Precision Metrology-Angular Measurement

Small Angle Measurement

Commercially available devices for small angle measurement

Type	Range	Resolution	Accuracy
Laser-Interferometer	±50 min(linear range) ±10 deg(w/correction)	0.1sec 0.1sec	0.1sec 0.1sec
Autocollimator	10min~10sec	range/1000	0.1sec
Electronic level (Talyvel)	±1deg	0.1sec	0.1sec

Commercially available devices for large angle measurement

Type	Range	Resolution	Accuracy
Optical Polygon (w/Autocollimator)	360 deg	360/N	0.1sec
Rotary Encoder	360 deg	360/N	0.001deg

1. Laser Interferometer with angular optics

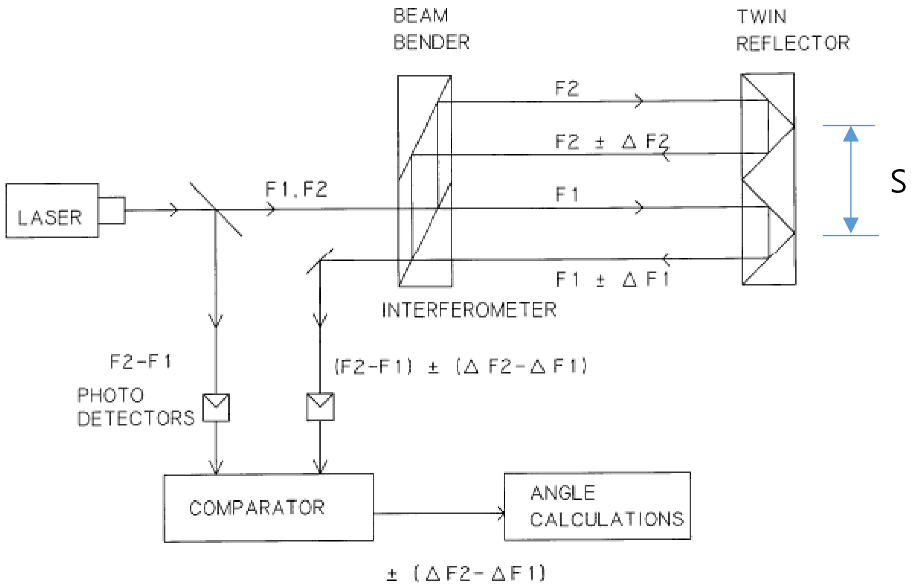


FIG.7.7 PRINCIPLE OF ANGLE MEASUREMENT WITH LASER INTERFEROMETER

Source: H.J.Pahk's PhD Thesis, University of Manchester

The angle, θ, can be calculated,

$\theta = \sin^{-1}(L_2 - L_1)/S \fallingdotseq (L_2 - L_1)/S$ for linear range

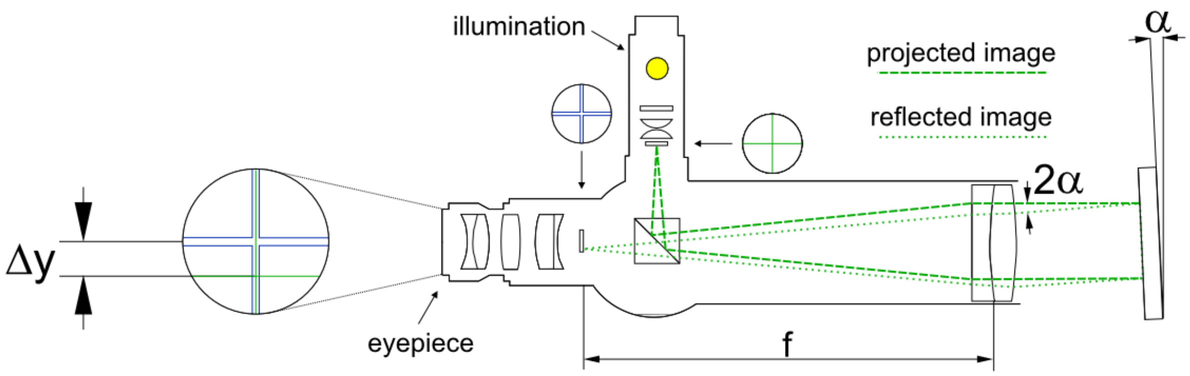
where L_2, L_1 are distances measured at the middle of reflector optics 1,2; thus

$L_2 - L_1 = \lambda_0/2 \cdot \Sigma(\Delta F_2 - \Delta F_1)\Delta t = \lambda_0/4\pi \cdot \Sigma(\Delta\varphi_2 - \Delta\varphi_1)$

And, S is the effective length between the two optics.

This method can be applied to the pitch and yaw measurements for the linear axis, but not for the roll measurement.

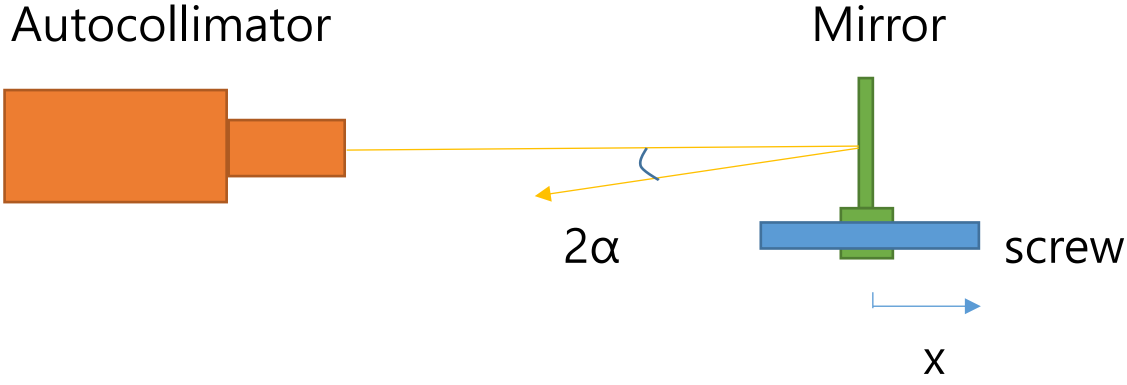
2. Autocollimator



Source:globalspec

When ΔY is the measured distance in the eyepiece, $\Delta Y = 2\alpha \cdot f$

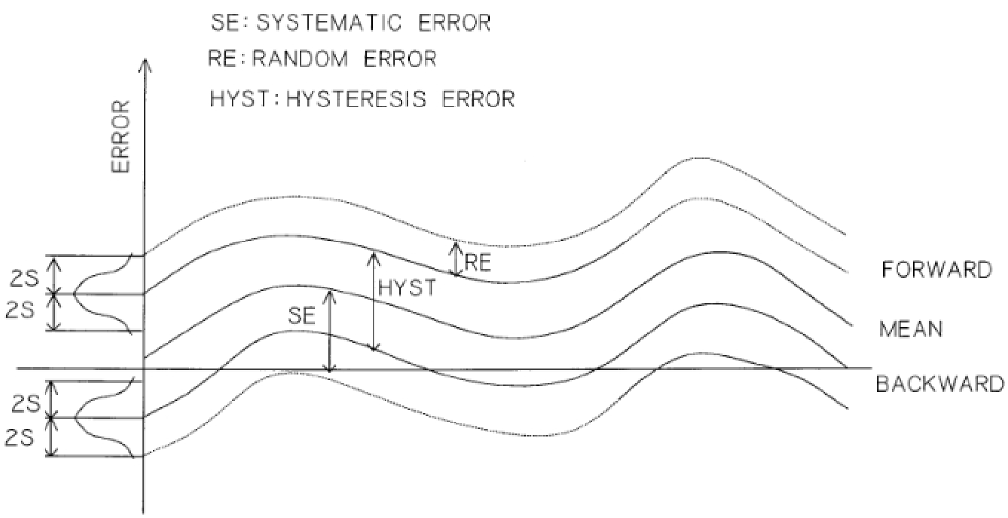
Thus angle $\alpha = \Delta Y / 2f$, where f=focal length of the lens



The pitch angle, and yaw angle can be measured by the autocollimator, but not for the roll measurement.

The angular error calibration is very similar to the linear positional error calibration case.

Source:Taylor Hobson



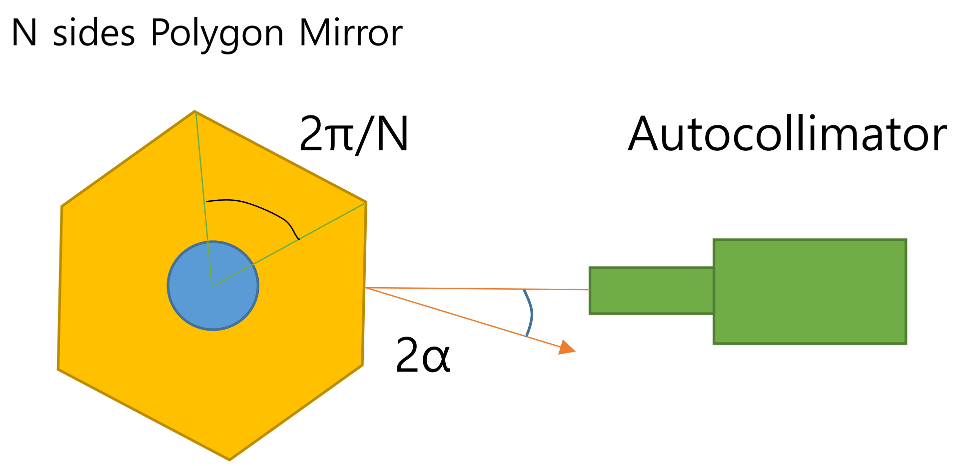
With the laser angular optics and the autocollimator, the measurable error components are;

Pitch and Yaw errors for X axis: Ey(X), Ez(X);

Pitch and Yaw angle for Y axis: Ex(Y), Ez(Y);

Pitch and Yaw angle for Z axis: Ex(Z), Ey(Z);

<u>Calibration of Rotary axis using Autocollimator</u>

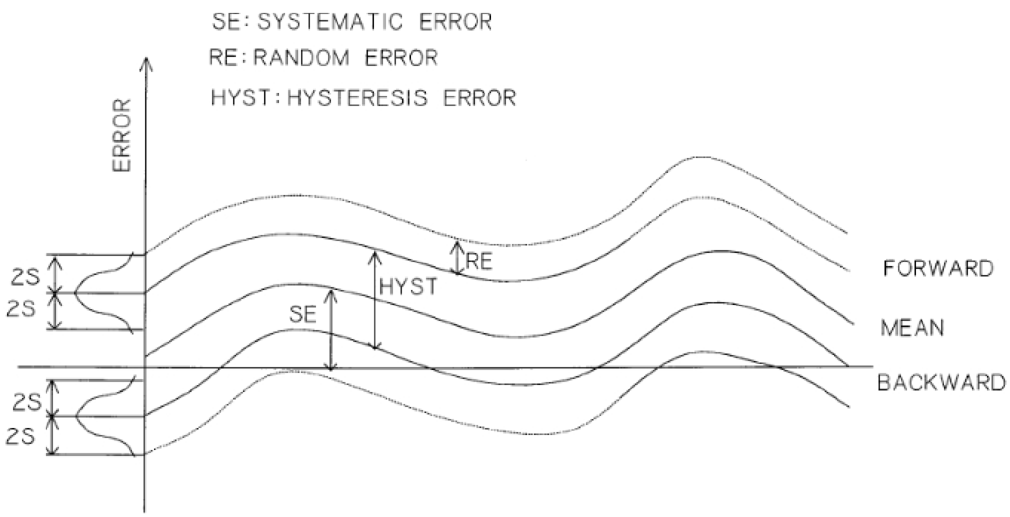


Index-Angle,i	Error, α_i	
0	0	reset
30	5″	
60	3″	
…….	….	
330	-3″	overtravel
330	-2.5″	

……	……	
0	-0.5″	overtravel
0	0.3″	
30	5.5″	

………………………………

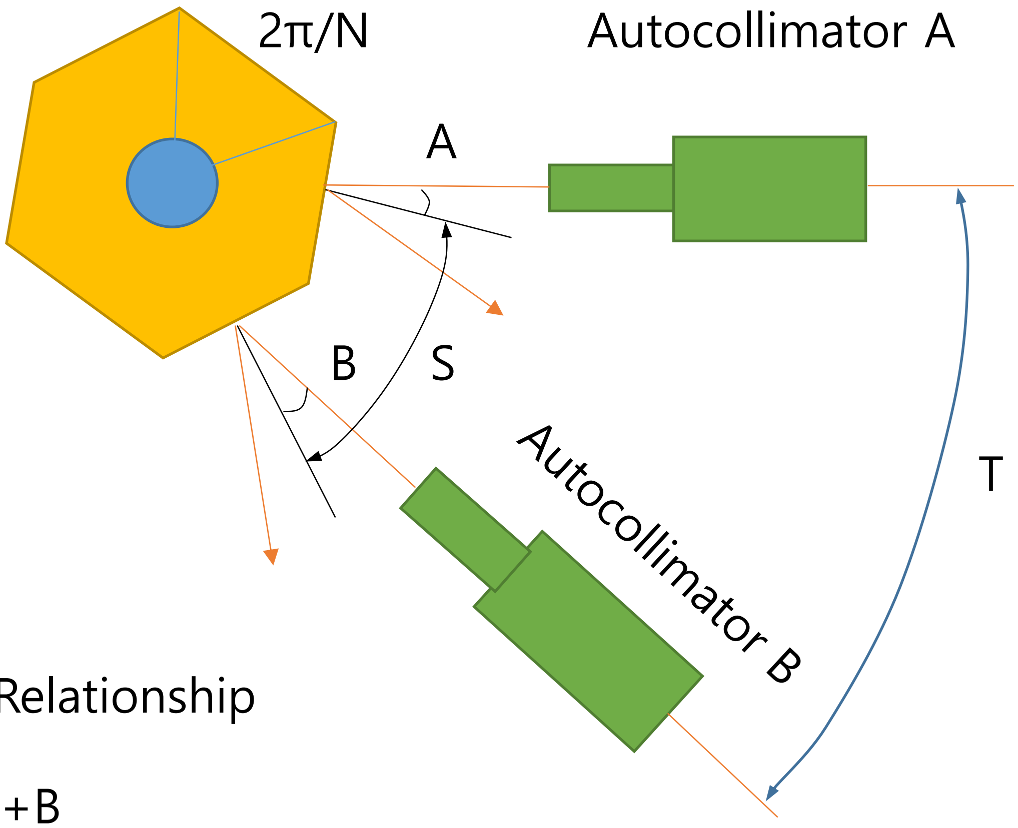
Repeat measurement procedures are followed, the calibration curve is similarly evaluated for the rotary axis.



Calibration curve for the rotary or indexing table

(Q: The accuracy of the Polygon Mirror?)

<u>Calibration of Polygon Mirror using two Autocollimators</u>



Angle Relationship

S+A=T+B

where S=Angle between the Sides

T=Angle between the Autocollimators, and

A, B are the measured angles from the two autocollimators

Thus

$S_1+A_1=T+B_1$ for the side 1

$S_2+A_2=T+B_2$ for the side 2

....

$S_N+A_N=T+B_N$ for the side N | +

$\Sigma S_i+\Sigma A_i=NT+\Sigma B_i$

$\Sigma S_i=360° \therefore T=(360+ \Sigma A_i- \Sigma B_i)/N$

Therefore, $S_1=T+B_1-A_1$

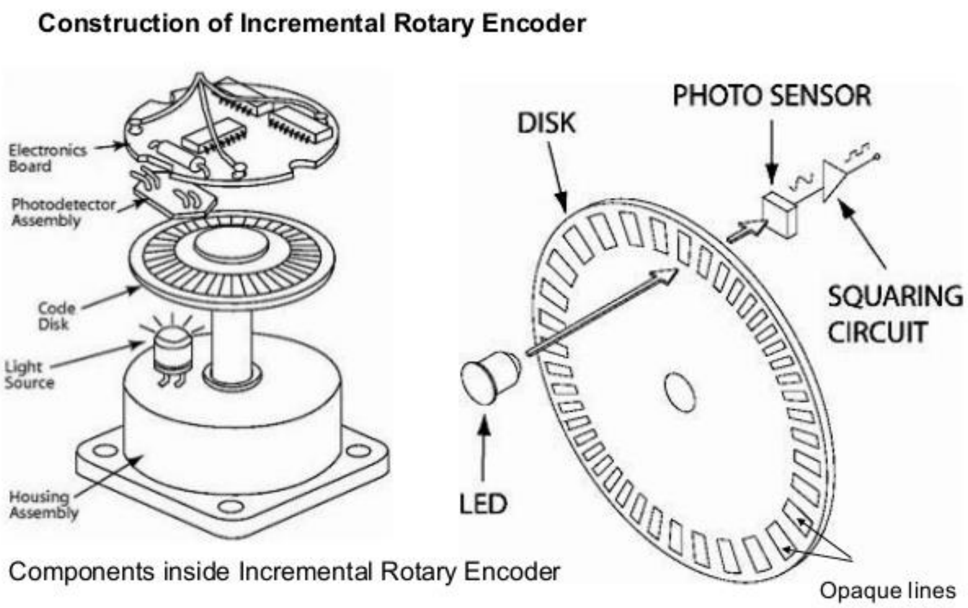
$S_2=T+B_2-A_2$, ...

$S_N=T+B_N-A_N$

All S_i are calculated, thus the polygon is calibrated.

For the index-angle calibration, the error of mirror, $E_i = S_i - 360/N$ should be added such that the indexing error becomes $E_i+\alpha_i$ for the ith side.

3. Rotary Encoder



Source: slide share

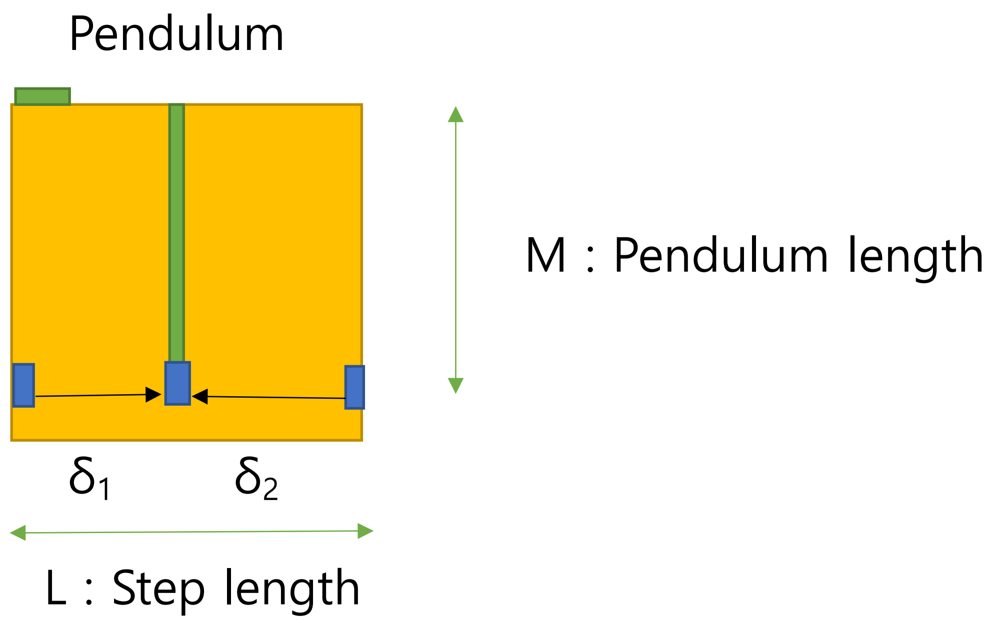
This is rotary version of linear optical scale, and the range is 360° and the resolution is 360°/N, where N is the number of divisions. Electronic interpolation gives very high resolution such as 0.001 deg or less.

4. Precision Level ('Talyvel')

:To measure the angle from the pendulum direction

For absolute or incremental angle measurements

Source:Taylor Hobson

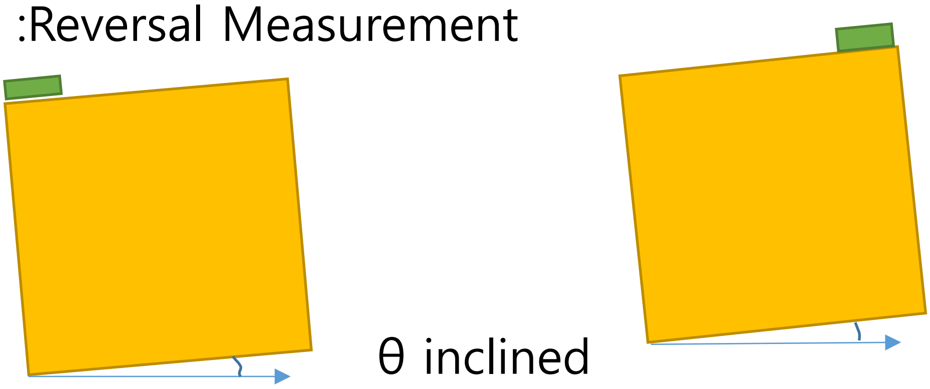


$\theta = (\delta_1 - \delta_2) / M$; angle from the direction of gravitation.

Generally, the reading of Level = $\theta + K$(offset), where K(offset) is adjustable by the knob.

How to measure the absolute angle from the gravitation?

:Reversal Measurement



$\theta_1 = \theta + K$ $\theta_2 = -\theta + K$

-Adjustment of K such that $\theta_1 = -\theta_2 = \theta$, or

-Calulation θ and K by the reversal technique

$\theta = (\theta_1 - \theta_2) / 2$, and $K = (\theta_1 + \theta_2) / 2$

by averaging reversal measurements.

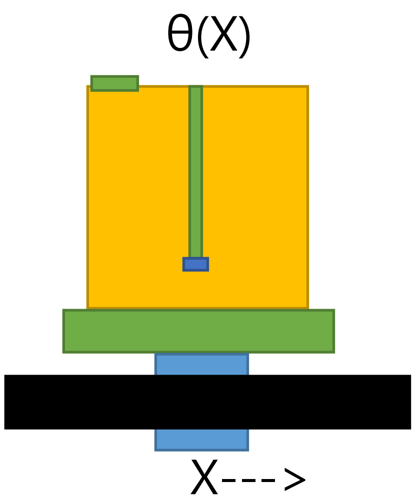
Two levels measurement

:Differential angle measurement, simultaneous roll/pitch angle measurement

-Level base length can be changeable by the level foot.

Measurable error components:

Roll and pitch for horizontal axis; pitch and yaw for vertical axis

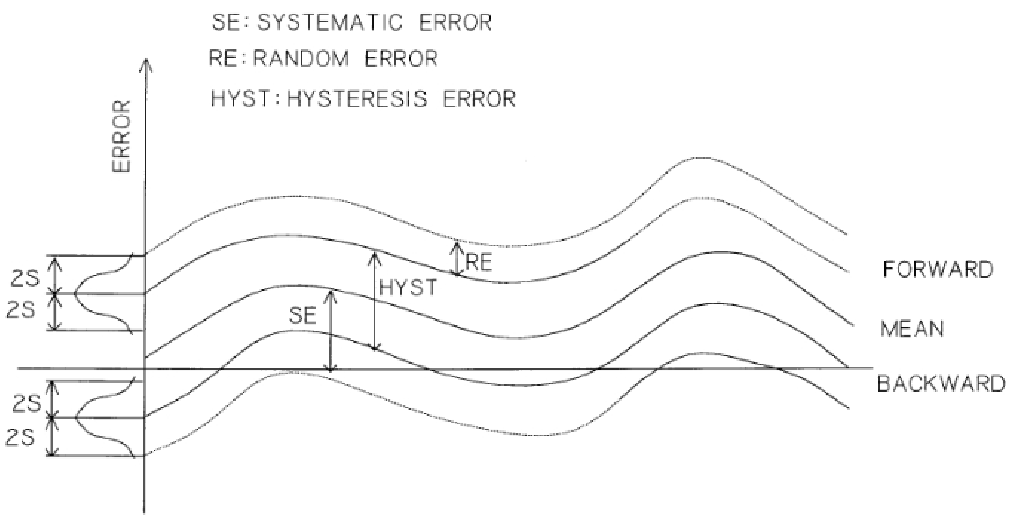


Errors Measurable

Ex(X), Ey(X);

Ey(Y), Ex(Y);

Ex(Z), Ey(Z);



The angular error calibration can be similarly performed.