tr>
<tr>
<td>8</td>
<td>Spectrograph Detector Focus Stage</td>
<td>DET</td>
<td>Continuous Linear Position</td>
<td>N/A</td>
</tr>
<tr>
<td>9</td>
<td>Order Sorting Mechanism</td>
<td>OSM</td>
<td>Discrete Angular Position</td>
<td>10</td>
</tr>
<tr>
<td>10</td>
<td>Immersion Grating Mechanism</td>
<td>IGM</td>
<td>Discrete Linear Position</td>
<td>2</td>
</tr>
<tr>
<td>11</td>
<td>Cross-Disperser Mechanism</td>
<td>XDM</td>
<td>Discrete Angular Position</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Continuous Angular Position</td>
<td>N/A</td>
</tr>
</tbody>
</table>
### iSHELL Preliminary Design Review: Mechanisms

- **High-Level Requirements:**

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Temp</th>
<th>Type</th>
<th>Range</th>
<th>Repositioning precision</th>
<th>Element size</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB mirror</td>
<td>~280 K</td>
<td>In/out</td>
<td>2 positions</td>
<td>± 0.5 mm</td>
<td>Beam</td>
</tr>
<tr>
<td>Gas cell</td>
<td>~280 K</td>
<td>In/out</td>
<td>2 positions</td>
<td>± 0.5 mm</td>
<td>Beam</td>
</tr>
<tr>
<td>Window cover</td>
<td>~280 K</td>
<td>In/out</td>
<td>2 positions</td>
<td>± 0.5 mm</td>
<td>Beam</td>
</tr>
<tr>
<td>K-mirror</td>
<td>75 K</td>
<td>Continuous</td>
<td>&gt; 360 degrees</td>
<td>± 0.1 deg on sky (1 pixel)</td>
<td>Beam</td>
</tr>
<tr>
<td>Slit wheel</td>
<td>75 K</td>
<td>Detent</td>
<td>5 positions</td>
<td>± 1 pixel</td>
<td>30 mm diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 mm thick</td>
</tr>
<tr>
<td>Dekker stage</td>
<td>75 K</td>
<td>Detent</td>
<td>4 positions</td>
<td>± 1 pixel</td>
<td>n/a</td>
</tr>
<tr>
<td>SV filter wheel</td>
<td>75 K</td>
<td>Detent</td>
<td>15 positions</td>
<td>± 0.1 mm</td>
<td>25 mm diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~5 mm thick</td>
</tr>
<tr>
<td>Order sorter wheel</td>
<td>75 K</td>
<td>Detent</td>
<td>10 positions</td>
<td>± 0.1 mm</td>
<td>6 x 10 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~3 mm thick</td>
</tr>
<tr>
<td>IG selection mirror</td>
<td>75 K</td>
<td>In/out</td>
<td>2 positions</td>
<td>± 0.1 mm</td>
<td>Beam</td>
</tr>
<tr>
<td>XD wheel</td>
<td>75 K</td>
<td>Detent</td>
<td>12 positions</td>
<td>± 1 pixel (15 arcsec)</td>
<td>~32 x 50 mm to</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~32 x 40 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>~ 7 mm thick</td>
</tr>
<tr>
<td>XD wheel tilt</td>
<td>75 K</td>
<td>Continuous</td>
<td>± 5 degrees</td>
<td>± 1 pixel (15 arcsec)</td>
<td>n/a</td>
</tr>
<tr>
<td>Spectrograph focus</td>
<td>75 K</td>
<td>Continuous</td>
<td>± 2 mm</td>
<td>± 50 µm</td>
<td>n/a</td>
</tr>
</tbody>
</table>
GENERIC BEARING MOUNT
Athermal Bearing Mount
Athermal Turret Axle Design

Angular contact bearing
Turret

Conical race

Collett

Wave spring washer provides axial preload force

Materials:
Aluminum
Brass
Steel

Axle
Athermal Turret Behavior

- Components contract as turret cools from ambient to operating temperature
- Aluminum turret & axle contract/expand as a rigid body

\[
\begin{align*}
T_{\text{max}} &= 295K \\
T_{\text{min}} &= 77K
\end{align*}
\]

- \(\%\text{Chg}_{\text{Al}} = -0.393\%\) (turret, collett, & axle)
- \(\%\text{Chg}_{\text{Invar}} = -0.041\%\) (bearing mat’l)
over temperature range

Bearings removed
Athermal turret axle design

- Eliminates axial & radial displacement of turret relative to axle due to CTE mismatches between steel bearings and aluminum turret during cool-down/warm-up.
- Turret/axle assembly (CTE) behaves as though it were a single material as temperature changes
- Turret remains aligned when warm or cold
- Don’t need to design in “warm” bearing clearances that makes turret sloppy when warm & tight when cold
DISCRETE ANGULAR POSITION MECHANISMS (DAPM)
DAPM: Choice of a type of wheel

Here is a summary of the pros and cons of a Geneva drive versus a compliant worm drive:

- **Pro**: Geneva mechanisms locate the wheel close to the required position => less detent force required
- **Pro**: Geneva mechanisms require less time to index than a worm drive because the reduction ration is usually less
- **Con**: Geneva mechanisms usually require the use of gear reduction.
- **Con**: due to the reduction and the use of a cam, Geneva mechanisms have more moving parts than a worm drive
- **Pro**: Geneva wheels are less expansive to fabricate than worm drives
- **Con**: Geneva mechanisms are limited in the number of discrete positions.
DAPM: The Modified Geneva
• In the detent position, the cam has a “dip” so that the detent arm is no longer in contact with the cam but only with the detent seat.
• when the drive bearing disengages from the Geneva wheel, the wheel is still held by the cam
DAPM: The Modified Geneva

- Zone 1 - Ramp up
- Follower travels from fully seated position to fully disengaged position
- Zone 2 – Constant speed
- Crank engages with the Geneva slot
  Turret gets moved to the next position
- Crank disengages with the Geneva slot
- Zone 3 – Ramp down
- Follower lowers back down and detent seats in V-groove of the next turret position to locate turret.
DAPM: The Modified Geneva

Geneva Drive Motor Loads For 1 Cycle:

Torque Loads on Motor vs Time

- Without motor gearbox
- With motor gearbox

ZONE 1
ZONE 2
ZONE 3

Time (sec)

- Drive Loads (with motor gearbox)
- Drive Loads (without motor gearbox)
- VSS 32 stepper max torque
- VSS 42 stepper max torque
DAPM: Slit Wheel + Order Sorter

- Optimized design to fit within extremely small space
- Light-tight separation plate (fore-optics / spectrometer)
DAPM: Order Sorting Mechanism

• 10 Discrete Positions
• Gearing = 2:1 ratio
• Enclosure:
  - 3-point mount ("ears")
  - Filter Cell Access
• 45° Fold Mirror Mount
• Motor Location:
  - Easier Access
  - Light-shielding
DAPM: Slit Wheel Mechanism

- 5 (10) Discrete Positions
- Gearing = 2:1 ratio
- Enclosure:
  - 3-point mount ("ears")
  - Slit Mirror Cell Access
- "light seal" around the Dekker mask.
- 22.5deg conical turret -> axle // to OSM axle
DAPM: Slit Wheel Mechanism
DAPM: Filter Wheel Mechanism

- 15 Discrete Positions
- Gearing: 1:1 Bevel + 4:1 Phytron Planetary Gear
- 45deg Turret for optimized space usage
- Light-tight Motor Mount
DAPM: Filter Wheel Mechanism

- Filter Cells Facilitate swap/replacement of filters
- 3-point support = Statically Determinate
- 2 different Cells with 2 different angles (Ghost)
DAPM: Filter Wheel Mechanism

Motor Mount Concept:

Cross-Section

Cold-Strap

Light-Shield
DAPM: Cross-Disperser Mechanism

- 12 Discrete Positions (+ Tilt)
- Gearing: 3:1 Bevel +
  4:1 Phytron Planetary Gear

- Grating angle to wheel optimized to reduce overall diameter while clearing the bearings mount
DAPM: Cross-Disperser Mechanism

- Gratings are mounted in removable modules.
- Optics modules are unique but are machined from identical blanks.

- Each grating is mounted in a module with mounting features that fully support the grating without over constraining it.
- The grating modules have no provisions for tip/tilt adjustment. One-time adjustments may be necessary by machining optics mounting surfaces.
CONTINUOUS ANGULAR POSITION MECHANISMS (CAPM)
CAPM: Image Rotator

- Designed by G. Muller
- First Concept
New Concept: 2 Folds and Cold Stop separated to facilitate Alignment
K-Mirror Assembly and K-Mirror Hub:

Note: The middle mirror of the K-mirror assembly is separated from the main hub because it would be very difficult to fabricate as one part.
a) 120 tooth brass worm gear
b) Hall effect sensor
c) Vespel worm
d) Drive shaft bearing
e) Flex coupling
f) Stepper motor

- Home position determined by state change of Hall-effect sensor (i.e. sense to not sense, but not vice versa)
- Count steps from home to determine position (Requires initialization procedure at startup)
• The brake straddles the worm gear similar to a bicycle brake and provides a clamping force via a compression spring.
• The braking force is adjustable by adjusting the compression spring preload.
CAPM: Cross-Disperser Tilt Mechanism

- XD Tilt Axis (Flex Pivots)
- XD Tilt Drive Lead Screw
- XD Tilt Drive Flex Pivots
- Optical Bench Bracket
- XD Tilt Drive Stepper
CAPM: Cross-Disperser Tilt Control

• Choice of a type of position sensor:

1. Hall Effect Sensor (F.W. Bell FH-301-040):

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Price</td>
<td>- Unknown Accuracy</td>
</tr>
<tr>
<td>- Already implemented in SpeX</td>
<td>- Too much effort needed to quantify at the level of accuracy required.</td>
</tr>
<tr>
<td>- Passive Sensing. Can be used simultaneously with Detector Readout.</td>
<td>- Range is limited. “Physical range reduction trick” (*) isn’t applicable.</td>
</tr>
<tr>
<td></td>
<td>- No package or mount included.</td>
</tr>
<tr>
<td></td>
<td>- Potential irregular magnetization</td>
</tr>
</tbody>
</table>

2. Eddy Current Sensor (Kaman DIT-5200L / 20N):

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Known accuracy.</td>
<td>- Price.</td>
</tr>
<tr>
<td>- Extremely Linear.</td>
<td>- Active sensor: can perturb detector readout.</td>
</tr>
<tr>
<td>- Range can be tuned using a “Physical range reduction trick” (*)</td>
<td>- Needs 10/15 minutes to warm up and give reliable data after turning it on =&gt; RF switch needed.</td>
</tr>
<tr>
<td>- Easier to implement</td>
<td></td>
</tr>
</tbody>
</table>

(*) The “Physical Range Reduction Trick” Can only be used with an active sensor and a passive target (aluminum). See Next Slide.
CAPM: Cross-Disperser Tilt Control
DISCRETE LINEAR POSITION MECHANISMS (DLPM)
Mask Shape and Dimensions:

- $4 \neq $ Slit Length
- Step width $> $ widest slit to decrease accuracy requirement on X.
- 22.5deg inclination of the opening to be $// $ to the beam.
DLPM: Dekker Mechanism

First Concept:

- Off-the-Shelf Piezo-Stage with Encoder (Cryogenic rated)
- Miniature Design
- Light-tight enclosure of the piezo-stage.

(dimensions in mm)
DLPM: Dekker Piezo-Stage Testing

- Refurbished an old instrument into a test dewar.
- Test plan includes cryo & vacuum test, position hold test, re-initialization test, hard-stop test and Lifecycles.
- First and second tests unsuccessful. No movement at 77K. Still troubleshooting with Vendor.
DLPM: Dekker Piezo-Stage Alternative Concept

- Flexure Stage designed using Flex-Pivots.
- Powered using a Stepper + Worm Gear + Eccentric Cam.
DLPM: Immersion Grating Mechanism

- Light-tight motor mount
- Mounting Sub-plate
- Preloaded Mirror Mount
- 45deg stage due to available Space
DLPM: Immersion Grating Mechanism

- Fold Mirror Mount
- Mirror Mount Positioning Feet
- Mirror Stop
- Mirror Mount Bracket
- Machined Springs (3)
- X and Y-axis Location
- Retaining springs
DLPM: Immersion Grating Mechanism

- Cold Strap Interface
- Immersion Grating Mount
- Immersion Grating
- Retainers
- Mask
- Heater Resistor
- Temperature Sensor
- G-10 Insulation Feet

[Image of DLPM: Immersion Grating Mechanism]
CONTINUOUS LINEAR POSITION MECHANISMS (CLPM)
CLPM: Detector Mount and Stage

- H2RG Detector Mount
- Baffle Tube
- G-10 Legs
- Lead Screw Drive
- Parallel Flexure
- Hall-Effect Position Sensor
- Bench Mount Bracket
- Phytron Planetary Gear
- Cold Strap Interface
CLPM: Detector Mount and Stage

- Focus Stage Design based on SpeX Flexure-Stage but with simplified gearing (off-the-shelf planetary) and improved anti-backlash system.

- “Configuration Board” for ARC controller cabling
CLPM: Detector Focus Stage

Anti-backlash System:
• Split-Nut preloaded with wave-spring
• Nuts shaped to stop relative rotation
• Preload > Flexure Axial Force + Moving Load
CLPM: Detector Mount and Stage

H2RG Mount with New Configuration Board: