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Institute of Machine Tools and Manufacturing

Open Loop Inertial Cross-Talk Compensation Based on Measurement Data

American Society for Precision Engineering,
2010 ASPE Annual Meeting, Atlanta, USA

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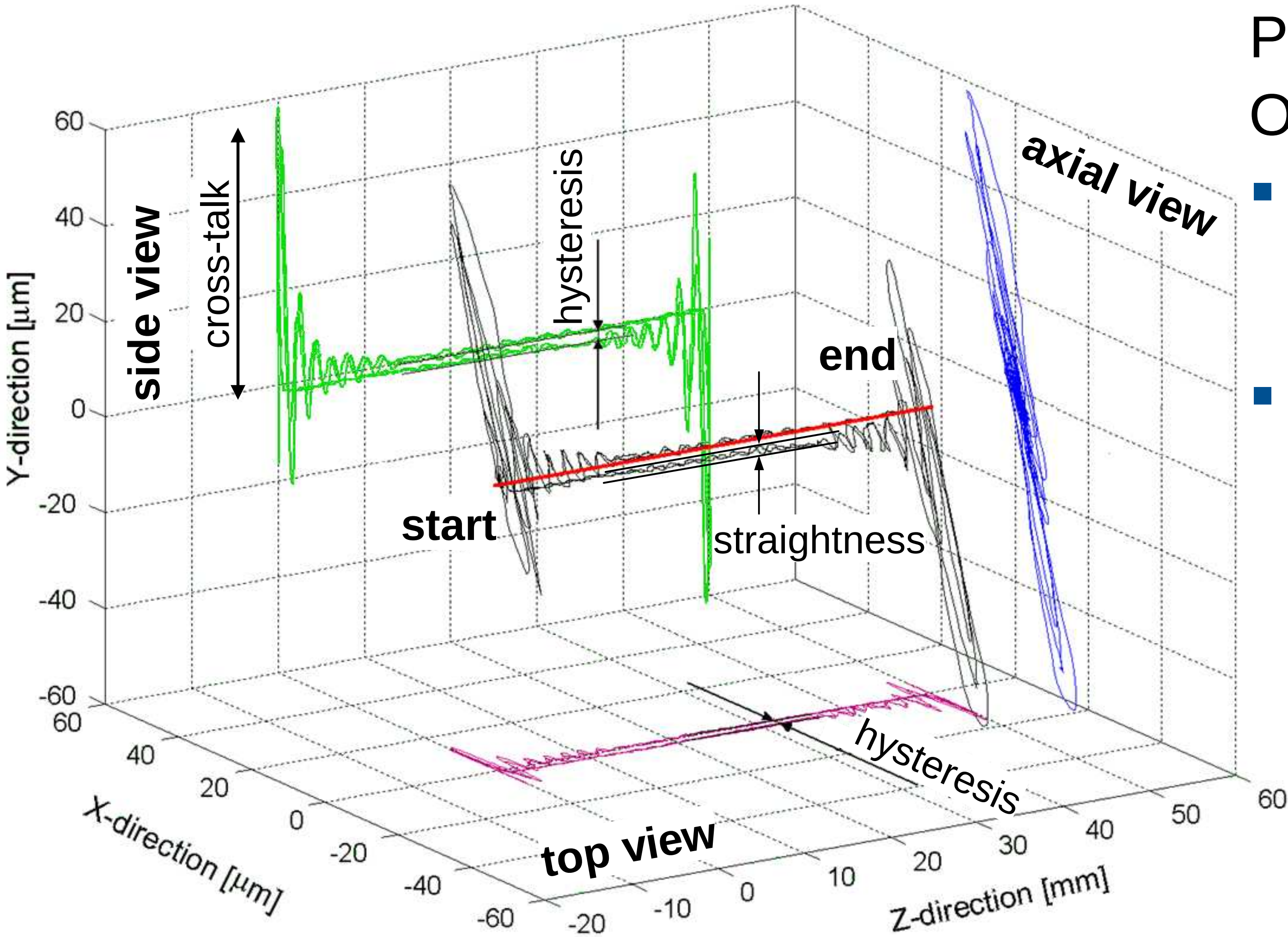
Content

Motivation



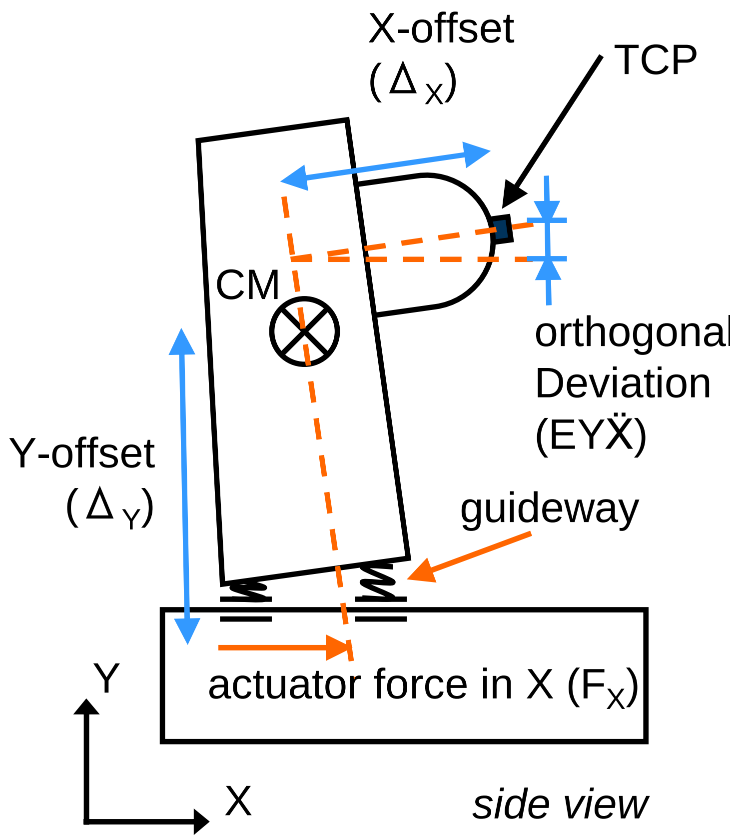
Positioning 50 mm

Order of errors:

- 5 µm
  - Straightness
  - Hysteresis
- 50 µm
  - Cross-talk

What is Cross-Talk?

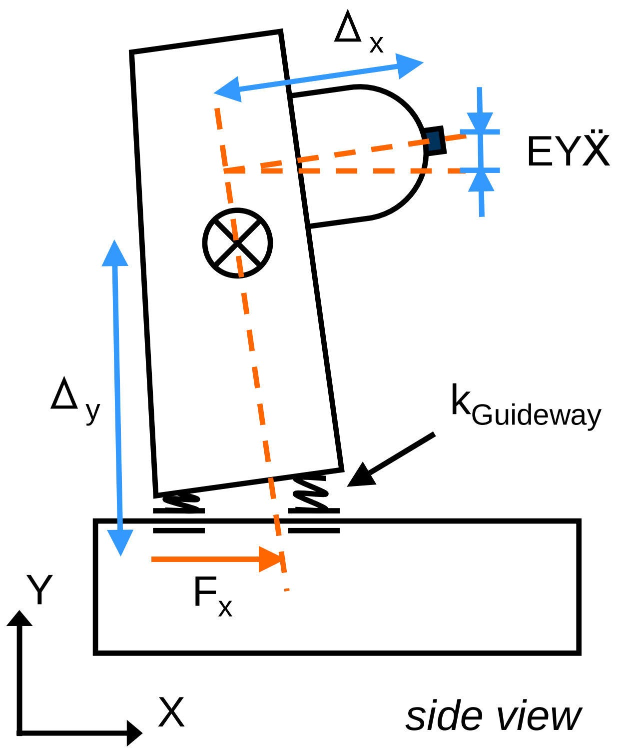
- Standard ISO/TR 230-8
  - inertial cross-talk
- Effect
  - Deviation orthogonal to the accelerated direction
  - $\ddot{X} \rightarrow EY\ddot{X}, EZ\ddot{X}$
- Influences
  - Stiffness k in guideway
  - Y offset (lateral) from point of force application and center of mass (CM) (Δ_Y)
  - X offset from center of mass to the tool center point (TCP) (Δ_X)
  - Acceleration (actuator force F_X)



Mathematical Description of Cross-Talk?

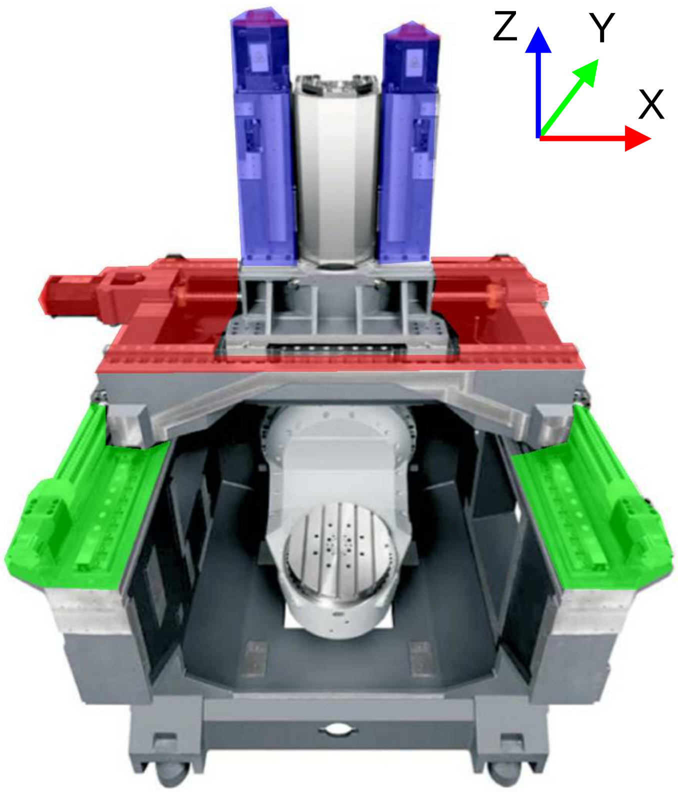
- Model
  - $EY\ddot{X}$ Cross-talk
  - ¢ Proportional factor
  - F_X Actuator force
  - Δ_Y Y offset (lateral)
  - Δ_X X offset
  - $k_{Guideway}$ Stiffness

- $$EY\ddot{X} = ¢ \cdot \frac{F_x \cdot \Delta_x \cdot \Delta_y}{k_{Guideway}}$$



Cross-Talk Countermeasures

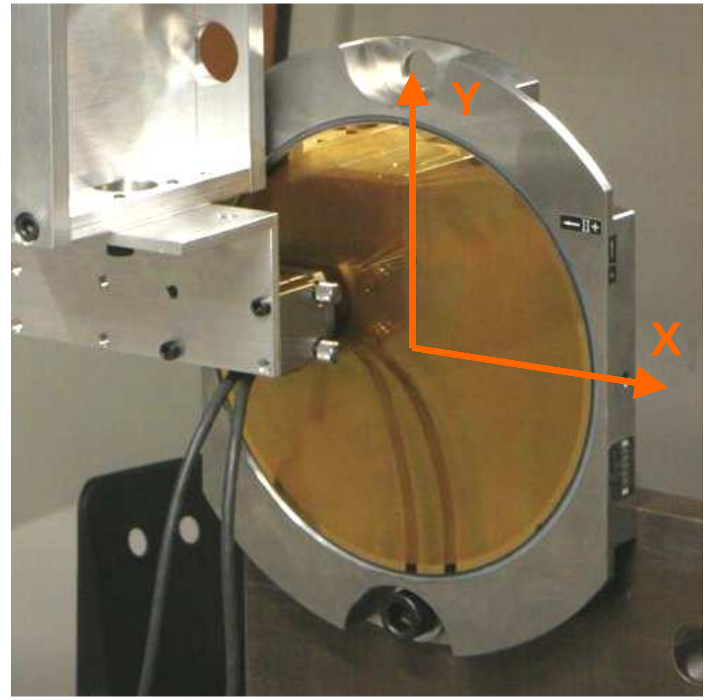
- Machine design
  - Drive in the center of gravity (DCG)
- Reduction of the dynamic parameters
- Compensation using numerical control (NC)
  1. Measurement of the cross-talk error
  2. Derivation of the cross-talk prediction model
  3. Compensation of the position set-point

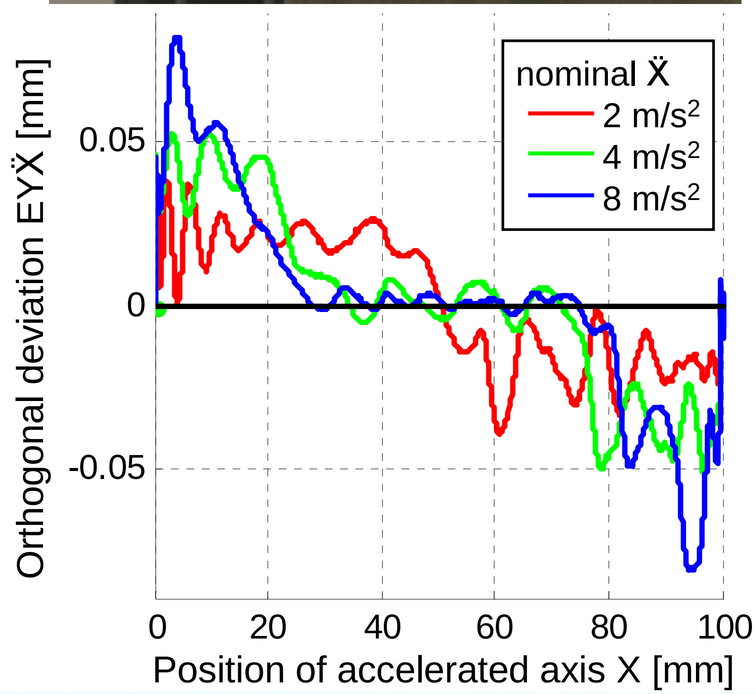


Mori Seiki, NMV5000 DCG
Photo: Mori Seiki

Cross-Talk Measurement

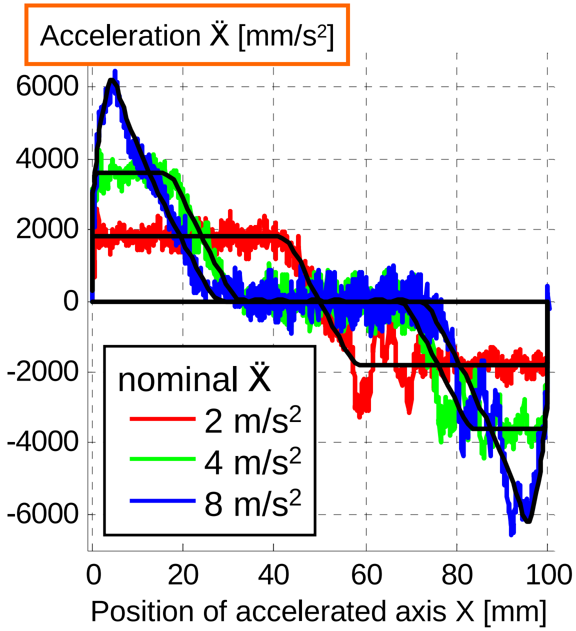
- Cross-grid XY-measurement
  - 2D
  - Optical measurement system
  - Non-contact
  - Similar principle to an optical linear scale
- Cross-Grid measurement for different
  - Y offsets (lateral)
  - Accelerations
  - X offsets do not change

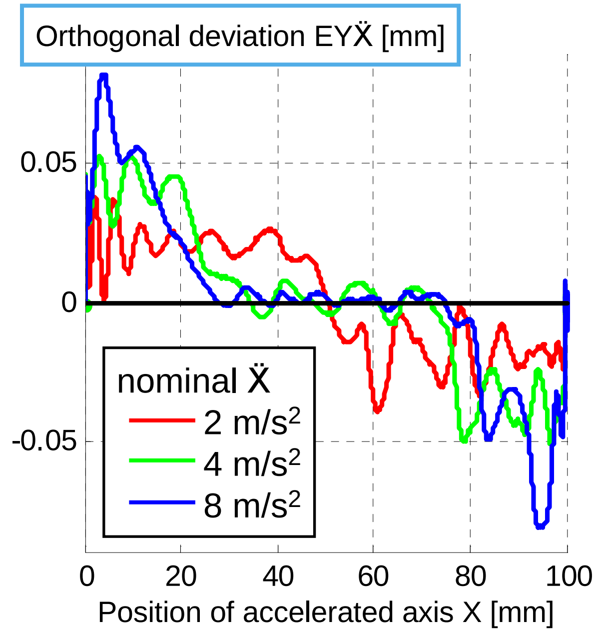


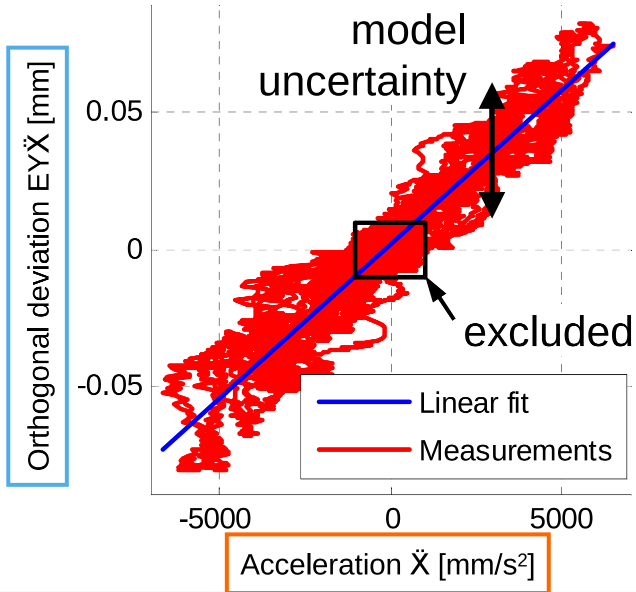


How to Model the Cross-Talk Effect
(Acceleration dependent for a given position)

- Orthogonal deviation $EY\ddot{X}$ is proportional to the acceleration $\ddot{X}$
- Linear fit of measurement data
- Exclude sections to improve the linear fit
  - Low accelerations: non-cross-talk deviations are dominant
  - Low orthogonal deviations: acceleration influenced by numerical effects



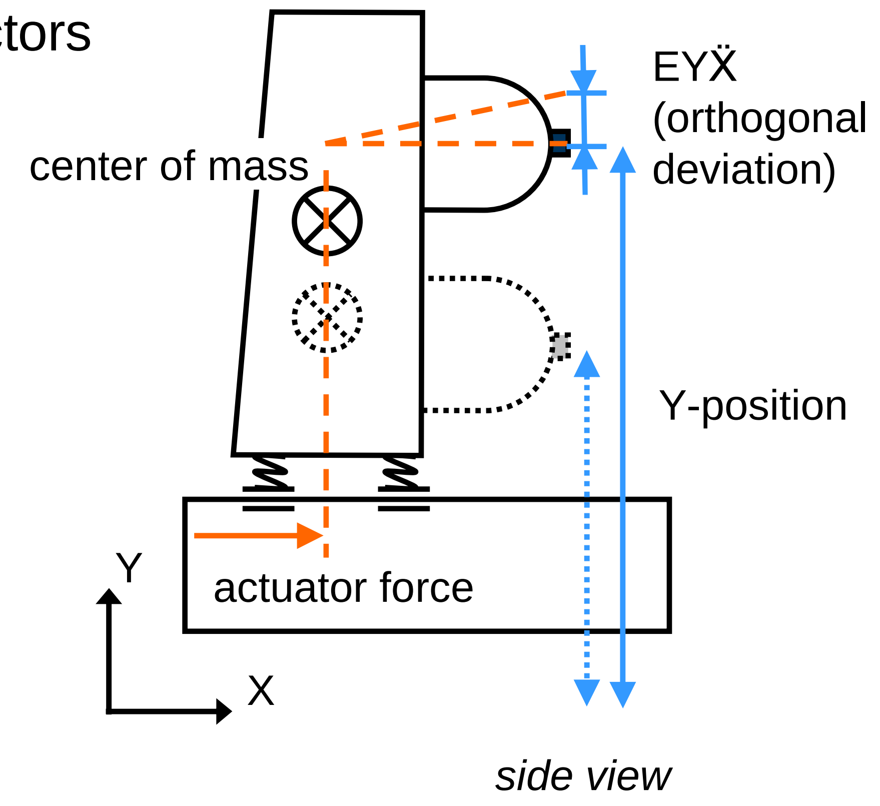




Position Dependence of Cross-Talk I

- Dependence of the Y-Position
  - Linear fitted proportionality factors

Y-Position Y_{TCP}	$EY\ddot{X}/\ddot{X}$ [µm/(m/s²)]
300 mm	7.6
1200 mm	10.8



Position Dependence of Cross-Talk II

- Proportionality factor EYẌ/Ẍ for any Y_{TCP}

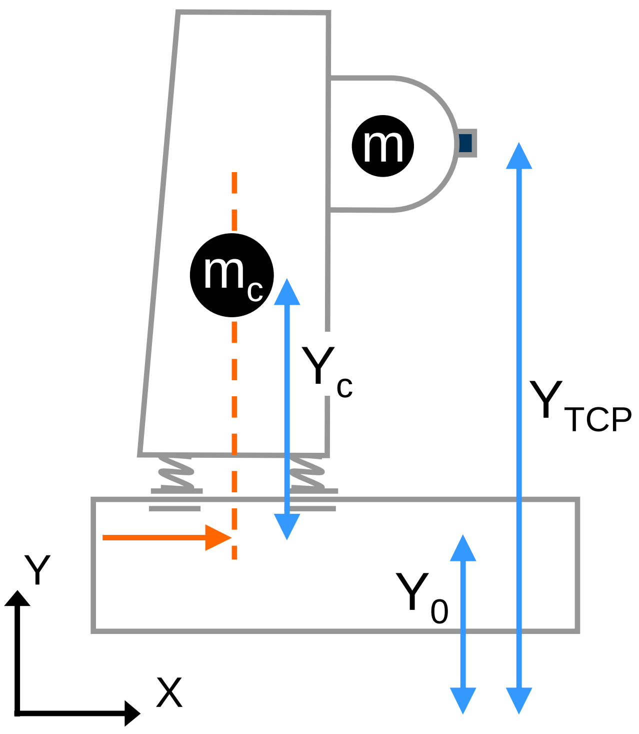
Y-Position	[µm/(m/s²)]
300 mm	7.6
Y_{TCP}	EYẌ/Ẍ
1200 mm	10.8

- Model

$$\mathrm{EY\ddot{X}}\left(Y_{TCP}, \ddot{X}\right) = ¢ \cdot \ddot{X} \cdot \left(Y_c \cdot m_c + \left(Y_{TCP} - Y_0\right) \cdot m\right)$$

$$= \ddot{X} \cdot \left(H_0 + H \cdot Y_{TCP}\right)$$

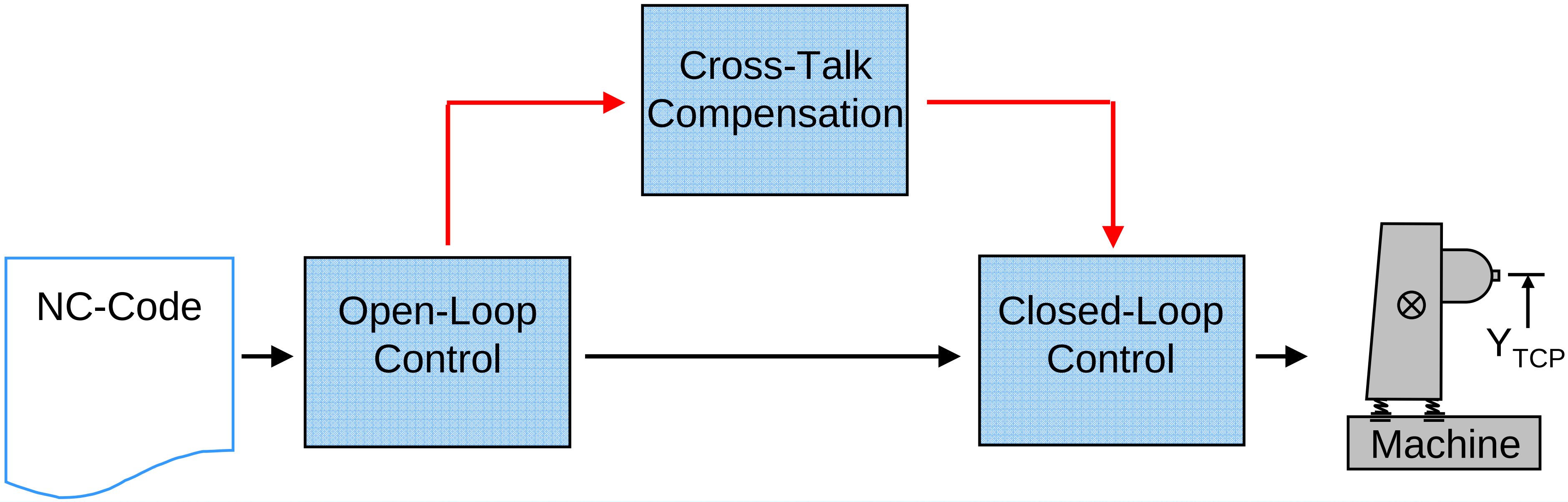
¢: proportional factor



side view

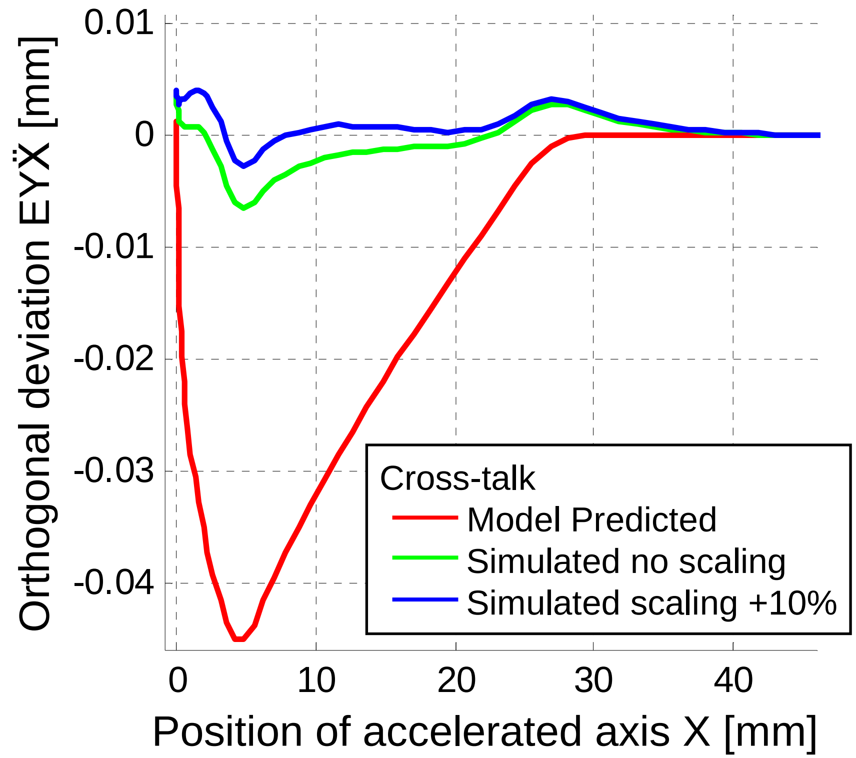
Compensation Procedure for Cross-Talk Error

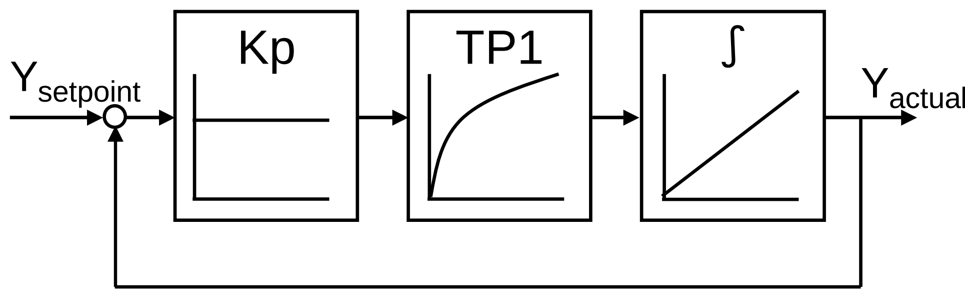
- Step 1: Measurement of the cross-talk error
- Step 2: Derivation of proportionality factors EYẌ/Ẍ
- Step 3: Compensation of the position set-point depending on the nominal acceleration and position



Limited Actuator Dynamics

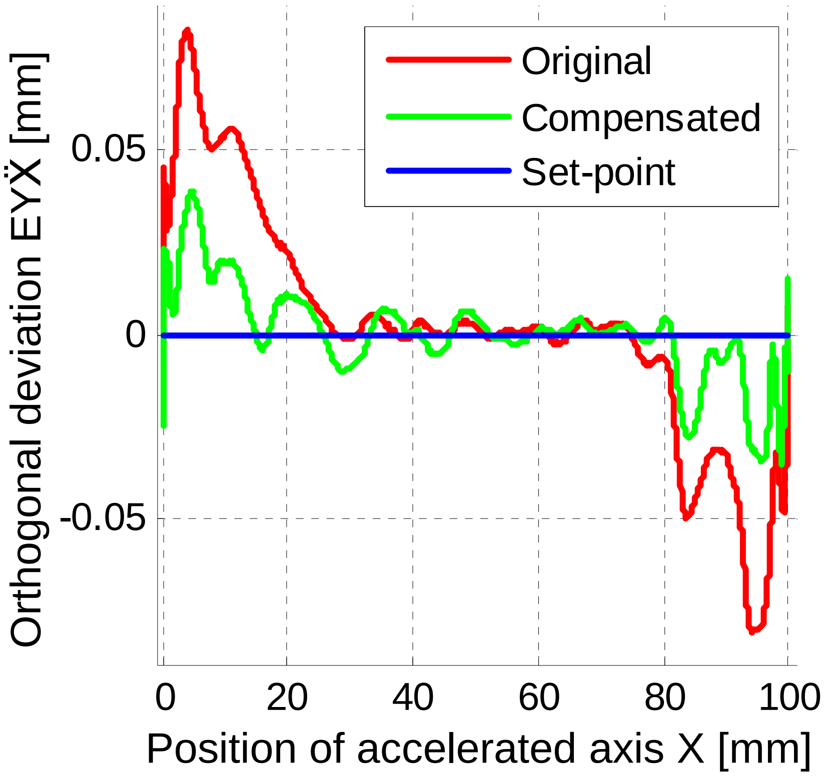
- Direct compensation
  - Add model predicted cross-talk to the set-point position of Y
  - Incomplete compensation
- Reason
  - Actuator dynamics, low pass behavior of the drive
  - Modeling with a TP1 element
- Improved compensation
  - Scaling of the model predicted compensation values





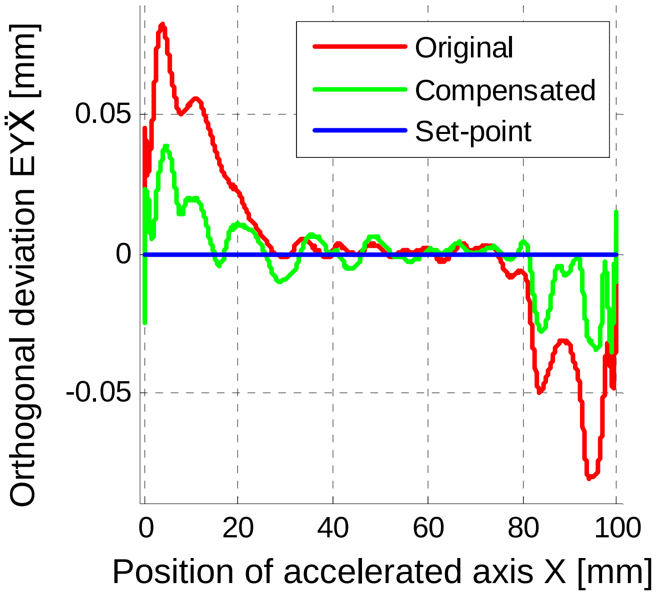
Results and Conclusion

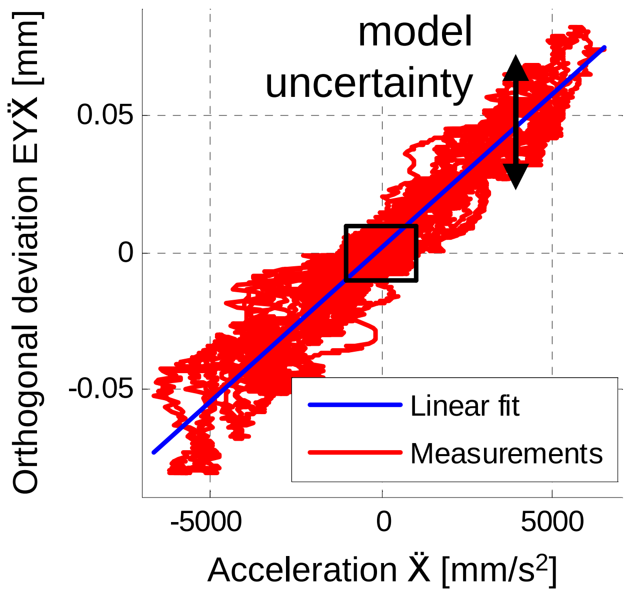
- Cross-talk reduction realized only by set-point modification
- Procedure can be used also with multi-dimensional movement
- Reduction of the orthogonal deviation of about 50% in experiment



Discussion

- Further reduction of cross-talk should be possible
- Model uncertainty is about ±20 μm
- To consider
  - Position control cycle time (4.5 ms)
  - Better inversion of the drive dynamics
  - Dynamics of the compensating axis

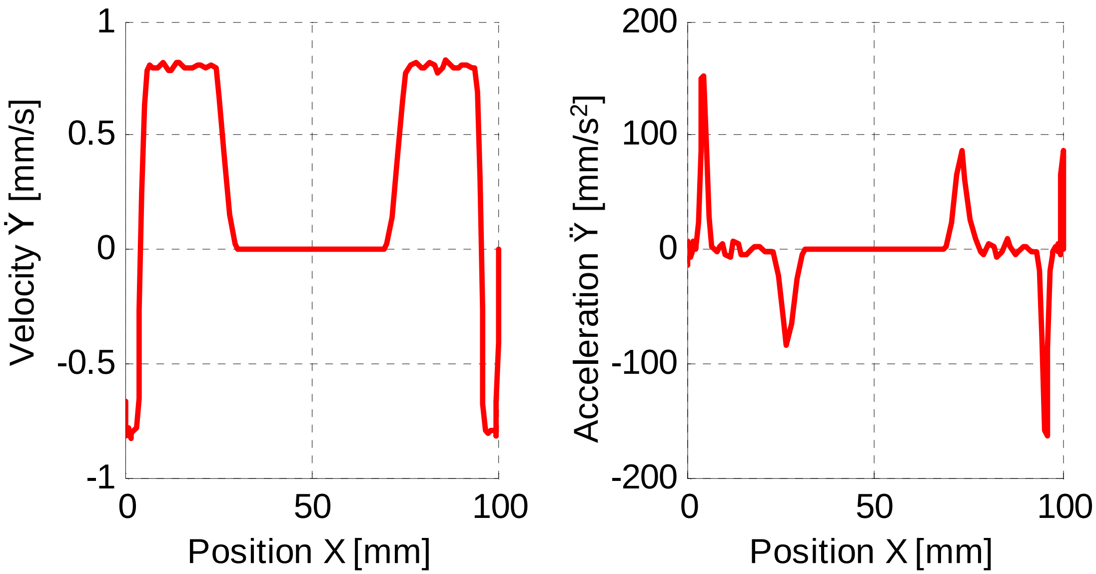




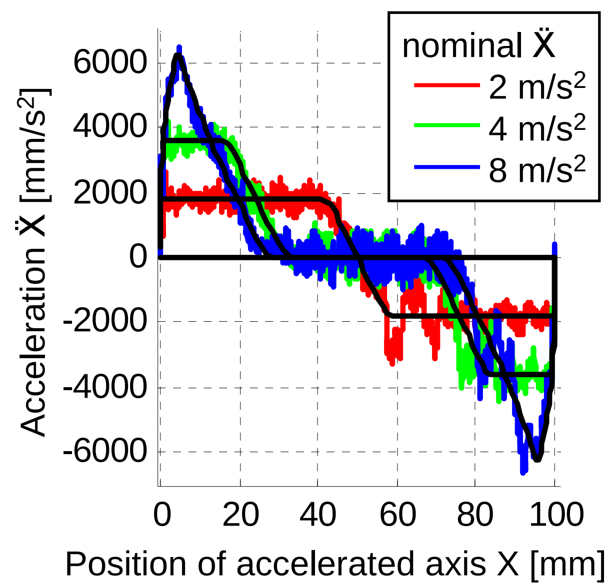
Influence of the Machine Dynamics

- Low machine excitation by the acceleration of the compensating axis
- Effects that can not be compensated (vibrations e.g.)

Velocity and acceleration of the compensating axis



Acceleration of the positioning axis



Summary

Compensation Procedure

- Measurement of the dynamic orthogonal deviation (cross-talk) during a single axis positioning movement
- Determination of the proportionality factors between acceleration and orthogonal deviation
- Position dependent model of the cross-talk
- Compensation of the nominal position values

Improvement:

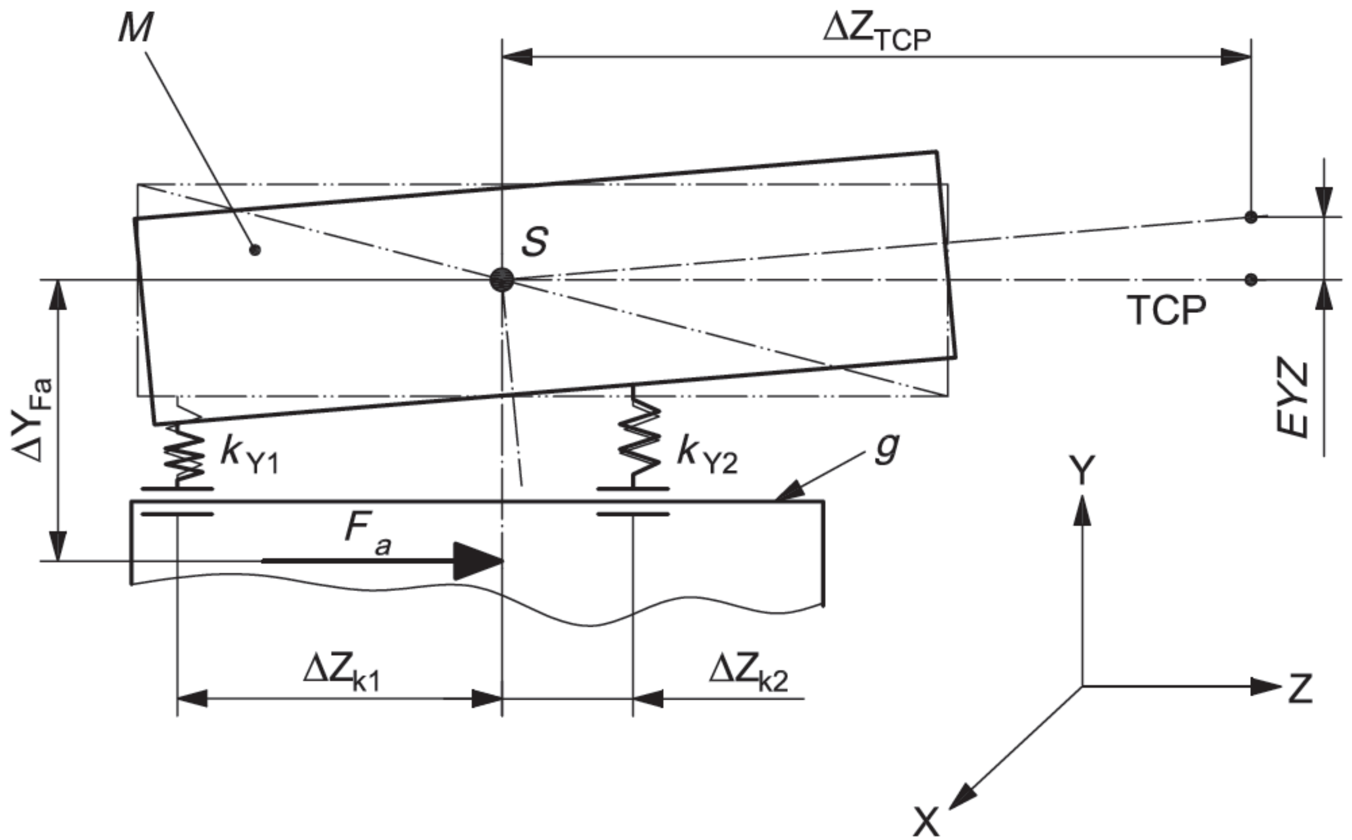
- The orthogonal deviation is reduced by 50% using the proposed compensation strategy.

Thank you for your Attention

Questions ?

Slides

Inertial Cross-Talk Principle – ISO/TR 230-8

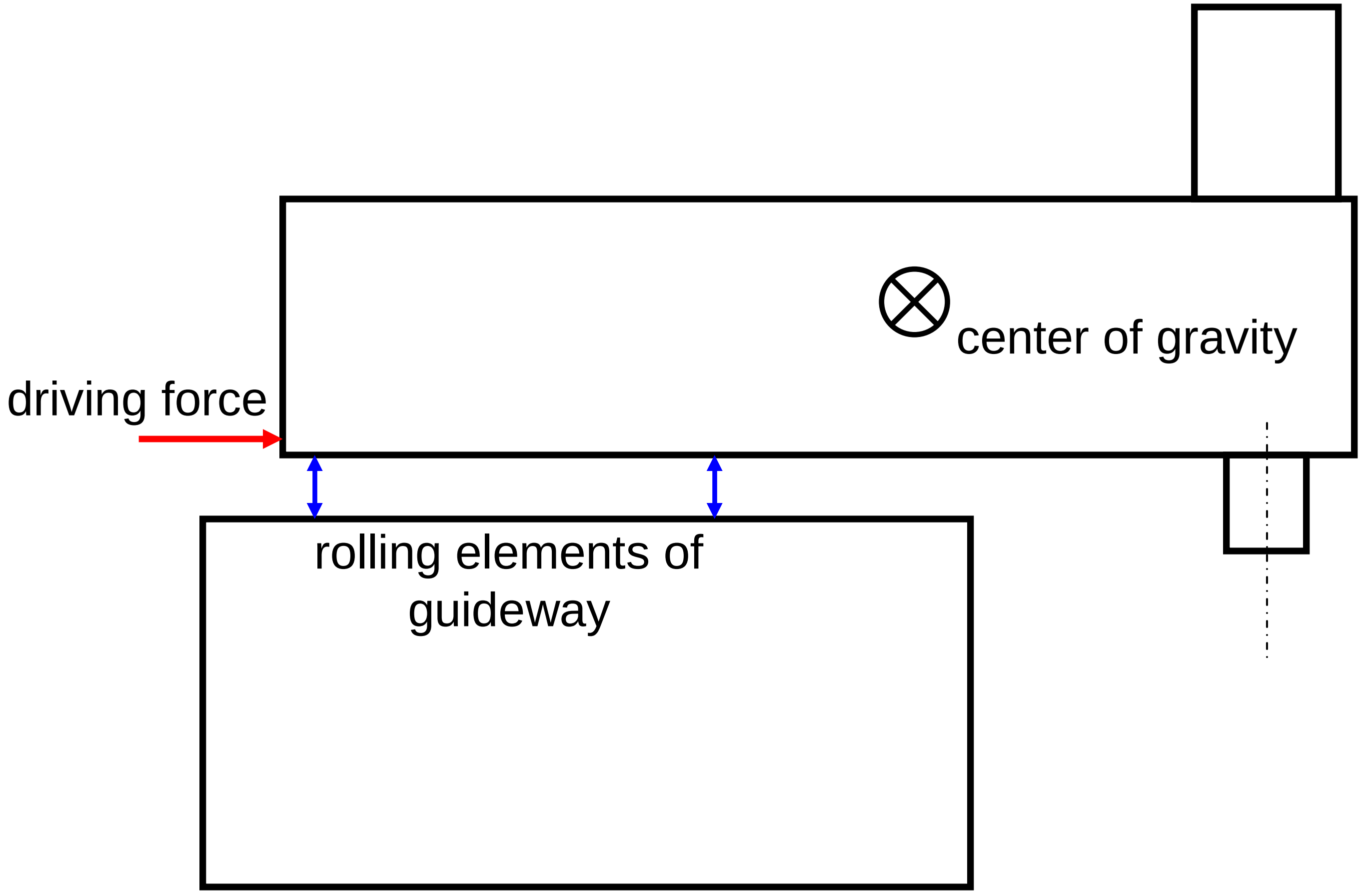


Key

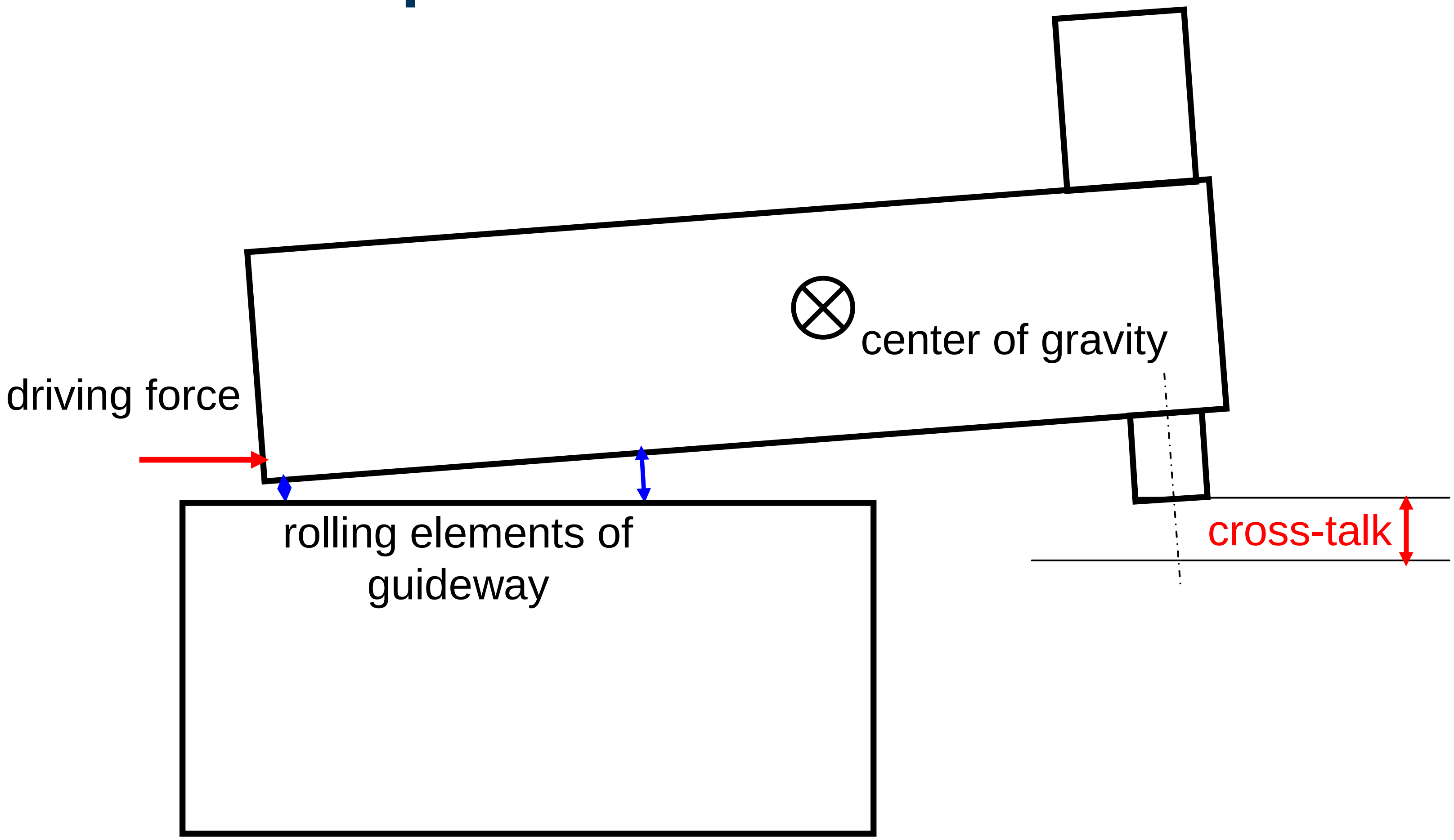
- M moving mass of the slide
- g guide-way system
- TCP tool centre point

"displacements perpendicular to the intended direction of motion, owing to a lateral offset between the driving force and the center of mass, which load to tilt motions during acceleration and deceleration"

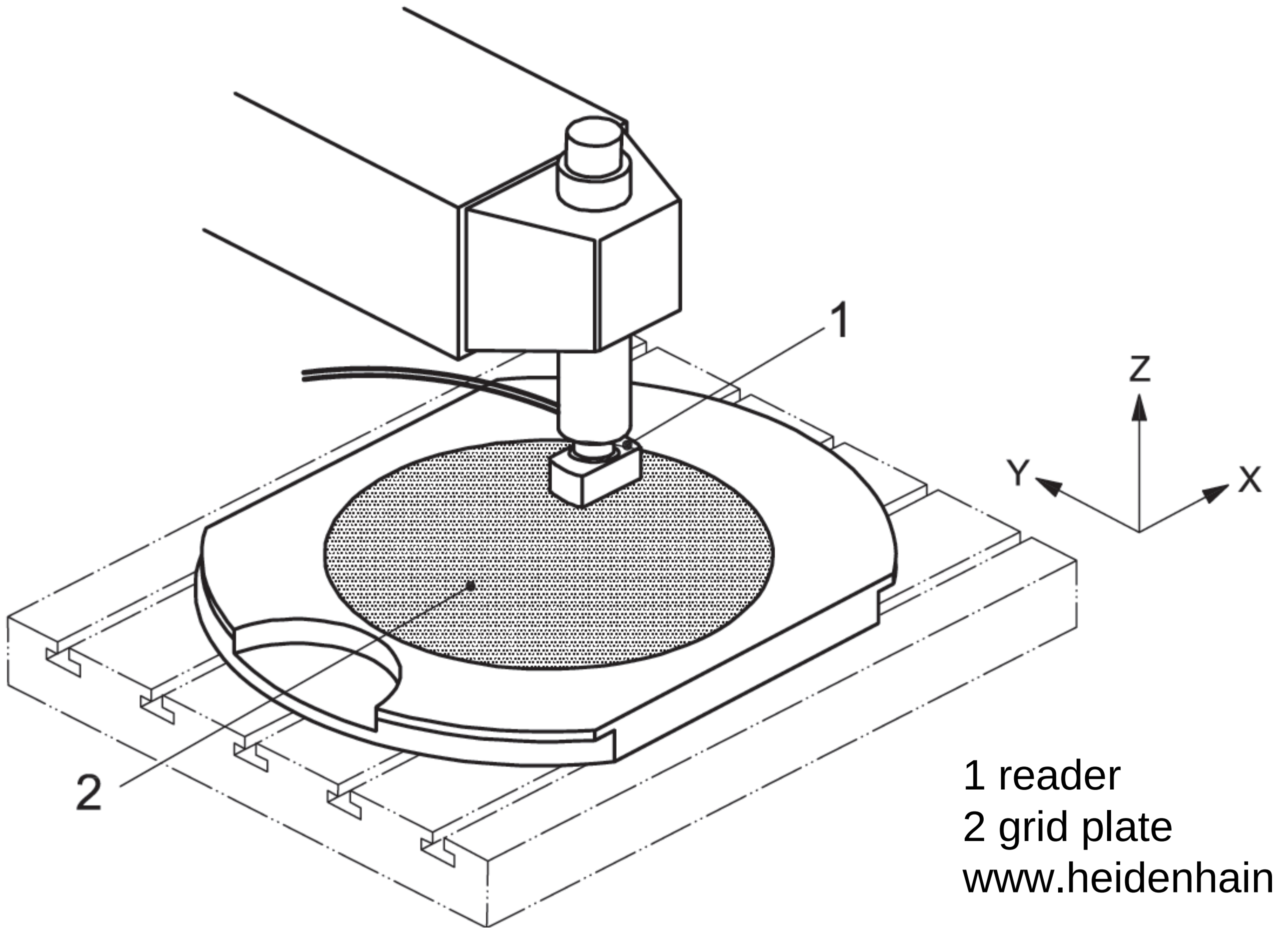
Cross-Talk Principle I



Cross-Talk Principle II

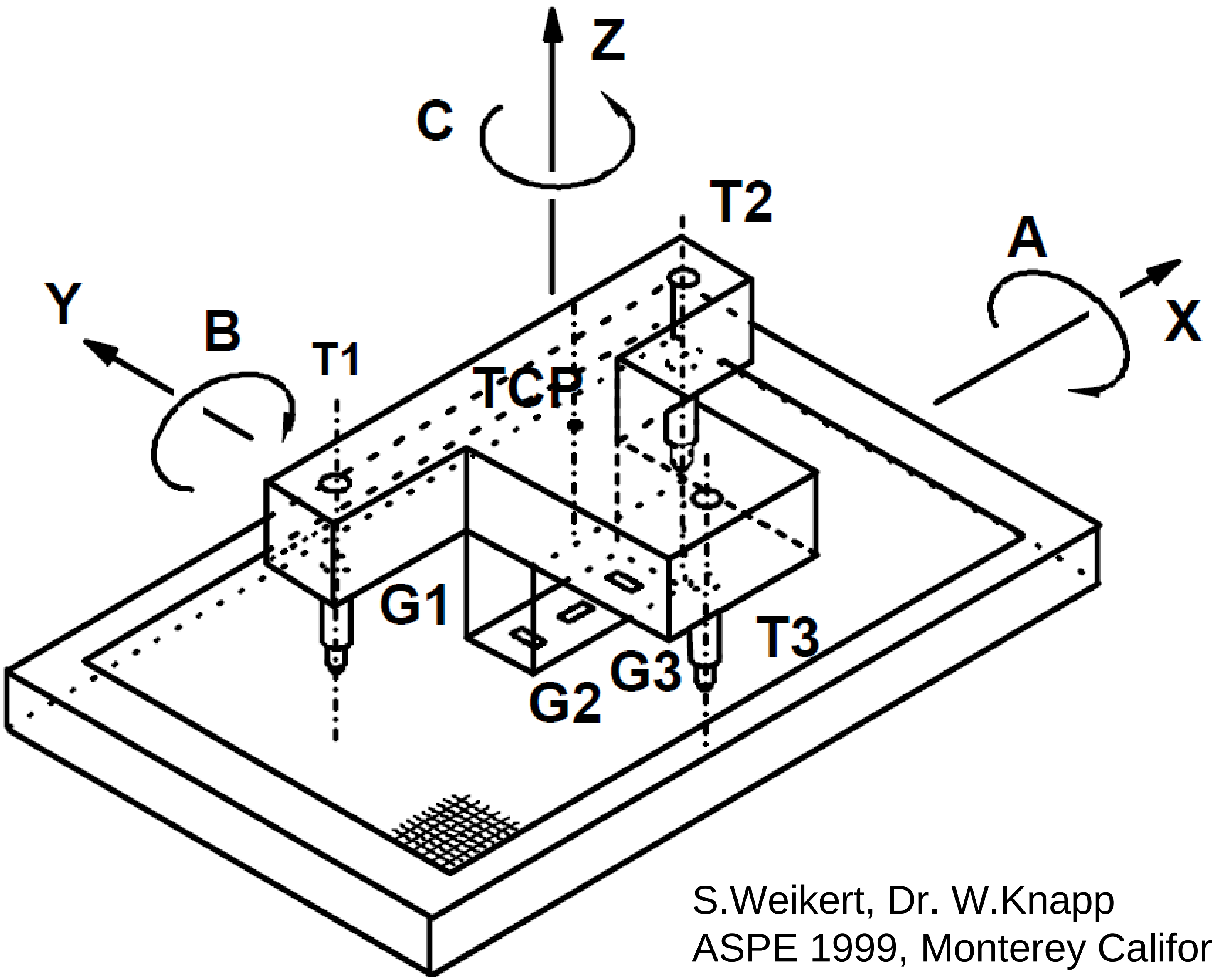


Cross-Grid



1 reader
2 grid plate
www.heidenhain.com

KGM+



S.Weikert, Dr. W.Knapp
ASPE 1999, Monterey California