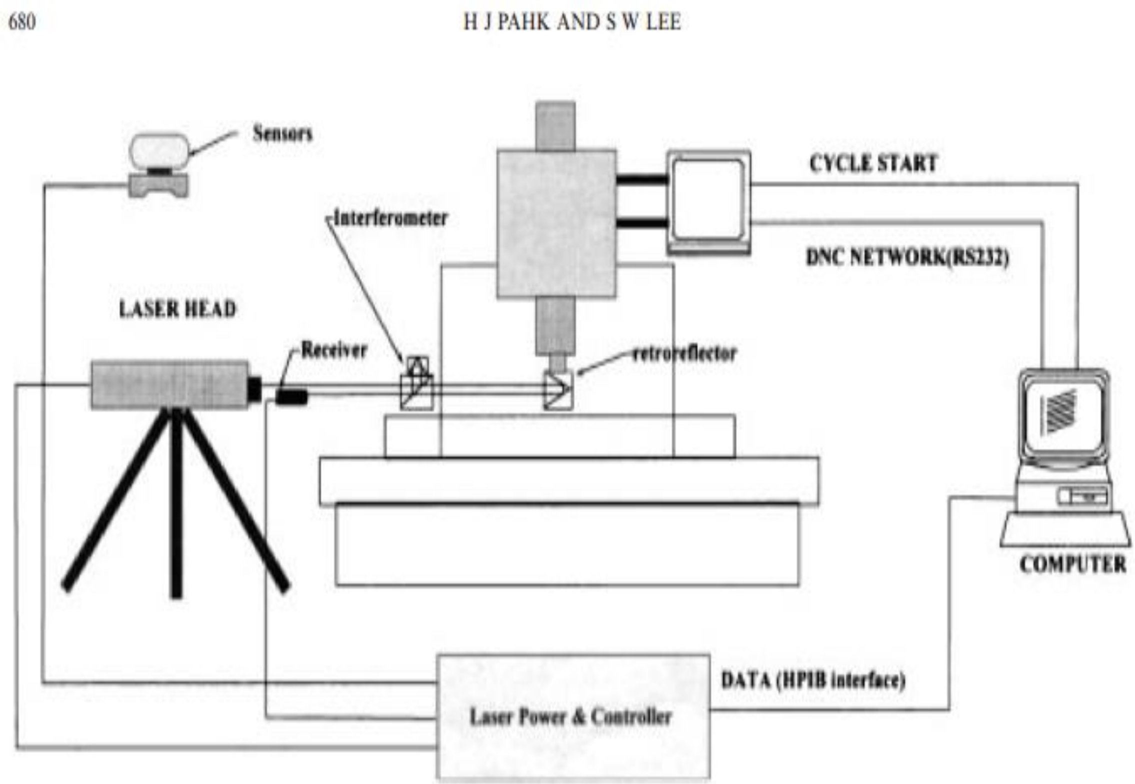
Precision Machine Design :

Error Assessment (Positional Error Calibration)

: Error=True Value- Nominal Value

3-5 Cycles of bi-directional measurement from 0mm to 1000mm at 100mm step, allowing over-travel at the edge of machine travel; to include any reversal error.



Typical Setup for Error Assessment

(Source: New error correction algorithms minimizing residual positional error for computer integrated calibration/correction system in CNC machine tools, H.J.Pahk, S.W.Lee, Proc. of Institution of Mechanical Engineers, 679-686, Vol213 part C, 1999)

Target	Nom	Laser	Error[mm]	
0	0	0 (reset)	0	forward
1	100	100.001	0.001	
2	200	200.003	0.003	
3	300	300.004	0.004	
4	400	400.005	0.005	
5	500	500.007	0.007	
6	600	600.008	0.008	
7	700	700.009	0.009	
8	800	800.010	0.010	
9	900	900.012	0.012	
10	1000	1000.014	0.014	overtravel
10	1000	1000.016	0.016	backward
9	900	900.014	0.014	
8	800	800.012	0.012	
7	700	700.010	0.010	
6	600	600.009	0.009	

Target	Nom	Laser	Error[mm]	
5	500	500.008	0.008	
4	400	400.007	0.007	
3	300	300.005	0.005	
2	200	200.004	0.004	
1	100	100.003	0.003	
0	0	0.002	0.002	overtravel

1st cycle---

0	0	0.001	0.001	forward
1	100	100.002	0.002	
2	200	200.004	0.004	
3	300	300.005	0.005	
4	400	400.007	0.007	
5	500	500.009	0.009	
6	600	600.010	0.010	
7	700	700.011	0.011	

Target	Nom	Laser	Error[mm]	
8	800	800.012	0.012	
9	900	900.014	0.014	
10	1000	1000.016	0.016	overtravel
10	1000	1000.018	0.018	backward
9	900	900.017	0.017	
8	800	800.015	0.015	
7	700	700.013	0.013	
6	600	600.011	0.011	
5	500	500.009	0.009	
4	400	400.008	0.008	
3	300	300.007	0.007	
2	200	200.005	0.005	
1	100	100.004	0.004	
0	0	0.003	0.003	overtravel

2nd cycle--

Target	Nom	Laser	Error[mm]	
0	0	0.002	0.002	forward
1	100	100.002	0.002	
2	200	200.005	0.005	
3	300	300.006	0.006	
4	400	400.008	0.008	
5	500	500.010	0.010	
6	600	600.011	0.011	
7	700	700.013	0.013	
8	800	800.014	0.014	
9	900	900.016	0.016	
10	1000	1000.018	0.018	overtravel
10	1000	1000.020	0.020	backward
9	900	900.019	0.019	
8	800	800.017	0.017	
7	700	700.015	0.015	

6	600	600.014	0.013
5	500	500.012	0.011
4	400	400.010	0.009
3	300	300.009	0.007
1	100	100.007	0.005
0	0	0.005	0.004

3rd cycle--

…

In this way the number of cycle can be increased, and the positional error calibration is performed at every target of machine travel for the bidirectional movement.

Positional Error Calibration

Forward measurement

The ith repeat *forward positional error* at the jth target, $X_{ji}\uparrow$

$X_{ji}\uparrow$ =the ith measurement error at the jth target

=Laser – Nominal = $L_{ji}\uparrow - N_j$

where L_{ji} is the ith repeat laser measurement at the jth target, and N_j is the nominal data.

The *forward mean positional error* at the jth target is

$\underline{X}_j\uparrow = \Sigma X_{ji}\uparrow / N$

where N= number of cycle=1,2..

The *forward standard deviation* at the jth target is

$\sigma_j\uparrow = \sqrt{\Sigma(X_{ji}\uparrow - \underline{X}_j\uparrow)^2/N-1}$

The *uni-directional repeatability* for forward direction at the jth target,

$UR_j\uparrow = 6\ \sigma_j\uparrow$

And the *maximum uni-directional repeatability* for the forward direction is,

$UR_{max}\uparrow = \text{Max } UR_j\uparrow$ (for j=1,2...)

<u>Backward measurement</u>

The ith repeat *backward positional error* at the jth target, $X_{ji}\downarrow$

$X_{ji}\downarrow$ =the ith measurement error at the jth target

=Laser – Nominal = $L_{ji}\downarrow - N_j$

where L_{ji} is the ith repeat laser measurement at the jth target, and N_j is the nominal data.

The *backward mean positional error* at the jth target is

$\underline{X}_j\downarrow = \Sigma X_{ji}\downarrow / N$

where N= number of cycle=1,2..

The *backward standard deviation* at the jth target is

$\sigma_j\downarrow = \sqrt{\Sigma(X_{ji}\downarrow - \underline{X}_j\downarrow)^2/N-1}$

The *uni-directional repeatability for backward direction* at the jth target,

$UR_j\downarrow = 6\ \sigma_j\downarrow$

And the *maximum uni-directional repeatability* for the forward direction is,

$UR_{max}\downarrow = \text{Max } UR_j\downarrow$ (for j=1,2…)

Mean positional error

The *mean positional error* or system positional error at the jth target

$\underline{X}_j$=(Forward mean positional error + Backward mean positional error)/2

$=(\underline{X}_j\uparrow + \underline{X}_j\downarrow)/2$

The *reversal error* (hysteresis error, or backlash error) at the jth target is,

R_j=Backward mean positional error- Forward mean positional error

$=\underline{X}_j\downarrow - \underline{X}_j\uparrow$

The *maximum reversal error*, R_{max}, is

R_{max}= Max R_j (j=1,2…)

The *maximum uni-directional repeatability* is,

UR_{max}= Max ($UR_j\uparrow$, $UR_j\downarrow$)=Max($6\sigma_j\uparrow$, $6\sigma_j\downarrow$), for j=1,2…

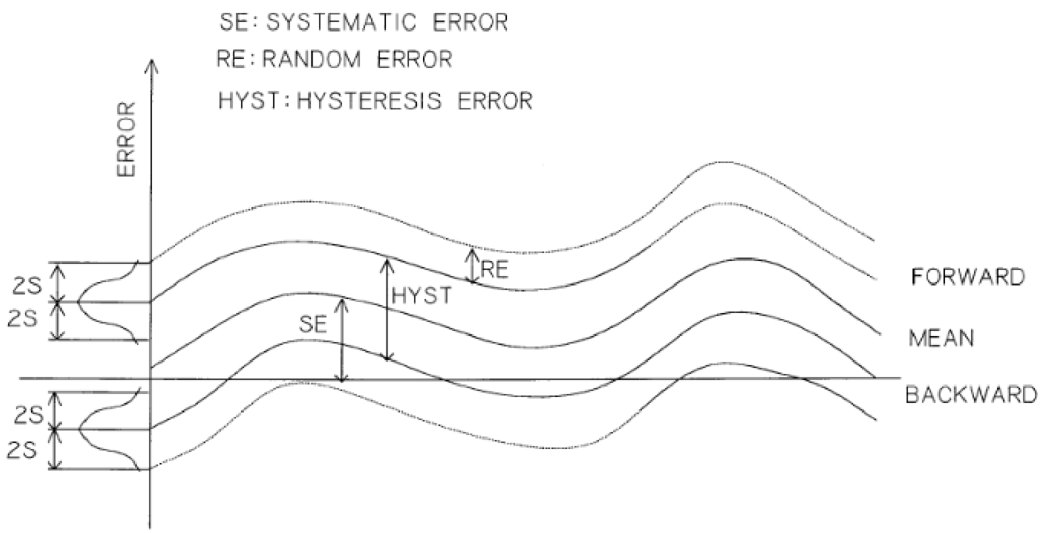
The *bi-directional repeatability* at the jth target is

$BR_j = |R_j| + 3(\sigma_j\uparrow + \sigma_j\downarrow)$

The *maximum bi-directional repeatability* is

BR_{max}=Max BR_j =Max ($|R_j| + 3\sigma_j\uparrow + 3\sigma_j\downarrow$), for j=1,2…

Positional error calibration



Error Calibration along a machine axis

(Note: s = σ, sample standard deviation, and 2σ for 95% probability, 3σ for 99% probability)

<u>Evaluation of Accuracy</u>

1. Bandwidth Method(ANSI)

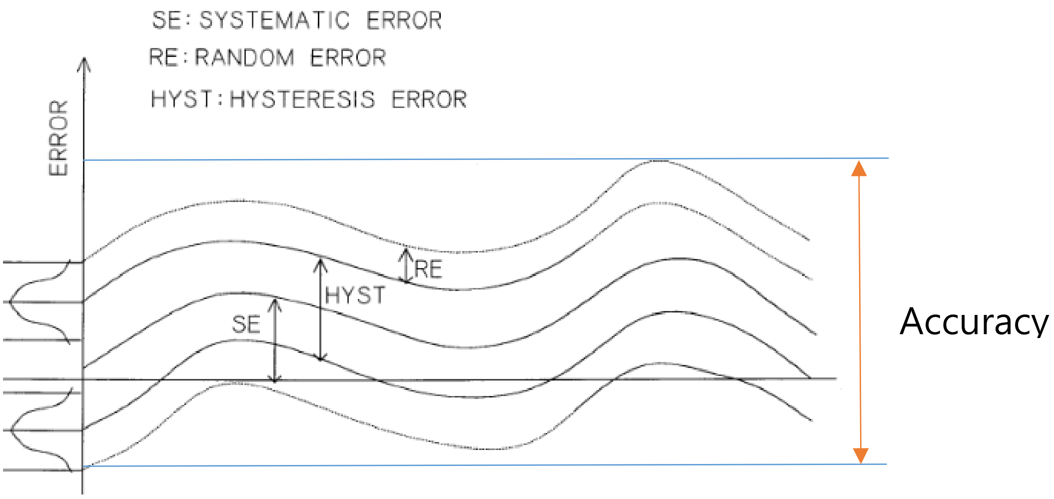
:The greatest difference in the positional error representation, Linear Displacement Accuracy, or Accuracy

$=$Maximum error – Minimum error

$=\text{Max}\ (X_j\uparrow \pm 3\sigma_j\uparrow,\ X_j\downarrow \pm 3\sigma_j\downarrow)\ (j=1,2\ldots)$

$-\ \text{Min}\ (X_j\uparrow \pm 3\sigma_j\uparrow,\ X_j\downarrow \pm 3\sigma_j\downarrow)\ (j=1,2\ldots)$

(*Discuss pros. and cons.)



The arrow indicates the Linear Displacement Accuracy, or Accuracy.

2. Tolerance Template Method (DIN, Europe)

:To describe the machine accuracy in relation to the length of travel.

The accuracy or uncertainty can be expressed as the function of the distance travelled, as indicated as red line.

$U = A+KL \leq B$

where A= offset in [um]

= maximum uni/bi-directional repeatability

$=\mathrm{Max}\ (6\sigma_j\uparrow,\ 6\sigma_j\downarrow)$ for uni-directional

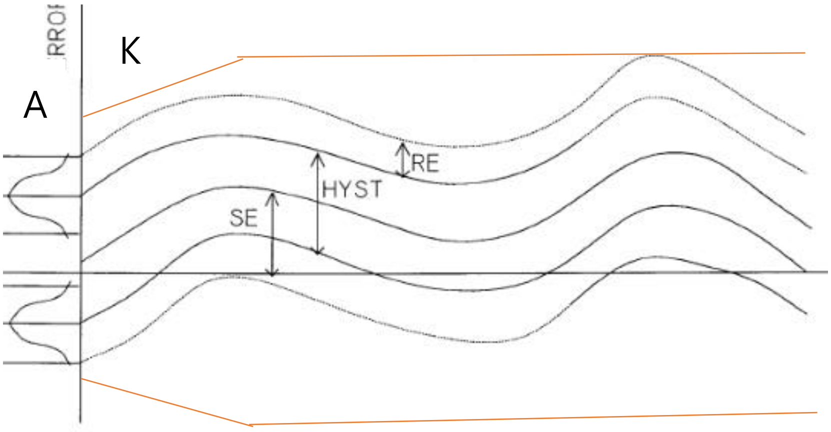
$=\mathrm{Max}\ (|R_j| + 3\sigma_j\uparrow + 3\sigma_j\downarrow)$ for bi-directional

B=Maximum error in [um]

K=slope to just enclose the error data over the machine travel, [um/m]

L=length of machine travel, [mm]

Offset=A,   Slope=K, Maximum Error=B



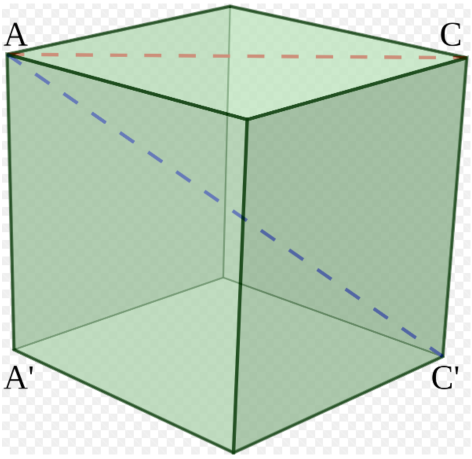
This is one of the most widely accepted method, and many industry currently use it as the accuracy or uncertainty evaluation.

Ex) $U = 2.0 + L/100 \leq 10$ [um]

HW1) For the given positional error data,

(1) Calculate the positional errors, and

(2) Evaluate the positional accuracy



Source:wikipedia

Face diagonals and space diagonals in the 2D/3D working space

The tolerance template can be extended to the 2D;

$U_2=A_2+K_2L \leq B_2$

Where U_2=accuracy (or uncertainty) in 2D work space

A_2=maximum repeatability in the length measurement error in 2D work space, [um]

K_2=slope to just enclose the length measurement error data over the 2D work space, [um/m]

B_2=maximum length measurement error in the 2D work space, [um]

L=length of machine travel along the 2D work space, such as face diagonals, [mm]

Also in the 3D working space;

$U_3=A_3+K_3L \leq B_3$

where U_3=accuracy (or uncertainty) in 3D space, [um]

A_3=maximum repeatability in the length measurement error in 3D work space, [um]

K_3=slope to just enclose the length measurement error data over the 3D work space, [um/m]

B_3=maximum length measurement error in the 3D work space, [um]

L=length of machine travel along the 3D work space, such as space diagonals, [mm]