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| **M1S Simulator** |
| Mirror simulator for M1DCS |

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# Introduction

This document describes a static model for the M1 mirror. The model solves the static force and moment balance equation for the mirror. The model can be used to simulate raising and lowering of the mirror and breakaway condition of the hardpoint. If needed, the model can further be integrated with mirror and actuator dynamics and external disturbances.

# Definitions, Acronyms, and Reference Documents

## Definitions

Table ‑: Definitions

|  |  |
| --- | --- |
| Term | Definition |
| Support actuator | The M1 Support Actuator Assembly with a single or triple air cylindesr designed to apply an axial support force or 3D x, y, z force. |
| Hardpoints | Six adjustable struts fixed to the underside of the mirror which rigidly define its position and are servo-controlled to zero load using an active control system. |
| Static Support | 3 D springs used to passively support the weight of the mirror. |

## Acronyms

[This section should list alphabetically each acronym used in the document, together with the acronym’s expanded meaning. See GMT Project Acronyms and Glossary document for guidance (GMT-REF-00362). Each acronym should be selected from the GMT Acronyms list. If it is not existing in the GMT Acronyms list, please ask the Configuration Management team ([gmt\_cm@gmto.org](mailto:gmt_cm@gmto.org))  to add it or show you how to add it yourself].

Table ‑: Acronyms

|  |  |
| --- | --- |
| Acronym | Description |
| GMT | Giant Magellan Telescope |
| CG | Center of gravity |
| DOF | Degrees of freedom |

## Referenced Documents

[List all Reference Documents. GMT referenced document should be selected from the list located in CM’s controlled area within DocuShare. DocuShare Links are to point to the “Properties” page of the referenced document as located within DocuShare].

Table ‑: Referenced Documents

|  |  |  |
| --- | --- | --- |
| Document Number | Title | DocuShare Link |
| GMT-REF-00189 | GMT Coordinate System and Vertical Datum | <https://docushare.gmto.org/docushare/dsweb/Services/Document-11101> |

# Mathematical Formulation

The model consists of the mirror and its support system of hardpoints, support actuators and equivalent static supports. Figure 1 shows the relative x-y location of hardpoint and static supports in M1T-B coordinate system. M1-T-B coordinate system is M1-T coordinate system (as defined in GMT-REF-00189) with origin shift to M1-B coordinate system (as defined in GMT-REF-00189) that has origin at the center of the mirror backplate when the mirror is at the default position. The mirror experiences reaction forces from its support system against the force of gravity that is acting on it. The variables defining various hardpoint, equivalent static support and mirror location as well as force and moment reactions from each support component is given in Table 4.

A picture containing object, drawing

Description automatically generated

Figure Location of hardpoints and equivalent static supports in M1-T-B coordinate system

Table ‑: Definition of various position variables, force variables and transforms.

|  |  |
| --- | --- |
| **Symbol** | **Description** |
|  | 3 equivalent static support |
|  | 6 hardpoints |
|  | x, y, z position of the static support-mirror interface node |
|  | x, y, z static support reaction forces |
|  | 9 x 1 vector of |
|  | 9 x 1 vector of |
|  | Hardpoint reaction forces on the mirror. |
|  | Position of the hardpoint-mirror interface node along hardpoint axis; hardpoint mirror encoder position |
|  | 6 x 1 vector of |
|  | 6 x 1 vector of |
|  | position of the hardpoint actuator encoder along hardpoint axis |
|  | 6 x 1 vector of |
|  | Mirror center location. |
|  | 6 x 1 vector of |
|  | Support actuator forces applied at the back of the mirror |
|  | 350 x 1 vector of |
|  | Mirror center node to Static support node transform |
|  | Transform from static support force to force moment about the origin. |
|  | Mirror center node to Hardpoint node transform |
|  | Transform from hardpoint force to force moment about the origin. |
|  | Transform from support actuator force to force moment about the origin. |
|  | Matrix to distribute force and moment to support actuator forces |
|  | Hardpoint breakaway stiffness matrix |
|  | Static support stiffness matrix |
|  | Gravity induced force and moment about the origin |
|  | Support actuator induced force and moment about origin |
|  | Static Support induced force and moment about the origin |
|  | Hardpoint induced force and moment about the origin |
|  | Location of mirror CG w.r.t the origin |
|  | Rotation matrix from OSS coordinate system to M1T-B coordinate system. |

The mirror motion is monitored w.r.t the origin of M1-T-B coordinate system. When the mirror raised to its default position, the mirror is at the origin hence . The hardpoint actuators are at midpoint of their range of travel, the breakaways are at midpoint of their range travel and the static support are completely relaxed. When the hardpoints actuator and breakaway are at their midpoint of travel it is the 0 point of their travel, i.e., . All hardpoint lengths are monitored with respect to these zero points. When the static support is completely relaxed, it marks the static support 0 point i.e., . All static support compression and expansion is w.r.t these 0 points. The mirror is supported against gravity by a combination of reaction forces from the static supports, hardpoints and actuators.

The force and moment balance at the origin is given by equation 1.

The following transforms give the relation between various locations and reaction forces,

Static supports

Hardpoints

Actuators

is the generic force moment combinations that is applied to the mirror.

The hardpoint breakaway stiffness and static support stiffness show a nonlinear behavior as shown in figure 2.

(b)

(a)

Figure 2 a) Static support force vs displacement per DOF b) Hardpoint breakaway force vs displacement per DOF

The stiffness equation for per DOF of static support can be written as follows:

is the static support gap.

The stiffness equation for per hardpoint breakaway can be written as,

is the breakaway force limit,

are diagonal matrices with stiffness of each DOF forming the diagonal elements.

Using the transforms equation 1 can be written as,

Using equation 12, the mirror position is given by,

Equation 13 gives the mirror position for any combination of static support, hardpoint and support actuator forces. The solution to this equation is indeterminant if matrix inverse is indeterminant. This can happen when both simultaneously become 0. This happens if the breakaway actives when the mirror is only supported by the support actuators. One needs to handle this special case in simulation.

The support actuator results force and moment can be a fraction of while raising and lowering the mirror.

is found by transforming the gravity vector from OSS coordinate system to M1-T-B coordinate system

is parametrized by zenith angle , mirror tilt and mirror clocking angle .

# MATLAB Implementation

The MATLAB implementation is done as a series of computations as new inputs become available to the simulator. The gravity vector acting on the mirror is defined by parameters listed in table 4-1. As the mirror moves these parameters may change. But this change will be very small and may be neglected for the purpose this simulation.

As stated in table 4-2 individual actuator forces and hardpoint actuator lengths are commanded to the mirror. If no actuator dynamics are involved . That is commanded force is the input force applied to the mirror or commanded hardpoint length is the change in hardpoint length.

The outputs of the simulation are actuator forces, hardpoint lengths, hardpoint reaction forces and mirror position as listed in Table 4-3. In the absence of system or sensor dynamics, the actuator forces and hardpoint lengths are transmitted directly from input to output that is . These are feedback signals to the control systems. The hardpoint reaction forces and hardpoint mirror encoder position are calculated in the simulation. They are directly fed to the output as if the no dynamics are involved. The mirror position is used for monitoring purposes.

The simulator is configured using mirror orientation

Table ‑: Initial configuration of the mirror.

|  |  |
| --- | --- |
| **Symbol** | **Description** |
|  | Zenith angle |
|  | Segment clocking |
|  | Segment tilt |

The inputs to the simulator are

Table ‑: Simulator inputs

|  |  |
| --- | --- |
| **Symbol** | **Description** |
|  | Support actuator forces command |
|  | Hardpoint actuator length command |

The outputs of the simulator are

Table ‑: Simulator outputs

|  |  |
| --- | --- |
| **Symbol** | **Description** |
|  | Hardpoint forces |
|  | Support actuator forces |
|  | Hardpoint actuator length |
|  | Hardpoint breakaway / mirror length |
|  | Mirror position |

The simulator starts with mirror resting on the static supports. The position of various elements and the reaction forces on the mirror are initialized for this state of the mirror.

Initialization:

Set or calculate initial and reaction forces using following steps.

1. Compute the force and moment about the M1-T-B coordinate system using equation 15
2. Since the mirror is supported only by static supports convert to using the transform in equation 4 where
3. Find the static support compression in each DOF using equation 10. We offset the by static support gap in the direction opposite of DOFs.
4. Convert to using equation 2.
5. Convert to using equation 5.
6. is commanded to make , when the hardpoint is locked up during cell startup operation.
7. at initialization as support actuators are applying no controlled force to the mirror.

Once the simulator variables are initialized the simulator is updated every step when new inputs in terms of and are available to the simulator. The following computations are done at every step:

Update variables at the step:

Inputs

1. Using from step update using equation 2 and 5
2. Update using equation 10 and 11
3. Calculate using equation 9
4. Calculate new mirror location using equation 13

Outputs