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Optical Lever Calibration

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1 ABSTRACT

This is a procedure in a step by step form to calibrate the suspended core optic, optical levers. It was derived from LIGO-T990026 by Mike Zucker. This document uses the formulas and techniques described in the above document and includes specific fixturing built to complete the calibration task. To better understand this process it recommended that one reads the above mentioned document.

2 KEYWORDS

Optical Levers, Quadrant Photo Diodes, Transmitter, Receiver, Parallel Glass Plate, Beam Displacement,

3 OVERVIEW

This calibration is to establish the angular motion expressed in micro radians per millivolts as seen by the quad photo diode output signal (receiver). The QPD readout is taken by using the optical lever “breakout” box and a VOM. This document lists the needed fixtures and instructions on their use, and work sheet to log the measurements (APPENDIX 1).

The DAQ system reads and calculates the same values as does the “break out” box and displays the “SUM” ,”PITCH” and “YAW” positions. The individual values for each quadrant of the diode are also displayed in units that reflect the actual voltages.

The calibration would be best to perform at the time the core optic is first installed while the optical lever is freshly nulled and does not disturb on going data trends. The installation and commisioning managers should determine the timing and needs to disturb existing systems by re-zeroing the optical levers or even bumping them around during a calibration.

4 HAZARDS

1. A class IIIa, <5mW laser diode emitting a 633nM beam is used for the optical lever light source. The typical 1/4 second blink reflex will protect your eyes from a brief direct or spectral reflection. Direct beam exposures of approximately 10 seconds or longer could cause eye damage.

5 REQUIREMENTS

1. Fixture number X-001 for the X-Axis measurement.
2. Fixture number Y-001 for the Y-Axis measurement.
3. 2 each 1mm thick BK7 plane parallel 2”dia glass plate.(n=1.52 refractive index)
4. Optical Lever “Breakout” box and its connecting cable.
5. 3 each 3’ - 4’ BNC cables.
6. 2 each Volt/Ohm/Meters.(VOM)
7. 4mm diameter aperture for setting beam diameter.

6 CALIBRATION PROCEDURE:

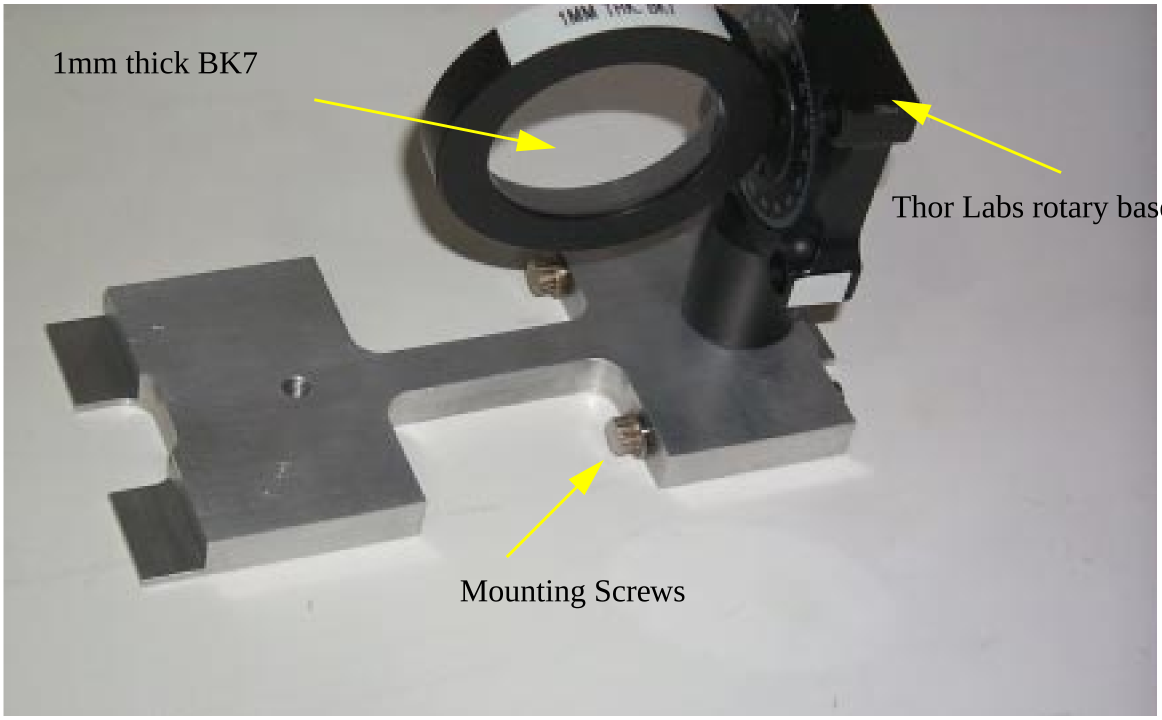
1. Record all current values if optical lever is operational.
2. Make sure the core optic is damped.
3. Turn on transmitter laser if not already on.
4. Remove the cover from the optical lever receiver box.
5. Confirm that the 633nM beam coming from the transmitter is approximately 4mm in diameter when focussed on the QPD (originally set to 2mm at MIT before shipping to sites or field adjusted at installation) Use the 4mm calibrated aperture to set the 4mm diameter at the QPD.
6. Connect the BNC cables to the SUM; X; and Y; outputs of the "Breakout" box.
7. Null the X and Y signals on the QPD by visually steering the beam to the center of the diode on the receiver. Fine tune the steering by bringing the X and Y signals as near to "zero" as practical. (+/-.003mV)
8. Mount X- axis fixture (X-001) to face of the receiver box with the glass plate between the steering mirror and the QPD and lightly tighten the mouting screw. (see photos page 5).
9. Connect the Break Out Box "Y_1" terminal to a VOM.
10. Connect the Break Out Box "X_1" terminal to a second VOM.
11. Rotate the graduated rotation stage while observing the "X_1" VOM. Stop when the reading is as near to "Zero" as practical.
12. Tilt the fixture on the receiver box until the "Y1" VOM reading is as near to "Zero" as practical.
13. Repeat step 10 to fine tune the zero position.
14. Remove the "Y_1" cable and connect it to the "SUM" terminal.
15. Record the SUM; X_1; and Y_1; DC voltages on the work sheet as the"Baseline" voltages to a mV precision. This is to establish the "zero" point for the rotation stage. Rotate the glass plate to a known angle from this "zero" point (e.i 20 degrees). To save time the angle should coordinate with an angle from the Appendix 1 Work Sheet as the displacement values have already been calculated.
16. Record the Sx (SUM) voltage and the X-axis values on the work sheet.
17. Verify that the Y value is near it original value.
18. Rotate the stage to at least 2 other angles and record these value to get a good average of the sensitivity.
19. Rotate the glass plate back to zero and double check that we recover the X_0 and S_0 values.
20. Remove the X-axis fixture.
21. Mount Y- axis fixture (Y-001) to face of the receiver box with the glass plate between the steering mirror and the QPD and tighten the mounting screws. (see photos page5)
22. Connect the Break Out Box "Y_1" terminal to a VOM.
23. Connect the Break Out Box "X_1" terminal to a second VOM.
24. Rotate the graduated rotation stage while observing the "Y_1" VOM. Stop when the reading is as near to "Zero" as practical.
25. Rotate the rotation stage base about the X axis using the mounting post as a pivot point while observing the "X_1" VOM. Stop when the reading is as near to "zero" as practical.
26. Repeat step 23 to fine tune the zero position.
27. Remove the "X_1" cable and connect it to the "SUM" terminal.
28. Record the SUM; X_1; and Y_1; DC voltages on the work sheet as the"Baseline" voltages to a mV precision. This is to establish the "zero" point for the rotation stage. Rotate the glass plate

to a known angle from this “zero” point (e.i 20 degrees). To save time the angle should coordinate with an angle from the Appendix 1 Work Sheet as the displacement values have already been calculated.

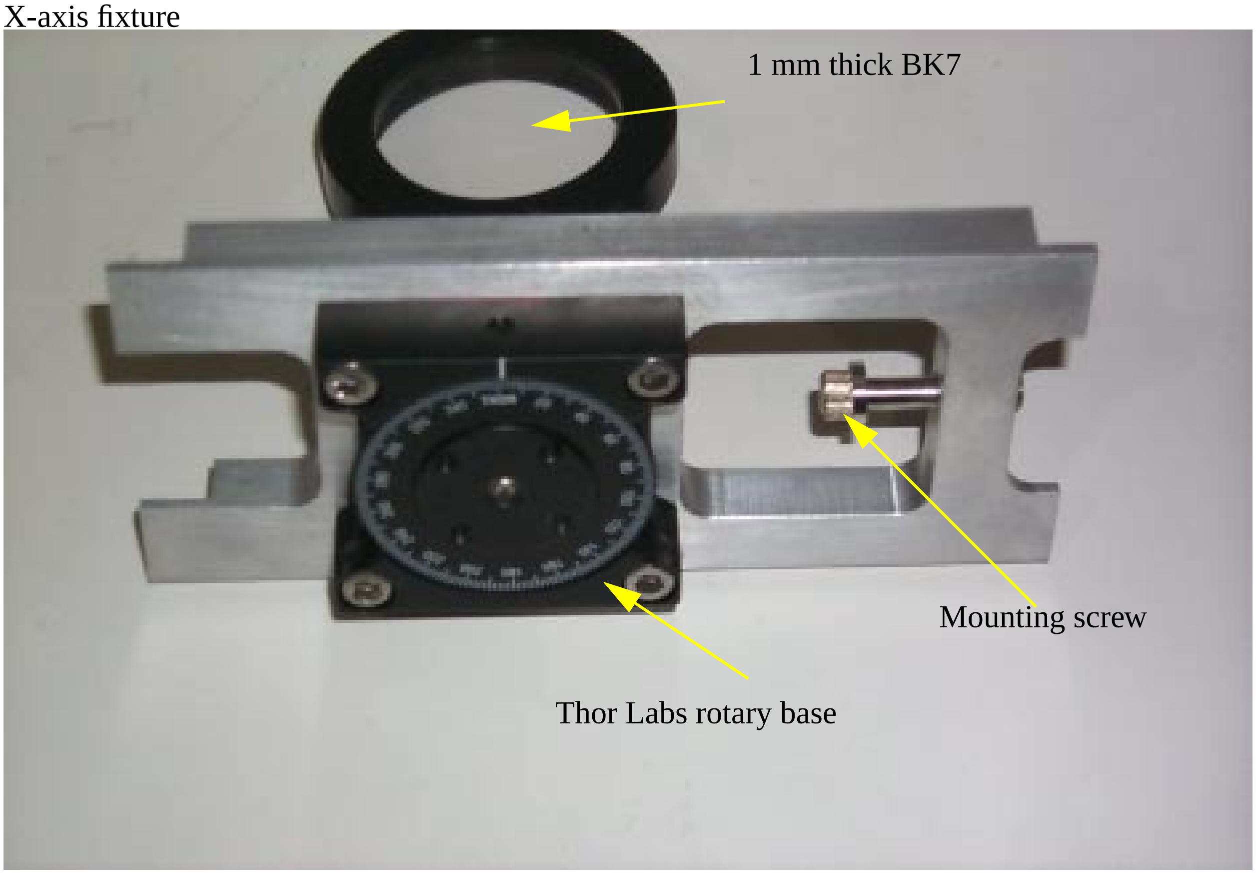
29. Record the Sy (SUM) value and theY-axis value on the work sheet.
30. Verify that the X value is near it original value.
31. Rotate the stage to at least 2 other angles and record these value to get a good average of the sensitivity.
32. Rotate the glass plate back to zero and double check that we recover the X_0 and S_0 values.
33. Remove the Y-axis fixture.
34. Calculate the angular sensitivity using the steps in Appendix 1.
35. Enter results into the appropriate e-log and note books.

X axis and Y axis Glass Plate Fixtures

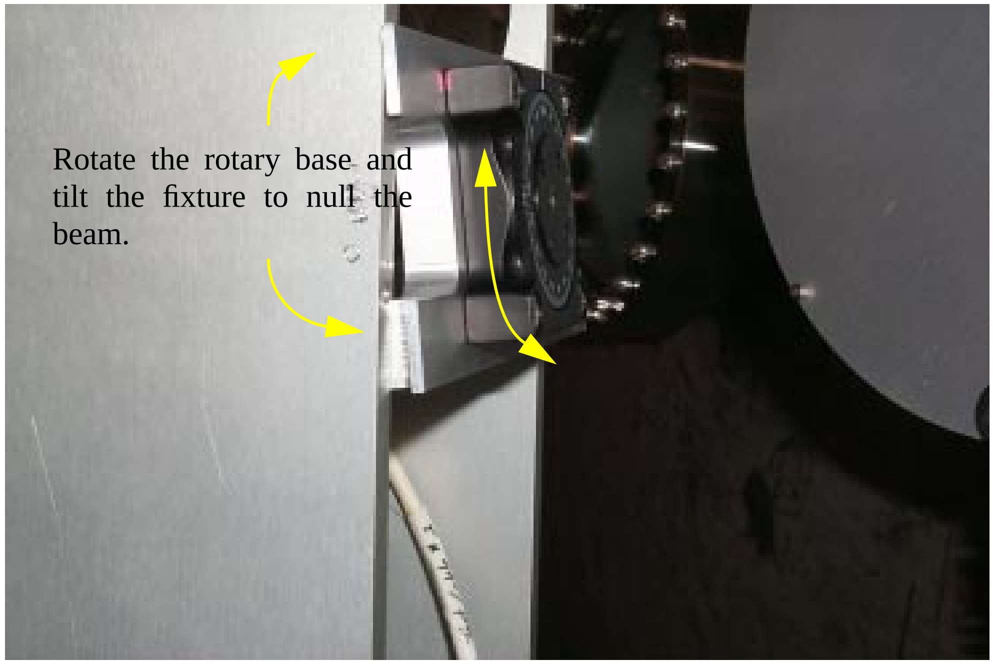
Y-axis fixture:

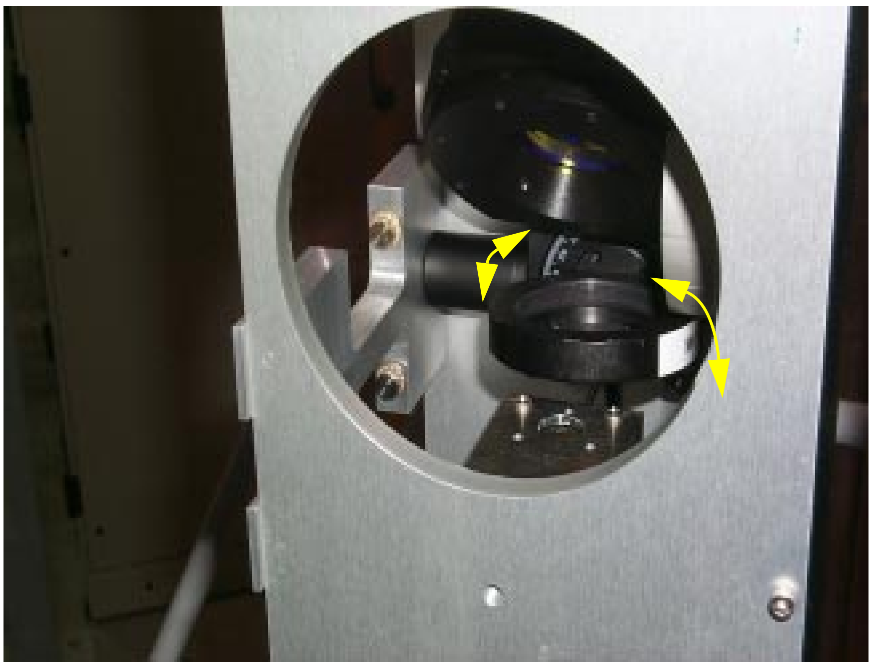


X-axis fixture



X-axis fixture

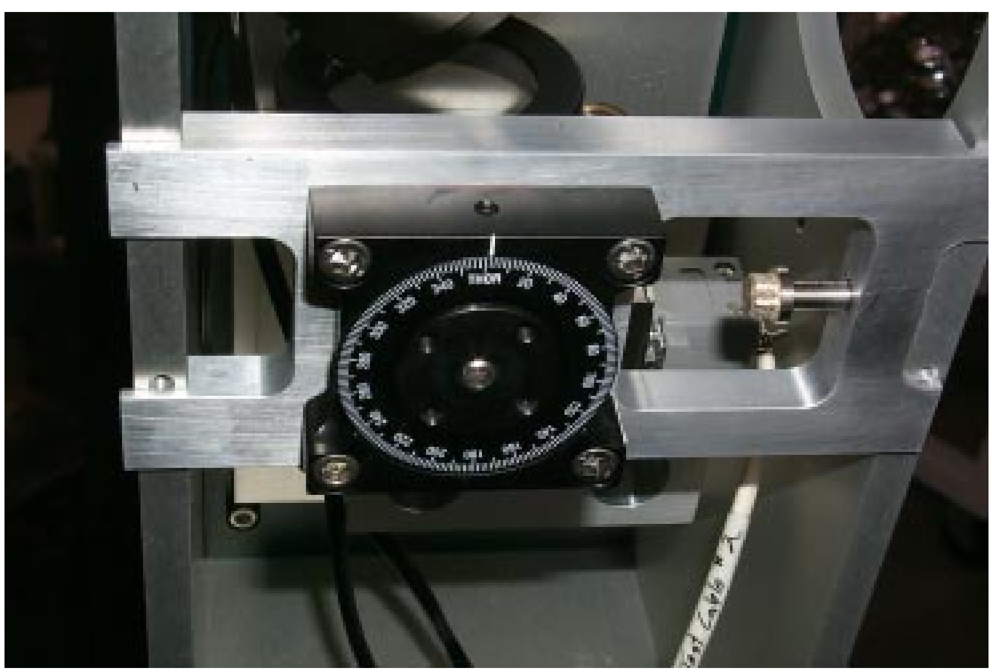




Y-axis

Pivot the rotary base about its mounting post and rotate the rotary base to null the beam on the QPD

X-axis fixture



APPENDIX 1 WORK SHEETS

Descriptions:

1. *d* = lateral displacement in mm.

Displacement *d* given by:

$$d = \frac{t \sin\left(\theta - \operatorname{asin}\left(\frac{\sin(\theta)}{n}\right)\right)}{\sqrt{1 - \frac{(\sin(\theta))^2}{n^2}}}$$

Results for given angles:

For a glass plate angle of 45 degrees use: *d* = .3358mm

For a glass plate angle of 40 degrees use: *d* = .2855mm

For a glass plate angle of 35 degrees use: *d* = .2400mm

For a glass plate angle of 30 degrees use: *d* = .1985mm

For a glass plate angle of 25 degrees use: *d* = .1604mm

For a glass plate angle of 20 degrees use: *d* = .1250mm

For a glass plate angle of 15 degrees use: *d* = .0920mm

For a glass plate angle of 10 degrees use: *d* = .0604mm

For a glass plate angle of 05 degrees use: d = .0299mm

Note: If the calibration plate is not precisely the angle we think it is to the beam, there will be an error in our assumed displacement *d.* This error works out to be about 4% per degree the plates angle deviates for a nominal setting of 45 degrees.

2. *t* = thickness of glass plate. (t = 1mm
3. *n* = refractive index of BK7 glass (n = 1.52)
4. S_0 = Sum "baseline" after inserting glass plate and in the nulled position.
5. X_0 = X "baseline" after inserting glass plate and in the nulled position.
6. Y_0 = Y "baseline" after inserting glass plate and in the nulled position.
7. X = X value after angled glass plate is rotated to the desired angle.
8. Y = Y value after angled glass plate is rotated to the desired angle.
9. Sx = Sum value after angled glass plate is rotated to the desired angle for X axis.
10. Sy = Sum value after angled glass plate is rotated to the desired angle for Y axis.

Recorded Values

For Core Optic:________________________________

Date: ______________________________ By ______________________________

Measurement	Angle & Displacement	VOM Values
S_0 = Sum "Baseline" after inserting glass plate and in the nulled position.		
X_0 = X "Baseline" after inserting glass plate and in the nulled position.		
Y_0 = Y "Baseline" after inserting glass plate and in the nulled position.		
S_X = Sum value after angled glass plate is rotated to the desired angle for X axis.		
X = X value after angled glass plate is rotated to the desired angle.		
S_Y = Sum value after angled glass plate is rotated to the desired angle for Y axis.		
Y = Y value after angled glass plate is rotated to the desired angle.		

To calculate the Linear Senstivity V/mm:

X-axis = $\frac{\delta X}{\delta x} = \frac{X \times \frac{S_0}{S_x} - X_0}{d}$ Y-axis = $\frac{\delta Y}{\delta y} = \frac{Y \times \frac{S_0}{S_y} - Y_0}{d}$

X-axis Calculated Results in V/mm: [ ]

Y-axis Calculated Results in V/mm: [ ]

Angular Sensitivities are found by multiplying these Linear Sensitivities by ***twice*** the lever arm listed in table 1 below.

2L x V/mm = #### rads = $\frac{\text{rads}}{10{,}000}$ = urads [ ]

Recorded Values

For Core Optic:________________________________

Date: ______________________________ By ______________________________

Measurement	Angle & Displacement	VOM Values
S_0 = Sum "Baseline" after inserting glass plate and in the nulled position.		
X_0 = X "Baseline" after inserting glass plate and in the nulled position.		
Y_0 = Y "Baseline" after inserting glass plate and in the nulled position.		
S_X = Sum value after angled glass plate is rotated to the desired angle for X axis.		
X = X value after angled glass plate is rotated to the desired angle.		
S_Y = Sum value after angled glass plate is rotated to the desired angle for Y axis.		
Y = Y value after angled glass plate is rotated to the desired angle.		

To calculate the Linear Senstivity V/mm:

X-axis = $\frac{\delta X}{\delta x} = \frac{X \times \frac{S0}{Sx} - X0}{d}$ Y-axis = $\frac{\delta Y}{\delta y} = \frac{Y \times \frac{S0}{Sy} - Y0}{d}$

X-axis Calculated Results in V/mm: [ ]

Y-axis Calculated Results in V/mm: [ ]

Angular Sensitivities are found by multiplying these Linear Sensitivities by ***twice*** the lever arm listed in table 1 below.

2L x V/mm = #### rads = $\frac{\text{rads}}{10{,}000}$ = urads [ ]

Recorded Values

For Core Optic:______________________________

Date: ______________________________ By ______________________________

Measurement	Angle & Displacement	VOM Values
S_0 = Sum "Baseline" after inserting glass plate and in the nulled position.		
X_0 = X "Baseline" after inserting glass plate and in the nulled position.		
Y_0 = Y "Baseline" after inserting glass plate and in the nulled position.		
S_X = Sum value after angled glass plate is rotated to the desired angle for X axis.		
X = X value after angled glass plate is rotated to the desired angle.		
S_Y = Sum value after angled glass plate is rotated to the desired angle for Y axis.		
Y = Y value after angled glass plate is rotated to the desired angle.		

To calculate the Linear Senstivity V/mm:

X-axis = $\frac{\delta X}{\delta x} = \frac{X \times \frac{S_0}{S_x} - X_0}{d}$

Y-axis = $\frac{\delta Y}{\delta y} = \frac{Y \times \frac{S_0}{S_y} - Y_0}{d}$

X-axis Calculated Results in V/mm:

Y-axis Calculated Results in V/mm:

Angular Sensitivities are found by multiplying these Linear Sensitivities by ***twice*** the lever arm listed in table 1 below.

2L x V/mm = #### rads = $\frac{\text{rads}}{10{,}000}$ = urads

Table 1.

LOS Description	L = Distance from Core Optic to Receiver in inches & mm
MMT3-2K	57.25” / 1454.15mm
RM-2K	169.50” / 4305.3mm
BS-2K	66.05” / 1677.67mm
FMx-2K	48.63” / 1235.08mm
ITMx-2K	1312.20” / 33329.88mm
ETMx-2K	239.70”/ 6088.38mm
FMy-2K	81.40” / 2067.56mm
ITMY-2K	1312.20” / 33329.88mm
ETMy-2K	239.7” / 6088.38mm
MMT3-4K	42.55” / 1080.77mm
RM-4K	128.35” / 3260.09mm
BS-4K	72.20” / 1833.88mm
ITMx-4K	1118.1” / 28399.74mm
ETMx-4K	239.70” / 6088.38mm
ITMy-4K	1217.10” / 30914.34mm
ETMy-4K	239.70” / 6088.38mm