SolarTrak®

Correction of Tracking Errors due to Misalignment of Axes

The SolarTrak® is a mathematically based system. Its perception of the universe is a computerized model (simulation) of the mechanism it controls and the position of the Earth with respect to the Sun at a given instant in time. It is able to compute the Sun's relative position to any point on the planet with an accuracy of less than $1/100^{th}$ of a degree. Its ability to then properly position a solar collector or reflector rests on the accuracy of the mathematical description of the mechanical system, the stiffness of the mechanical system and the precision of the position feedback system.

The major points of the mechanical description are:

1. The specification of the Ideal Coordinate Reference Frame
2. A mathematical model of motion with respect to position feedback
3. A definition of range of motion

The stiffness of the mechanical system includes:

1. Mechanical Backlash
2. Torsional and bending stiffness of drive members
3. Issues of binding and excessive friction

The precision of the position feedback system involves:

1. Repeatability of actual position vs. reported position
2. Available resolution of feedback pulses (turncounts) per unit rotation

Correctible Errors

For there to be the option of correction, there must be predictability of the error. Tracking errors due to backlash or bending are less than fully predictable using conservative means. In bending situations, the result is generally an accumulation of strain through several components and cross-sections. Measurements can be taken and an approximate correction can be tried. Backlash, depending on the stiffness of the drive train, changes with too many variables. Producing a mechanical situation that forces the system to one limit or the other in the backlash range by utilizing gravity or spring loading is generally the best approach.

Geometrically based errors are much more approachable although there are circumstances that require mechanical rather than mathematical approaches to correction.

Even the best tower installations are subject to slight errors in plumb. And for those who are using something other than a tower, a more fundamental definition would be that any rotation (not translation) in the Primary axis (fixed to Earth) or the Secondary axis (moving reference frame about Primary axis) with respect to the primary axis When tracking accuracy of less than a half-degree is required, it is best to measure the actual tower tilt and allow the SolarTrak® to compensate. The effects can be extreme near the beginning and end of the solar day where a small tilt can actually be magnified.

The basic effect is similar to the result of specifying the wrong latitude and longitude or running the clock always an hour slow. The results of a tilted tower.

Screwjack parameters must be computed by the book. That book is attached. A tilt-roll system has zero tilt when the roll is centered and the array is facing straight up vertically. The centered roll has nothing to do with the zero point it just helps to envision the situation.
  The roll axis has its zero at Due East. That means at Solar Noon the roll axis is at 90 degrees. This must be kept in mind when computing Beta, SJ#1 for the roll axis.

  1. Start the program hooked up to a SolarTrak that has a tracker that you can aim at the Sun.

  2. Set the SolarTrak clock to atomic time. Every 24 seconds is a tenth of a degree in polar rotation. Clock accuracy during calibration can be critical if high accuracy is to be achieved.

  3. With the array set for a Morning Ref. Check, press the RESET button on the SolarTrak or Alt-F5 on the PC keyboard to perform a ref. check before your very eyes. Verify that it does it properly. Later in the day, another ref. check should be done to verify repeatability.

  4. Do a 'Set Sun Offset' to put the array exactly on Sun. Watch it track for a minute. Use one end of the update range all the way through. I usually wait for the update and make sure it centers exactly to take data. In actual operation it will fall slightly behind then move slightly ahead for best operation.

    *** DO NOT INITIALIZE FILE OR TAKE DATA POINTS WHILE ARRAY IS VERY NEAR LIMITS OF MOTION ****   (software or hardware limits)

  5. On the PC, press Alt-F3 to Initialize the data file. It will ask for verification for performing the command. This command will be done only once but it depends on you to make sure that is the case.

  6. If you like pressing lots of buttons you can use Alt-F7 to take a data point but lazy person that I am, I included the '.' (period) as an alternate key for this command.

Press '.' to take the first data point immediately.
     It will ask if you did a ref check
     It will ask if you did a 'Set Sun Offset'
     It will ask if you like the way it is tracking

     It will ask you these same questions for each data point. If you answer NO to any of them, that data point will not be included in the computations although the aborted attempt will be apparent if you look at the data file.

     After the third question is answered it will take a few seconds to gather the data. It will take the current sun position and the new references offsets (changed by the 'Set Sun Offset') and log the values in the data file. It *should* say it is doing so but it doesn't do that right so don't hit any keys while this is going on. WAIT for the question about whether to 'store the point or not' comes up.
    It lets you reject the data point if you don't think the result (being displayed) is realistic. How to judge that realism is part of the complexity of this procedure. Usually it has something to do with changes in turncounts that don't match observation.

  7. To take more data points, repeat at about 30-45-minute intervals doing a 'Set Sun Offset', watching it track for a minute and taking a point on the PC.

After about five data points, the program will start appending the data point collection process with a display of computed error parameters and then a couple of plots.

The Error Parameters are the current estimated coefficients of the equations:

Axis 1 Error = - [P1 * SIN(AX1) / TAN(AX2)]
                                    + P2 - [P3 * COS(AX1) / TAN(AX2)] - (P5 * AX1)

Axis 2 Error = [P1 * COS(AX1)] - [P3 * SIN(AX1)] + P4 - (P6 * AX2)

Where AX1 and AX2 are the current sun angle in the native reference frame (ie. Tilt-Roll). When error data do not fit into the framework provided by the terms in these equations, they are either ignored (not usually the case) or interpreted in some fashion as doing so.

If the tower (or frame) is only slightly misaligned, the resulting error coefficients should be equally small. Do not expect much if the misalignment is over ten degrees.

You may get the message 'Parameters still unrealistic'. This means that the coefficients are coming out really large and probably don't make any sense. It also probably means that the errors don't properly fit in the available mathematical framework.

That's what can go wrong. If things go better than that, you will get some small numbers on the screen. Cute little things aren't they? Make a mental note (or a real one) of the values. You will be watching from point to point whether they change very much.
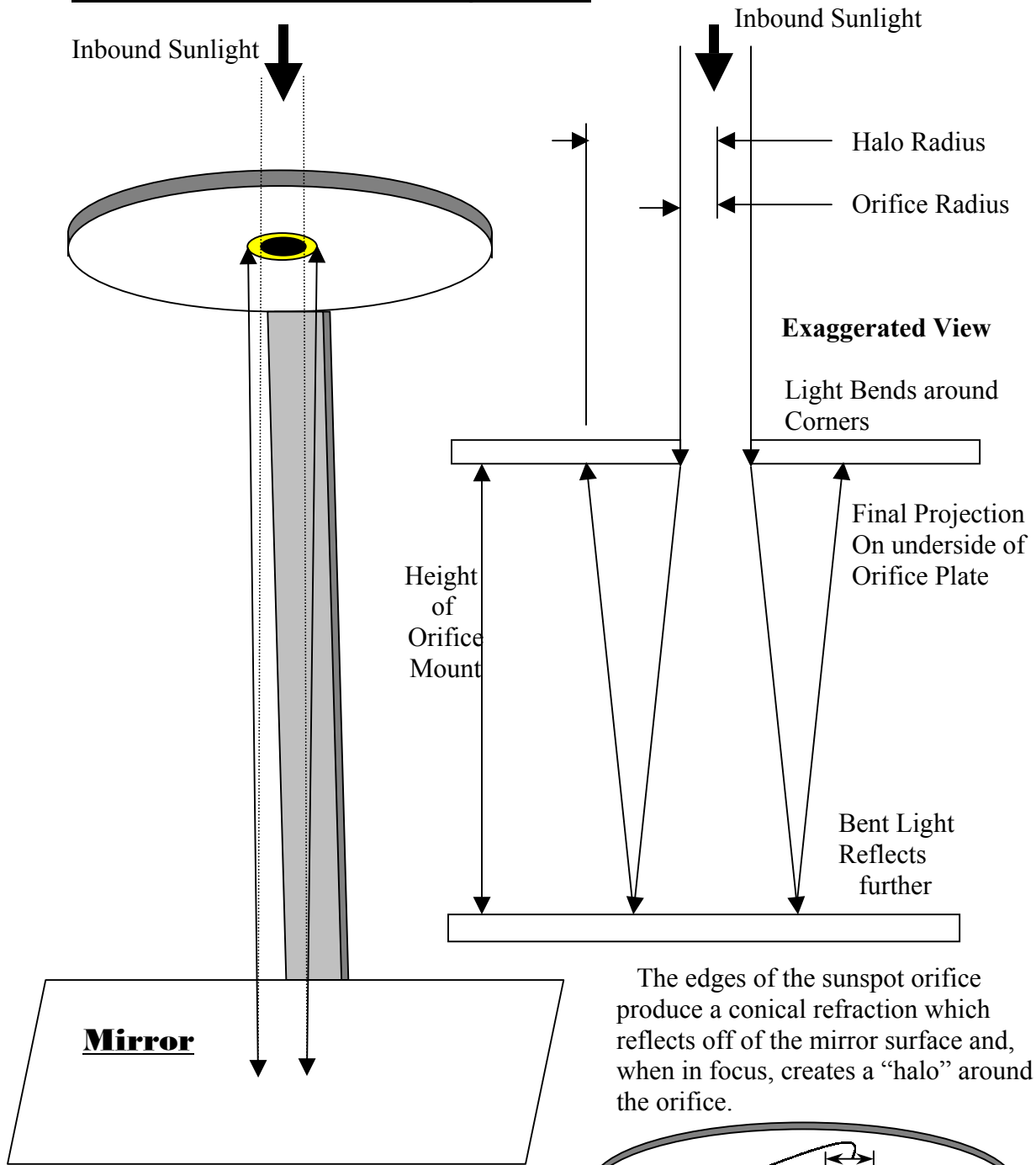
Press a key to proceed to the error plot. This takes a little getting used to. It is very rough. The data is presented as dots at the time interval taken with bright amber for Axis 1 errors and bright green for Axis 2. Both sets of data are plotted against Solar Time. Overlaid on that data is series of evenly spaced dots computed from the current error coefficients at ten-minute intervals. Admittedly, this plot can sometimes look more like an explosion. When things are more compliant, the error function will follow the data points to some observable extent.

Part of deciding when you've succeeded in the calibration is based on the point-to-point changes. Large changes in the error coefficients, once they are displayed, are signs of data values falling well outside the predicted error function, which embodies all data thus far. This often occurs within the first ten points but should dissipate rapidly after that. Conversely, successive data points falling more precisely on the previous error function (coefficients are not changing much or at all) show a workable match between the observed (measured) error and the computed error function.

In between data points, you can recompute coefficients and display the data from a given file by pressing Ctrl-F9. Use the space bar to find the correct file then 'Enter' to open it. The file names will be displayed just below the screen title, six lines up from the bottom of the screen.

When you do 'Set Sun Offset's be systematic. If the system needs to be adjusted backward from the current tracking direction, move behind the Sun first then adjust it forward to the correct position. This places some control on the backlash issue.
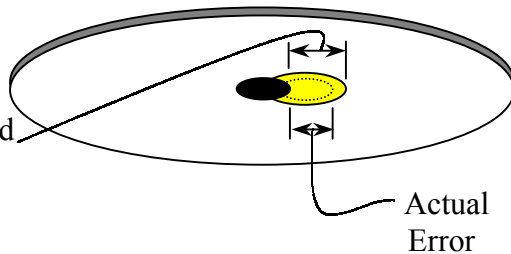
Reflected Sunspot Pointing Device

Inbound Sunlight

Inbound Sunlight

Halo Radius

Orifice Radius

Exaggerated View

Light Bends around Corners

Final Projection On underside of Orifice Plate

Height of Orifice Mount

Bent Light Reflects further

Mirror

The edges of the sunspot orifice produce a conical refraction which reflects off of the mirror surface and, when in focus, creates a "halo" around the orifice.

When off center, the sunspot exaggerates the actual error.

Measured Error

Actual Error

It must be reduced by the difference between the orifice radius and sunspot radius.
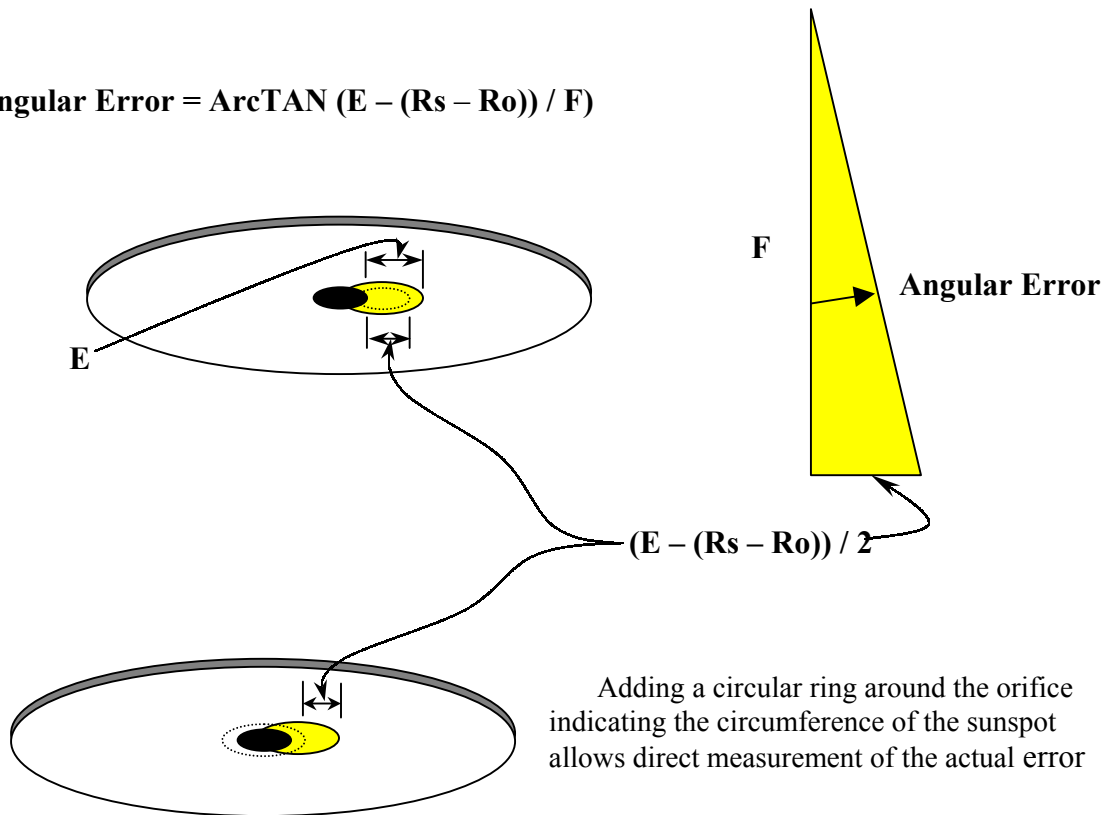
Quantification of Error

Requirements:
      1. Measure 'Height of Orifice Mount' (**H**), Focal length = **F = 2 * H**
      2. Measure Orifice Diameter (**Do**), Orifice Radius = **Ro = D0 / 2**
      3. Measure Sunspot Diameter (**Ds**), Sunspot Radius = **Rs = Ds / 2**
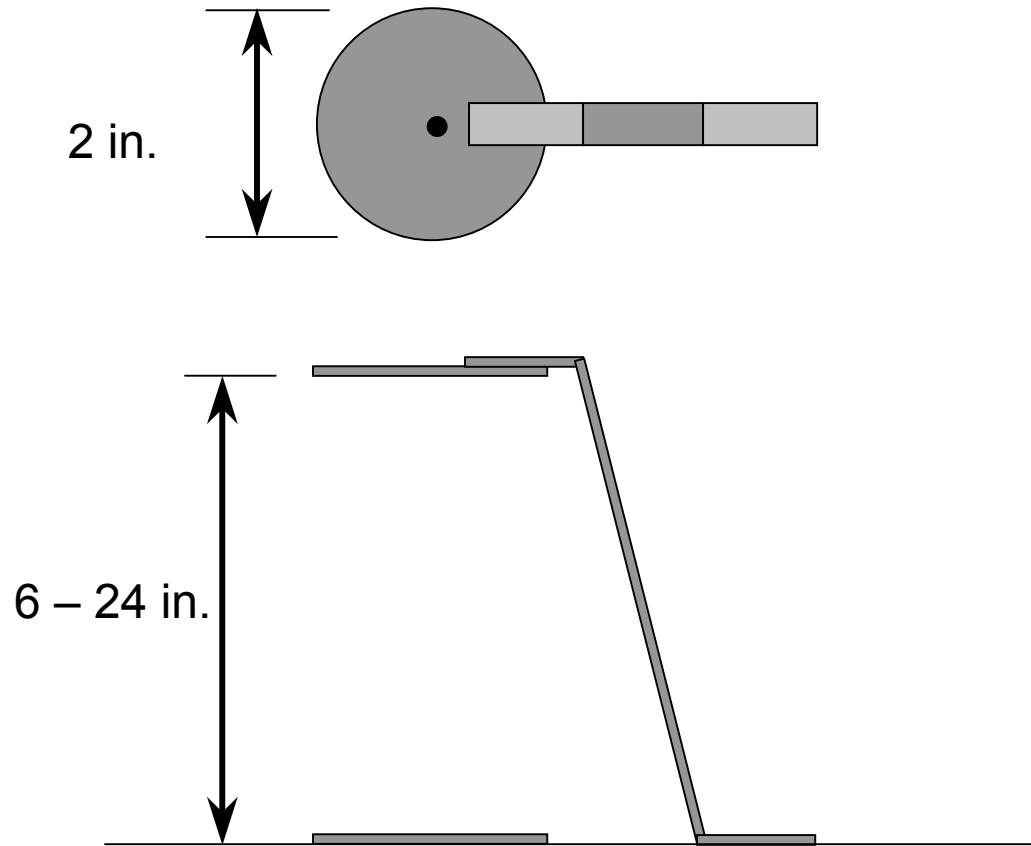   4. Measure Error (**E**), from edge of hole to edge of sunspot

*** Any Consistent Units will do ***

Assumption: Small Angle Rule: **Sin θ = θ (in radians), θ < 0.1 rad.**

Angular Error = ArcTAN (E – (Rs – Ro)) / F)

F

Angular Error

E

(E – (Rs – Ro)) / 2

Adding a circular ring around the orifice indicating the circumference of the sunspot allows direct measurement of the actual error
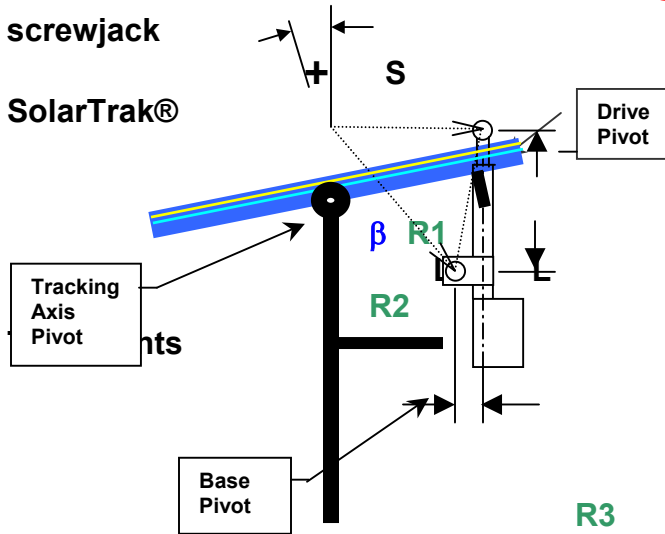
Basic Pointing Device Design

The mirror must be attached to a surface guaranteed parallel to the Elevation or Roll axis while perpendicular to the Azimuth or Tilt axis.

Appendix C:

screwJACK\\\\\\\\\\\\Parameter Computation

SJP #1,2, & 3 are

screwjack

SolarTrak®

parameters stored in the

R1, R2, R3 & β are constants
(measured in inches)

Drive Pivot

β R1

Tracking Axis Pivot

R2

L

Gear Ratio = (+/-) counts/inch
(+) if S increases with

SJP #3 = R1^2 + R2^2 – R3^2

SJP #2 = (+/-) 2 * R1 * R2
(–) if S increases with L

Base Pivot

R3

SJP #1 = β

(1) $L = \sqrt{R1^2 + R2^2 - R3^2 - 2 * R1 * R2 * COS(S + β)}$

(2) $L = \sqrt{SJP\#3 + SJP\#2 * COS(S + β)}$

(3) $β = ACOS\{ (L^2 - R1^2 - R2^2 + R3^2) / (- 2 * R1 * R2) \} - S$

(4) $β = ACOS\{ (L^2 - SJP\#3)/ SJP\#2\} - S$ 　　and　$L^2 = L1^2 - R3^2$

　　　　　　　　or

(5) $β = ACOS\{ (L1^2 - R3^2 - SJP\#3)/ SJP\#2\} - S$

Measure the R1 and R2 Center-to-Center lengths carefully. The line of measurement should always be perpendicular to both centerlines being measured.

Measure R3 perpendicular to the centerline of the jack tube to the center of the Base Pivot bolt. For a Von Weise jack, R3 = 2".

Compute β by:
1: Measuring the angle accurately.
2: Measure L1 (Between Drive Pivot and Base Pivot)
3: Compute β using equation (5) above.
4: Repeat 1 – 3, using S = some different angle to check for consistency.
5: Enter β in degrees.

Equation (1) above is used for converting a specific Sun angle to a specific screwjack extension point. Equations 4 or 5 should be used to determine β depending on the quantity (**L or L1**) measured. If E-W Tilt-Roll is the active geometry, remember that due East (not Up or South) is zero degrees.