Tangent Load Cell Fault Detection

Overview

This document explains the calculations to determine if a tangent link actuator is not working properly, or the mirror is tending to an unsafe position.

Code in ts_mtm2 LabVIEW project

This calculation is done in **TangentLoadCellFaultDetection.vi**.

Tangential Actuators

The M2 is an active mirror with 72 axial actuators and 6 tangential actuators. Figure 1 shows the 6 tangential actuators located at **A** ring and labeled with A1 - A6.

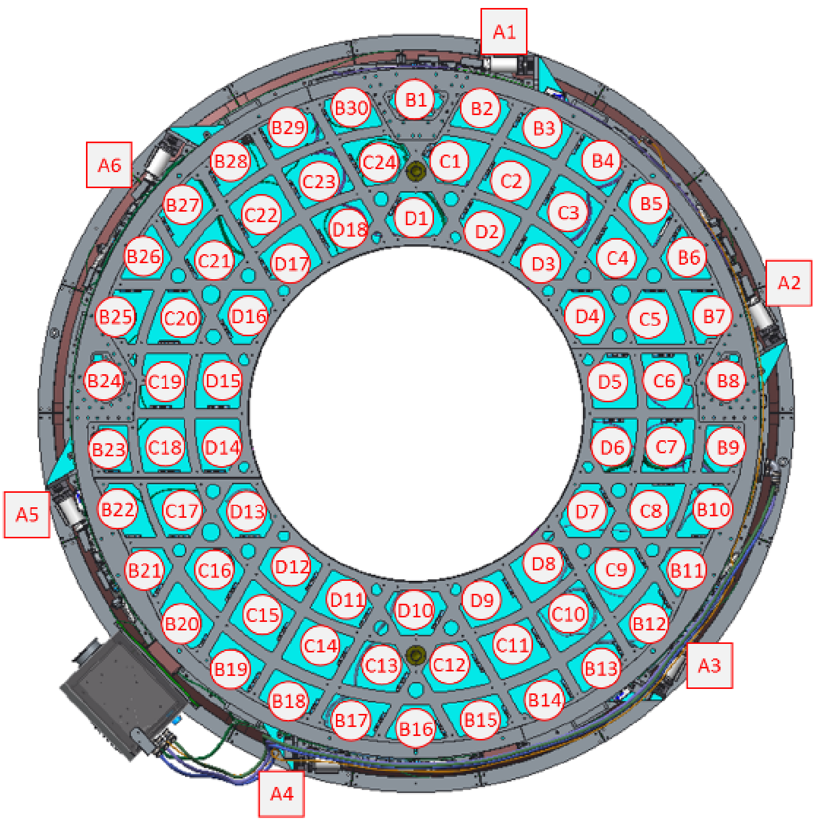

Figure 1: Axial and tangential actuators labeled on Cell Weldment.

Tangential Actuator Forces

The tangential forces are defined with the vector of tangential forces $\vec{f_{\tan}}$ in N as the following:

$$\vec{f_{\tan}} = (f_{A,1...6})$$

Figure 2 shows the orientation of tangential link actuator forces on M2 mirror. Each actuator is separated 60 degrees from center of mirror.

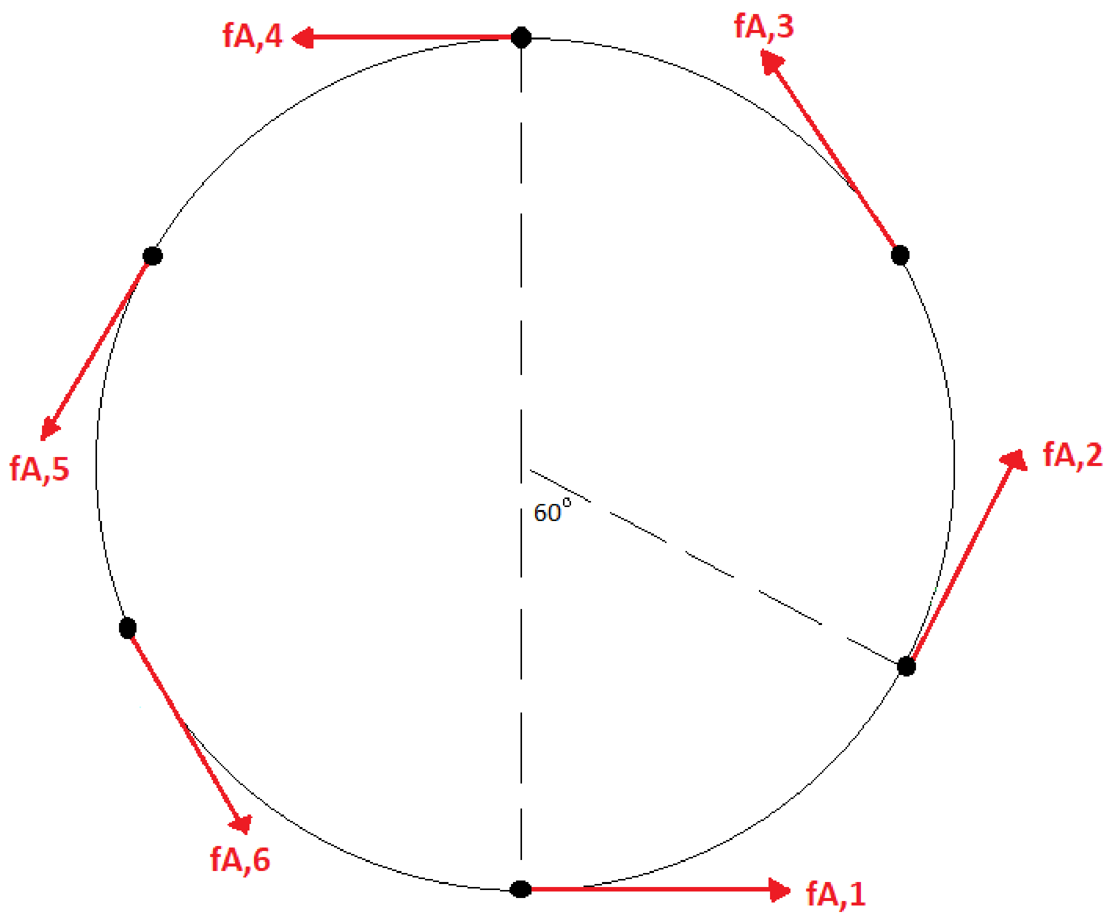

Figure 2: Tangential link actuator forces on M2 mirror.

Alt-Azimuth Mount

Vera Rubin telescope uses an alt-azimuth mount that supports and rotates telescope about two perpendicular axes, one vertical and the other horizontal. The vertical axis varies the azimuth of pointing direction of the instrument (azimuth motion), and the horizontal axis varies the altitude angle of pointing direction (altitude motion). When telescope varies the altitude angle, also known as elevation angle ($\theta^{\circ}_{\mathrm{EL}}$), zenith distance ($\theta^{\circ}_{\mathrm{Zd}}$) varies, because $\theta^{\circ}_{\mathrm{Zd}} = 90^{\circ} - \theta^{\circ}_{\mathrm{EL}}$, in Figure 3:

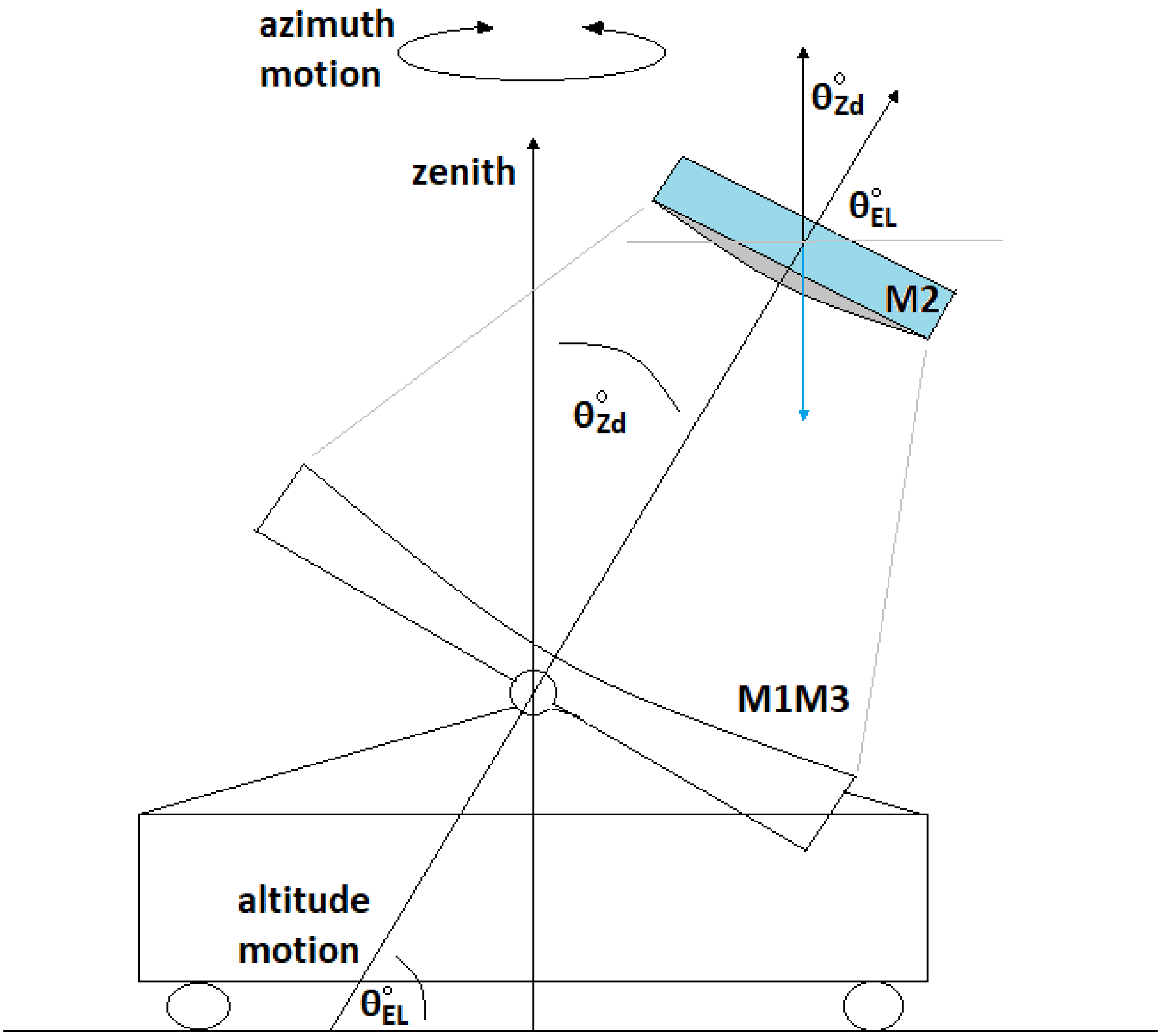

Figure 3: M2 mirror in the alt-azimuth mount.

Tangential Load Fault Monitoring

To protect the integrity of mirror, it is necessary to determine if a tangent link actuator is not working properly, or mirror is tending to an unsafe position, monitoring tangential actuator forces. When mirror is on tilt orientation, tangential forces have to compensate gravity force of mirror ($f_w sin(\theta^{\circ}_{\mathrm{Zd}})$), in Figure 4. f_w is the mirror weight (m_{mirror}) in kg times the gravity acceleration (g).

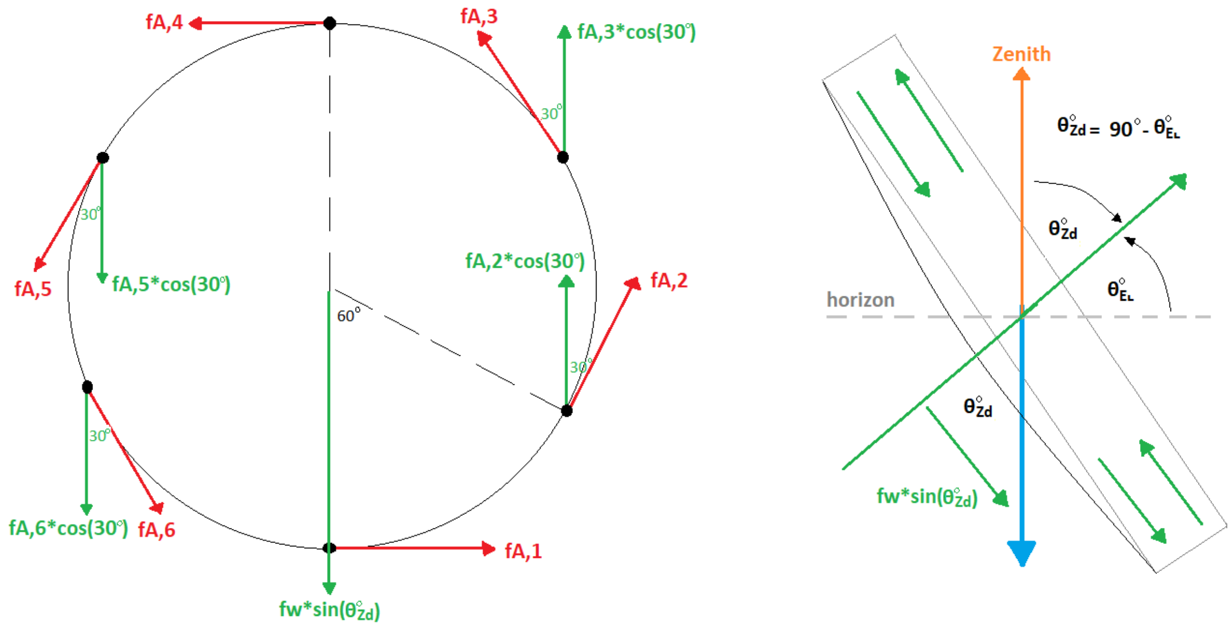

Figure 4: Tangential force components and gravity force on M2 mirror pointing to horizon with $\theta^{\circ}_{\mathrm{EL}}$.

LSST engineers suggested Harris developer used $f_w = 15140$ N, this considers $m_{\mathrm{mirror}} = 1545$ kg, but is necessary to replace it with the real measured value.

The components of tangential forces shown in Figure 4, have to compensate gravity force, that depends on $\theta^{\circ}_{\mathrm{Zd}}$, to avoid mirror is tending to an unsafe position, in the following:

$$-f_{A,2}cos(30^{\circ}) - f_{A,3}cos(30^{\circ}) + f_{A,5}cos(30^{\circ}) + f_{A,6}cos(30^{\circ}) - f_w sin(\theta^{\circ}_{\mathrm{Zd}}) = 0 \qquad (1)$$

It is noted that the coordinate system of M2 is different from the telescope's coordinate system, which the positive direction is defined from M2 to M1M3 (in Harris's viewpoint), Figure 5. Harris developer considered that tangential actuators A2 and A3 are in compression, so $f_{A,2}$ and $f_{A,3}$ have a negative sign, and tangential actuators A5 and A6 are in tension, so $f_{A,5}$ and $f_{A,6}$ have a positive sign in (1).

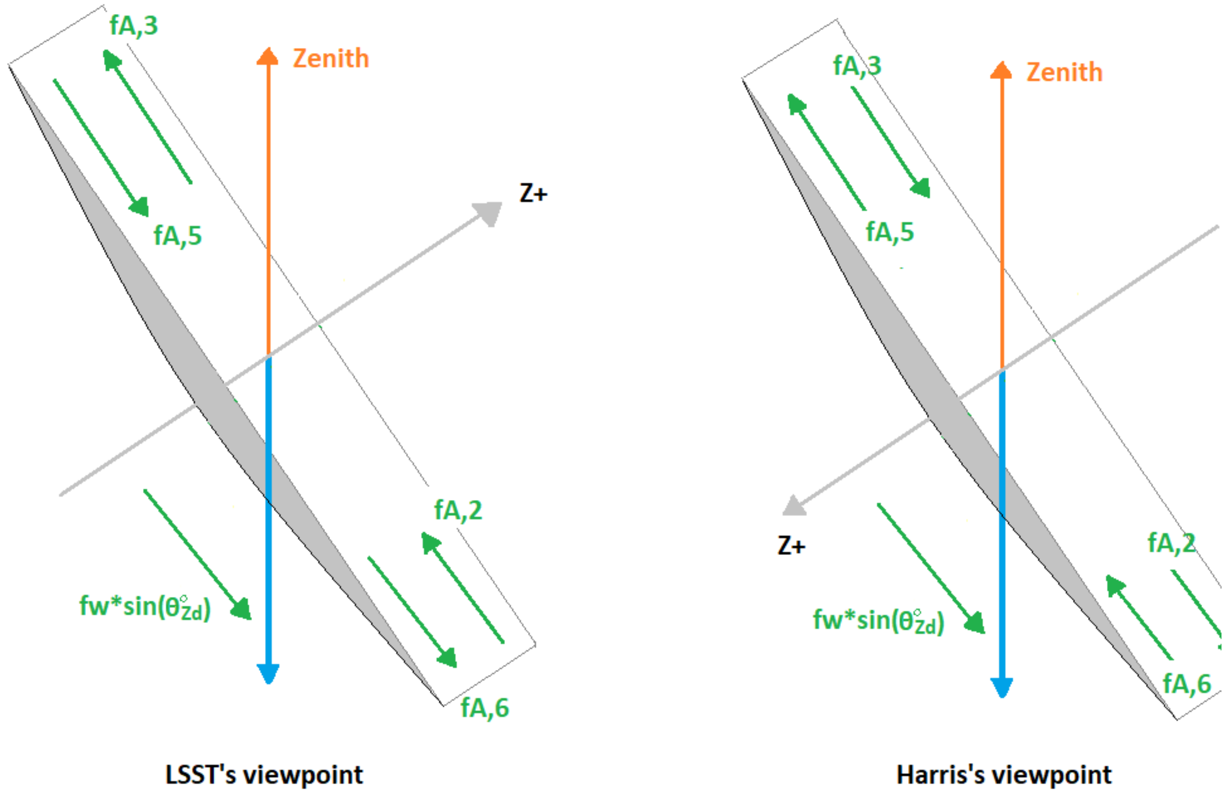

Figure 5: Different coordinate systems based on LSST's viewpoint and Harris's viewpoint.

The measurement of tangential force components must have certain restrictions. Any deviation of these restrictions will be considered a tangential load fault, and this will happen when one of these errors occurs: (1) tangential weight error, (2) load bearing error, (3) net moment error, and (4) non-load bearing error. These errors will be described in the following sections.

Tangential Weight Error

On (1) instead of comparing with zero, it is necessary to compare with the tangential weight error ($e_{\text{tan,weight}}$) in N, in the following:

$$\left|(-f_{A,2} - f_{A,3} + f_{A,5} + f_{A,6})cos(30^{\circ}) - f_w sin(\theta^{\circ}_{\text{Zd}})\right| \geqslant e_{\text{tan, weight}} \qquad (2)$$

If the above equation is true, there is the tangential load fault.

Load Bearing Error

The gravity force on mirror is distributed equally between four of the six tangent actuator. The other two are only required for stability. These four actuator forces must be compared with the load bearing error (e_{bearing}) in N, in the following:

$$\left|f_{A,2}cos(30^{\circ}) + \frac{f_w sin(\theta^{\circ}_{\text{Zd}})}{4}\right| \geqslant e_{\text{bearing}}$$

$$\left|f_{A,3}cos(30^{\circ}) + \frac{f_w sin(\theta^{\circ}_{\text{Zd}})}{4}\right| \geqslant e_{\text{bearing}}$$

$$\left|f_{A,5}cos(30^{\circ}) - \frac{f_w sin(\theta^{\circ}_{\text{Zd}})}{4}\right| \geqslant e_{\text{bearing}}$$

$$\left| f_{A,6} cos(30^\circ) - \frac{f_w sin(\theta^\circ_{\mathrm{Zd}})}{4} \right| \geqslant e_{\mathrm{bearing}}$$

If any of the above equations is true, there is the tangential load fault.

Net Moment Error

It is necessary to avoid the M2 mirror tending to an unsafe position, so the net moment on mirror has to be zero, in the following:

$$d \sum_{i=1}^{6} f_{A,i} = 0 \ , \qquad (3)$$

where d is the distance of each actuator to the center of the mirror.

Because d is unequal to zero, we have:

$$\sum_{i=1}^{6} f_{A,i} = 0 \qquad (4)$$

Instead of comparing (4) with zero, it is necessary to compare with the net moment error (e_{moment}) in N, in the following:

$$\left| \sum_{i=1}^{6} f_{A,i} \right| \geqslant e_{\mathrm{moment}} \qquad (5)$$

If the above equation is true, there is the tangential load fault.

Non-Load Bearing Error

As described before, there are two tangential actuators used only for stability: A1 and A4 in Figure 1. In these non-load bearing actuators there is no load, so $f_{A,1} = 0$ and $f_{A,4} = 0$. It is necessary to compare them with the non-load bearing error (e_{nonload}) in N instead of zero, in the following:

$$|f_{A,1}| \geqslant e_{\mathrm{nonload}}$$

$$|f_{A,4}| \geqslant e_{\mathrm{nonload}}$$

If any of the above equations is true, there is the tangential load fault.

Support Documents

The following documents are created to support the conversion of these calculations into software programming.

Input/Outputs/Constants

The io_TangentLoadCell_v02.csv file contains simulated inputs, outputs, and constants elements, obtained from the **TangentLoadCellFaultDetection.vi**.

Connections Mapping

The io_TangentLoadCellConnMap_v02.csv file contains a one-to-one relationship of inputs, outputs, and constants from the **TangentLoadCellFaultDetection.vi** and the **io_TangentLoadCell_v02.csv** file.