Precision Metrology 22

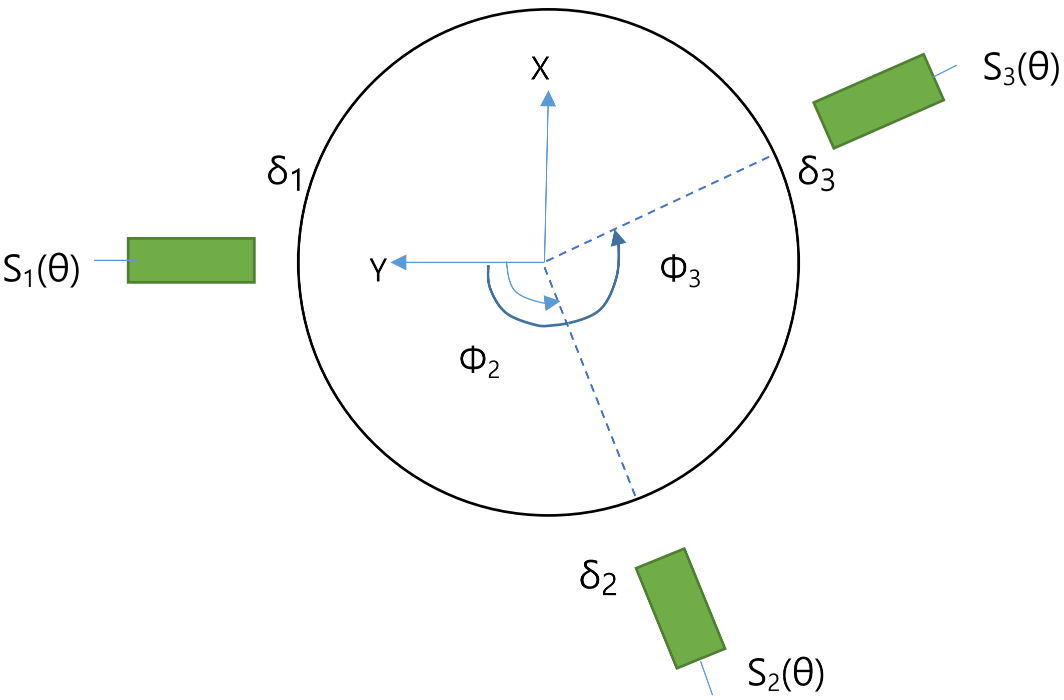
For the reversal method in spindle measurement;

[Q: Two set-ups for each component?

$X(\theta), Y(\theta), R(\theta)$: 3 unknowns to measure?]

-><u>Three-points (three probes) method</u>

:To use three probes such that the radial error motions $X(\theta)$, $Y(\theta)$, and the roundness profile, $R(\theta)$, of master disc can be measured with one set-up.



$\delta_1, \delta_2, \delta_3$: stand-off distances from each sensor when disc rotates θ angle

$r(\theta)$=radius from the Axis of Rotation when the disc rorates θ angle

(Q: $r(\theta)$ vs $R(\theta)$?)

$S_1(\theta)=\delta_1+r(\theta)+Y(\theta)$

$S_2(\theta)=\delta_2+r(\theta-\Phi_2)+Y(\theta)\cos\Phi_2-X(\theta)\sin\Phi_2$

$S_3(\theta)=\delta_3+r(\theta-\Phi_3)+Y(\theta)\cos\Phi_3-X(\theta)\sin\Phi_3$

Build a new function, S_0 ;

$S_0=S_1+a_2S_2+a_3S_3$ and

$r(\theta)$=radius from the Axis of Rotation when the disc rorates θ angle

$=r_0+\Sigma[A_k\cos k\theta+B_k\sin k\theta]$, Σ for k=1 to ∞

$\therefore S_0(\theta)=(\delta_1+a_2\delta_2+a_3\delta_3)+ r_0+\Sigma[A_k\cos k\theta+B_k\sin k\theta]$

$+a_2[r_0+\Sigma\{A_k\cos k(\theta-\Phi_2)+B_k\sin k(\theta-\Phi_2)\}]$

$+a_3[r_0+\Sigma\{A_k\cos k(\theta-\Phi_3)+B_k\sin k(\theta-\Phi_3)\}]$

$+[1+a_2\cos\Phi_2+a_3\cos\Phi_3]Y(\theta)-[a_2\sin\Phi_2+a_3\sin\Phi_3]X(\theta)$; eq(1)

and remembering,

$\cos k(\theta-\Phi_2)=\cos k\theta\cos k\Phi_2+\sin k\theta\sin k\Phi_2$

$\sin k(\theta-\Phi_2)=\sin k\theta\cos k\Phi_2-\cos k\theta\sin k\Phi_2$

$\cos k(\theta-\Phi_3)=\cos k\theta \cos k\Phi_3+\sin k\theta \sin k\Phi_3$

$\sin k(\theta-\Phi_3)=\sin k\theta \cos k\Phi_3-\cos k\theta \sin k\Phi_3$

Arranging eq(1) in terms of constant, $\cos k\theta$, $\sin k\theta$;

Constant term: $\delta_1+a_2\delta_2+a_3\delta_3+r_0(1+a_2+a_3)$

$\cos k\theta$ term

$=A_k+a_2[A_k\cos k\Phi_2-B_k\sin k\Phi_2]+a_3[A_k\cos k\Phi_3-B_k\sin k\Phi_3]$

$=A_k\ [1+a_2\cos k\Phi_2+a_3\cos k\Phi_3]-B_k\ [a_2\sin k\Phi_2+a_3\sin k\Phi_3]$

$=A_k\alpha_k-B_k\beta_k$, where

$\alpha_k=1+a_2\cos k\Phi_2+a_3\cos k\Phi_3$; $\beta_k=a_2\cos k\Phi_2+a_3\sin k\Phi_3$

$\sin k\theta$ term

$=B_k+a_2[A_k\sin k\Phi_2+B_k\cos k\Phi_2]+a_3[A_k\sin k\Phi_3+B_k\cos k\Phi_3]$

$=A_k\ [a_2\sin k\Phi_2+a_3\sin k\Phi_3]+B_k\ [1+a_2\cos k\Phi_2+a_3\cos k\Phi_3]$

$=A_k\beta_k+B_k\alpha_k$

Thus,

$S_0(\theta)=[\delta_1+a_2\delta_2+a_3\delta_3+r_0(1+a_2+a_3)]+\alpha_1 Y(\theta)-\beta_1 X(\theta)+$

$\Sigma[(A_k\alpha_k-B_k\beta_k)\cos k\theta+(A_k\beta_k+B_k\alpha_k)\sin k\theta$

$\equiv S_0+\Sigma[F_k\cos k\theta+G_k\sin k\theta]$ ($\because$ 2π period)

By comparison,

$S_0= \delta_1+a_2\delta_2+a_3\delta_3+r_0(1+a_2+a_3)$, constants to be ignored

Choose a_2,a_3,Φ_2,Φ_3 such that

$\alpha_1=1+a_2\cos\Phi_2+a_3\cos\Phi_3=0$ and

$\beta_1=a_2\sin\Phi_2+a_3\sin\Phi_3=0$

$\therefore$ $a_2=\sin\Phi_3/\sin(\Phi_2-\Phi_3)$, $a_3=-\sin\Phi_2/\sin(\Phi_2-\Phi_3)$

And,

$A_k\alpha_k-B_k\beta_k=F_k$, and $A_k\beta_k+B_k\alpha_k=G_k$

$\therefore$ $A_k=(F_k\alpha_k+G_k\beta_k)/(\alpha_k^2+\beta_k^2)$, and $B_k=(G_k\alpha_k-F_k\beta_k)/(\alpha_k^2+\beta_k^2)$

Once A_k, B_k are calculated,

$r(\theta)= r_0+\Sigma[A_k\cos k\theta+B_k\sin k\theta]$ can be calculated, ignoring constant terms

->Roundness profile from Axis of Rotation, $r(\theta)$

->Roundness profile from GC, $R(\theta)$

$R(\theta)=r(\theta)-(r_0+A_1\cos\theta+B_1\sin\theta)$

$Y(\theta)=S_1(\theta)-\delta_1-r(\theta)$, and ignoring constant terms

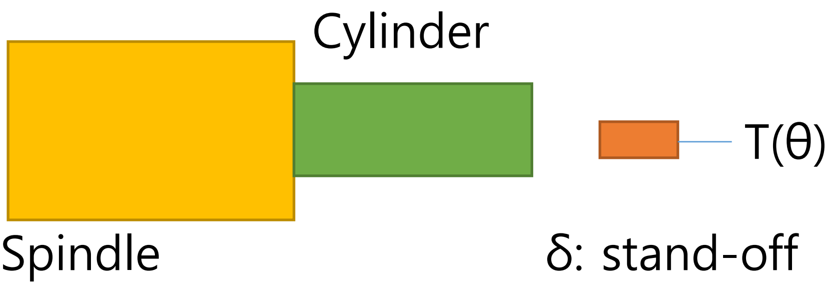
$X(\theta)=[-S_2(\theta)+\delta_2+r(\theta-\Phi_2)+Y(\theta)\cos\Phi_2]/\sin\Phi_2$, ignoring constant terms

Therefore, $R(\theta)$, $X(\theta)$, $Y(\theta)$ can be measured from

the S_1, S_2, S_3 measurements.

Measurement of Axial motion and Tilt motion

Master cylinder/disc with Cap sensor, LVDT



$T(\theta)=\delta+Z(\theta)$, δ:stand-off distance

$=T_0+\Sigma[a_k\cos k\theta+b_k\sin k\theta]$, Σ for $k=1$ to ∞

$T_0=\int T(\theta)d\theta/2\pi\equiv\delta$

$a_k=\int T(\theta)\cos k\theta d\theta/\pi$, $b_k=\int T(\theta)\sin k\theta d\theta/\pi$

$\therefore$Axial motion, $Z(\theta)=T(\theta)-T_0$

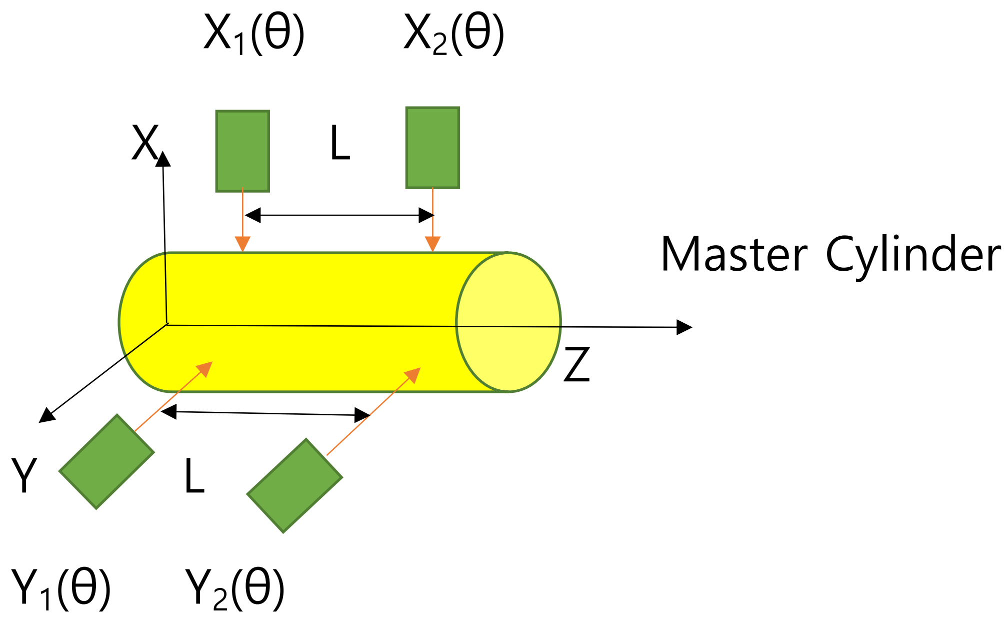
Fundamental motion=once per revolution

$=a_1\cos\theta+b_1\sin\theta$

:due to non-squareness of thrust bearing (axial motion)

:due to eccentricity (radial motion)

Tilt motion



\+ sign:closer

X_1,X_2: X radial motion at 1, 2 locations

$\beta(\theta) = [X_2(\theta)-X_1(\theta)]/L$, Tilt motion in Y direction[urad]

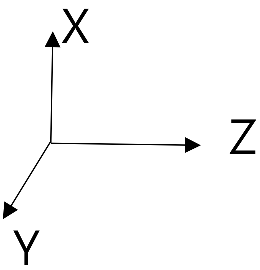
Y_1,Y_2: X radial motion at 1, 2 locations

$\alpha(\theta) = -[Y_2(\theta)-Y_1(\theta)]/L$, Tilt motion in X direction[urad]

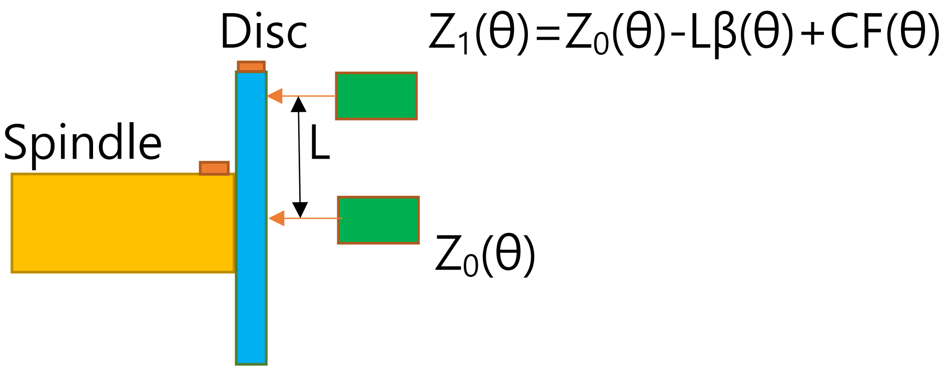
Reversal Technique for Tilt Motion:

When the form error of Cylinder/Disc is not negligible, the reversal technique is applied.

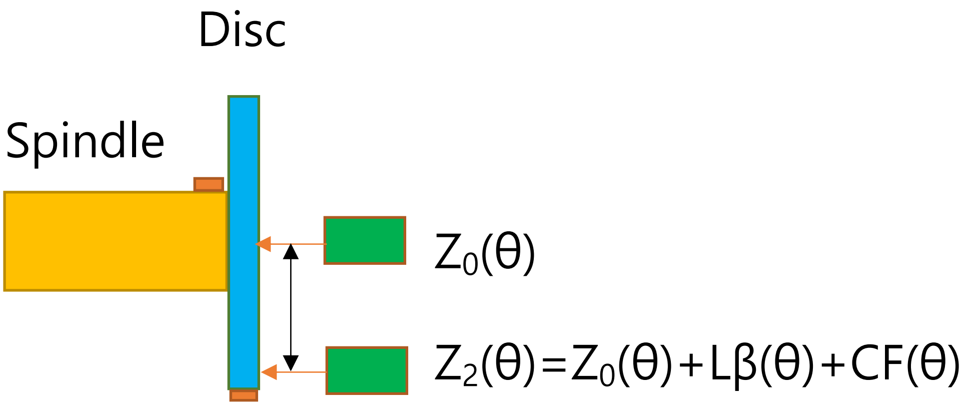
CF(θ): Circular Flatness of Disc/Cylinder



0 deg



180 deg



Thus,

$\beta(\theta)=[(Z_2-Z_0)-(Z_1-Z_0)]/2L$,

∴ Tilt motion in Y direction=$\beta(\theta)-\beta(0)$

Circular Flatness of Disc/Cylinder

$CF(\theta)=[(Z_2-Z_0)+(Z_1-Z_0)]/2$

∴Circular Flatness of Disc/Cylinder=$CF(\theta)-CF(0)$

Similarly, Tilt motion in X direction can be measured when the measurement is performed at 90 deg/270 deg rotation.