

Open Loop Inertial Cross-Talk Compensation Based on Measurement Data

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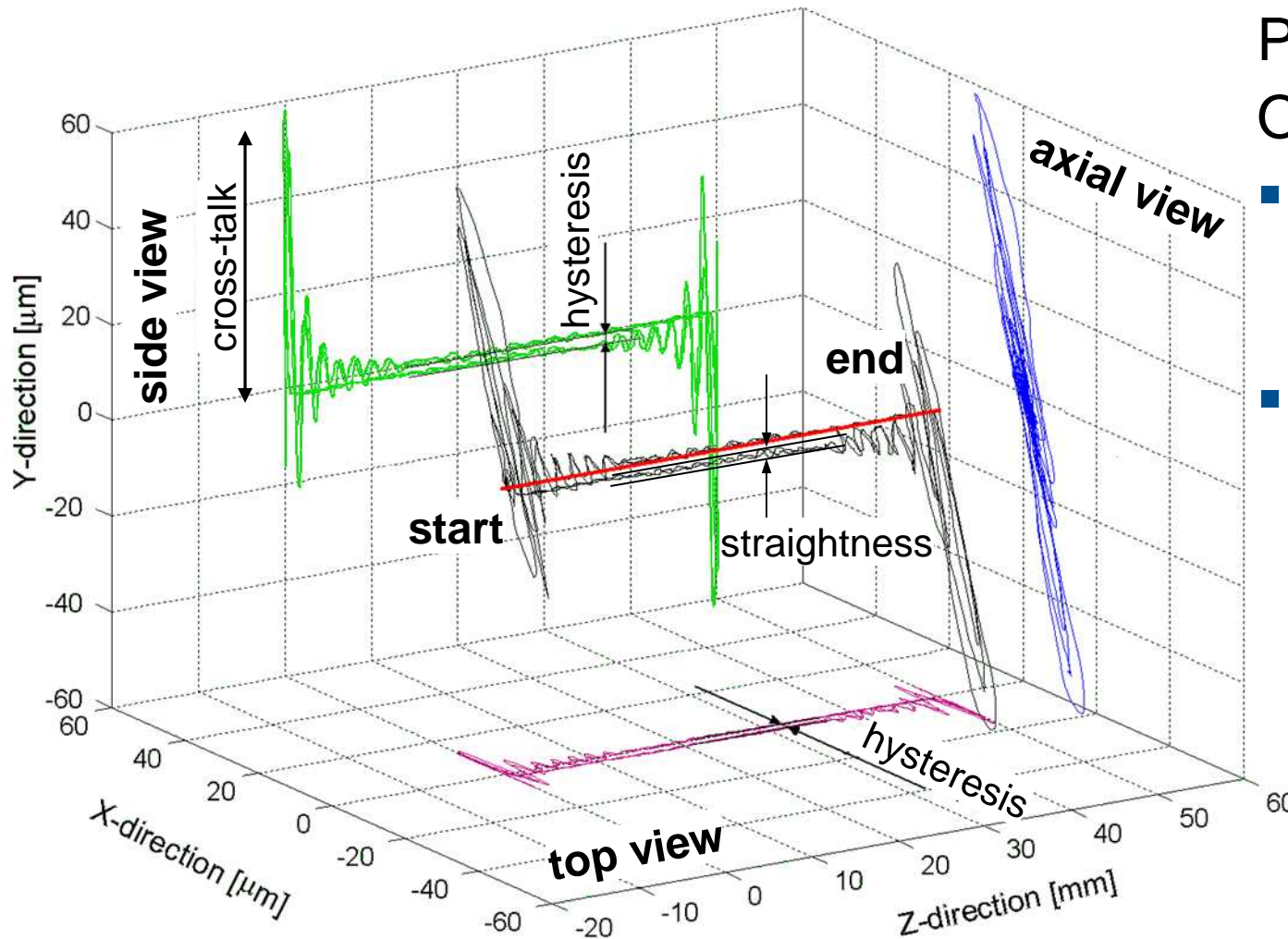


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Content

- Motivation
- What is Cross-Talk?
- Measurement
- Modeling
- Compensation Procedure
- Results and Conclusion

Motivation

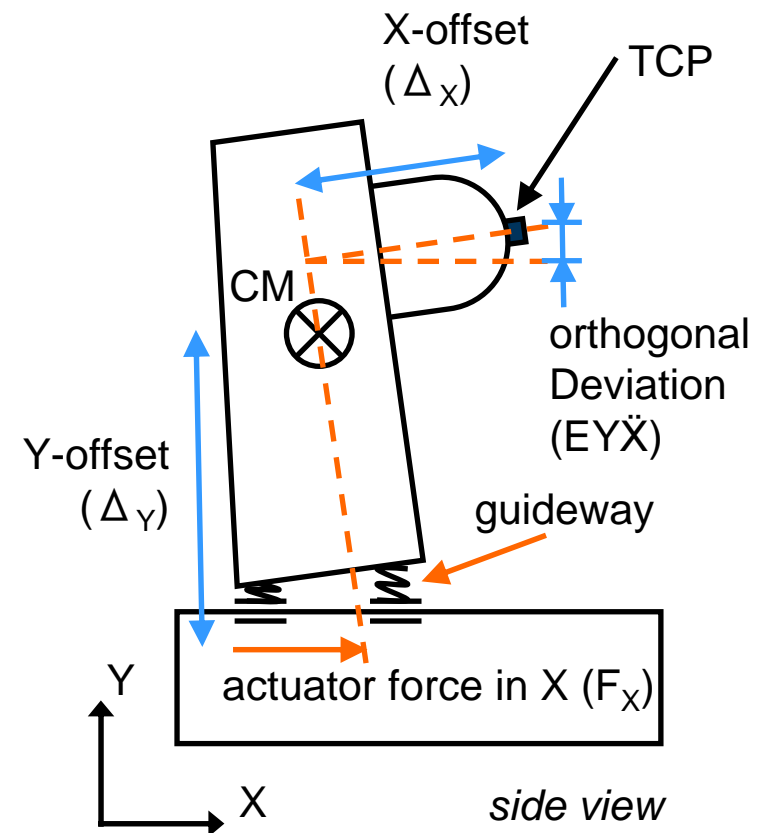


Positioning 50 mm
Order of errors:

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

What is Cross-Talk?

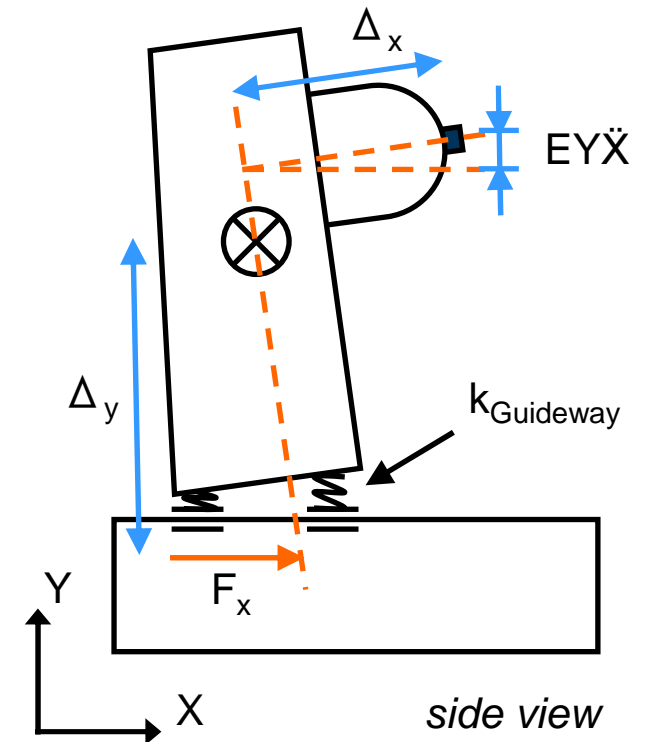
- Standard ISO/TR 230-8
 - inertial cross-talk
- Effect
 - Deviation orthogonal to the accelerated direction
 - $\ddot{X} \rightarrow EY\ddot{X}, EZ\ddot{X}$
- Influences
 - Stiffness k in guideway
 - Y offset (lateral) from point of force application and center of mass (CM) (Δ_Y)
 - X offset from center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



Mathematical Description of Cross-Talk?

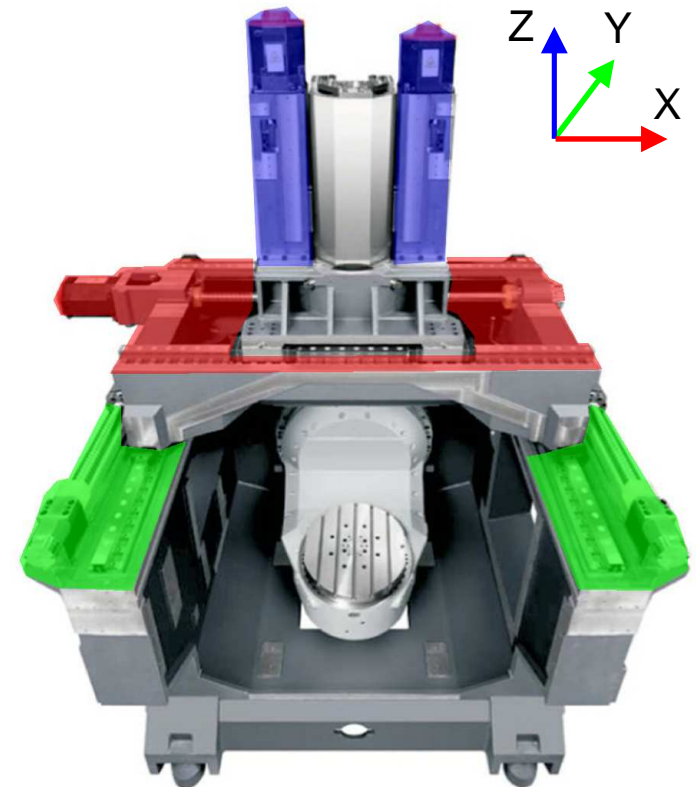
- Model
 - $EY\ddot{X}$ Cross-talk
 - ϕ Proportional factor
 - F_x Actuator force
 - Δ_y Y offset (lateral)
 - Δ_x X offset
 - k_{Guideway} Stiffness

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



Cross-Talk Countermeasures

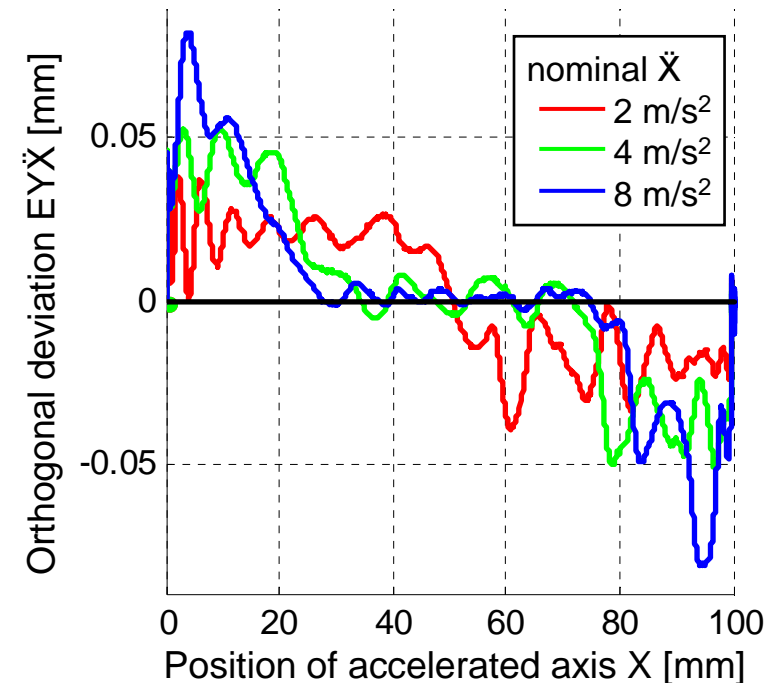
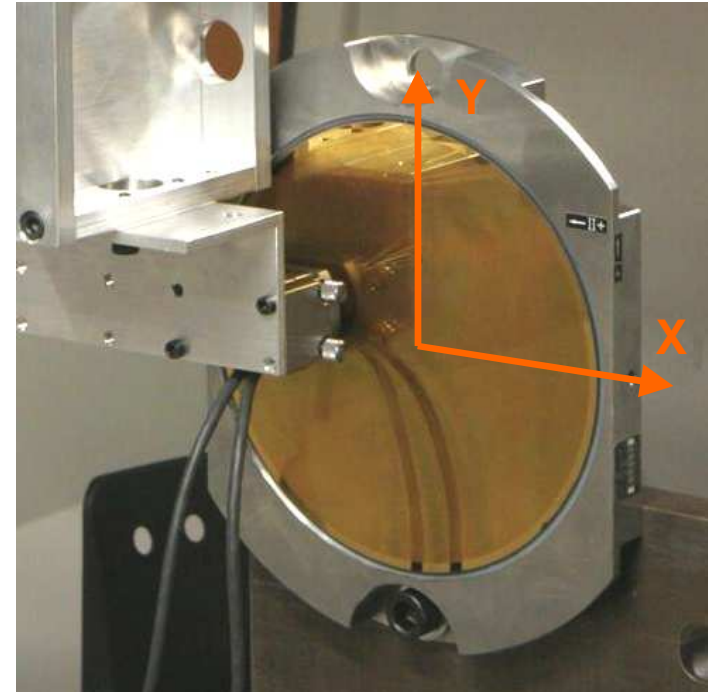
- Machine design
 - Drive in the center of gravity (DCG)
- Reduction of the dynamic parameters
- Compensation using numerical control (NC)
 1. Measurement of the cross-talk error
 2. Derivation of the cross-talk prediction model
 3. Compensation of the position set-point



Mori Seiki, NMV5000 DCG
Photo: Mori Seiki

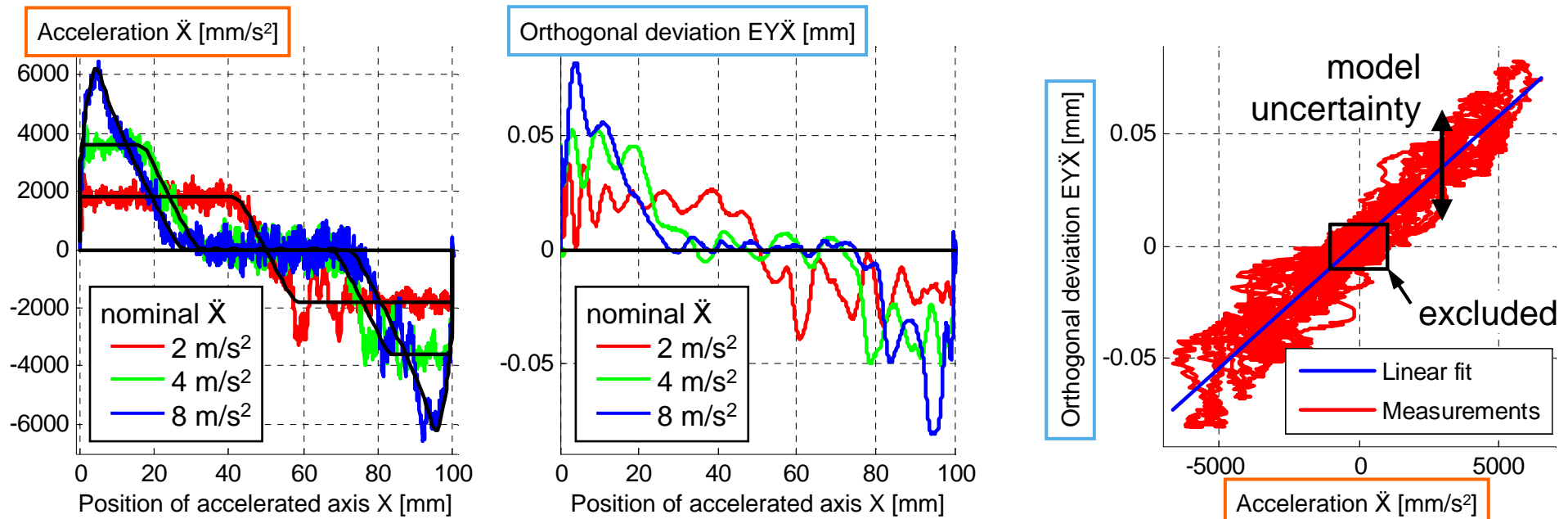
Cross-Talk Measurement

- 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)

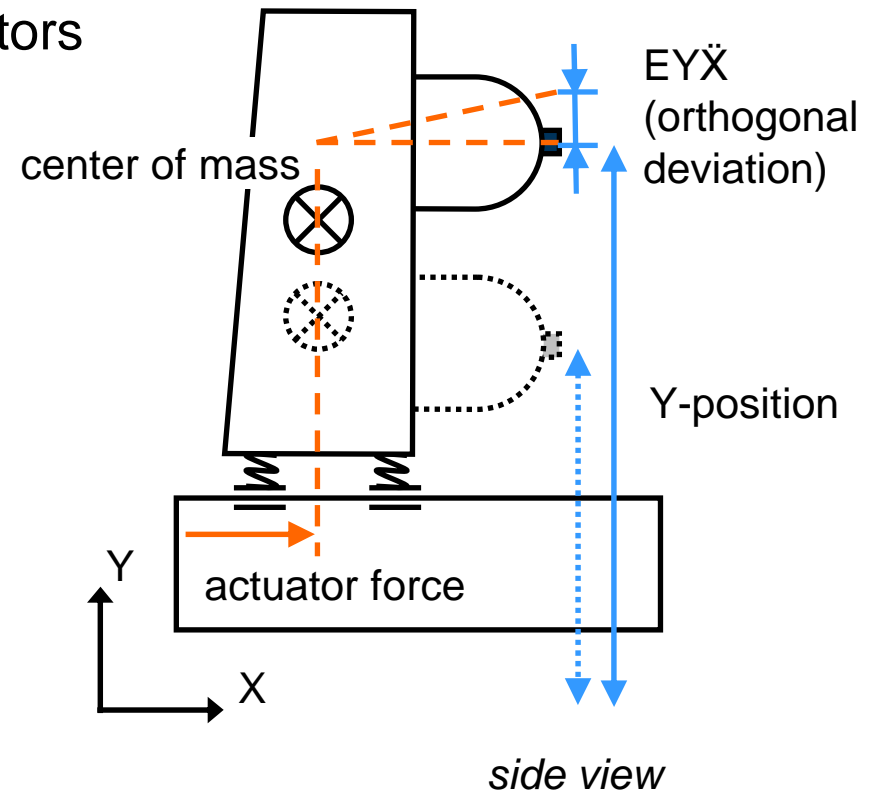
- Orthogonal deviation $EY\ddot{X}$ is proportional to the acceleration \ddot{X}
- Linear fit of measurement data
- Exclude sections to improve the linear fit
 - Low accelerations: non-cross-talk deviations are dominant
 - Low orthogonal deviations: acceleration influenced by numerical effects



Position Dependence of Cross-Talk I

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

Y-Position	$E_{Y\ddot{X}/\ddot{X}}$
Y_{TCP}	$[\mu\text{m}/(\text{m}/\text{s}^2)]$
300 mm	7.6
1200 mm	10.8



Position Dependence of Cross-Talk II

- Proportionality factor $EY\ddot{X}/\ddot{X}$ for any Y_{TCP}

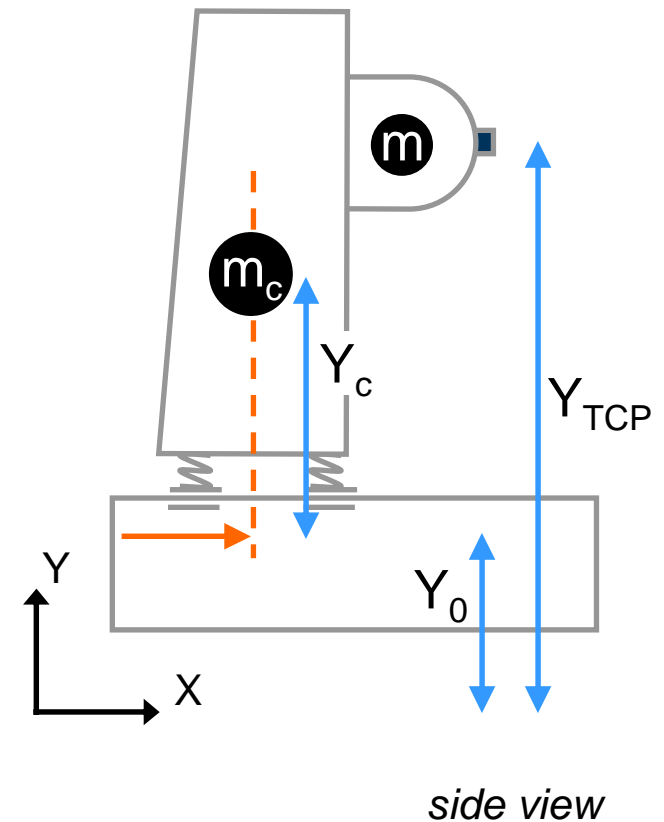
Y-Position	[$\mu\text{m}/(\text{m}/\text{s}^2)$]
300 mm	7.6
Y_{TCP}	$EY\ddot{X}/\ddot{X}$
1200 mm	10.8

- Model

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

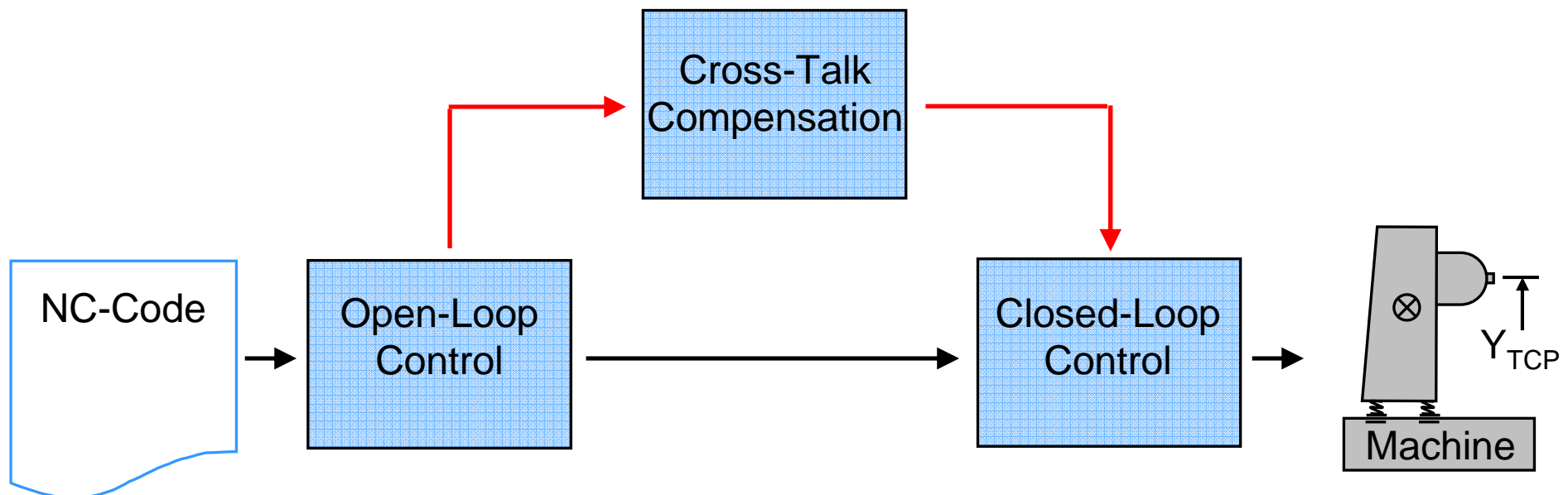
$$= \ddot{X} \cdot (H_0 + H \cdot Y_{TCP})$$

ϕ : proportional factor



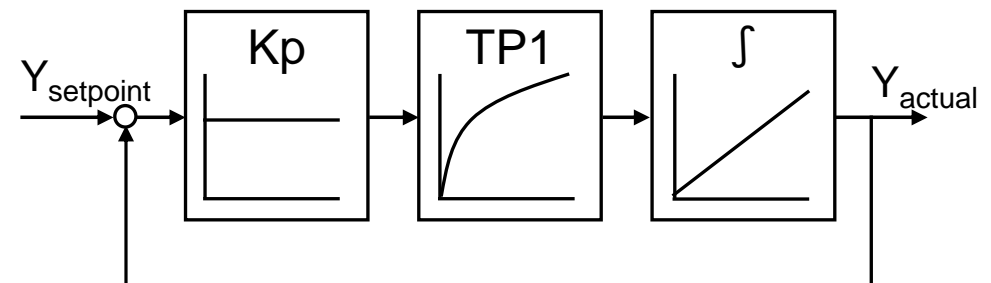
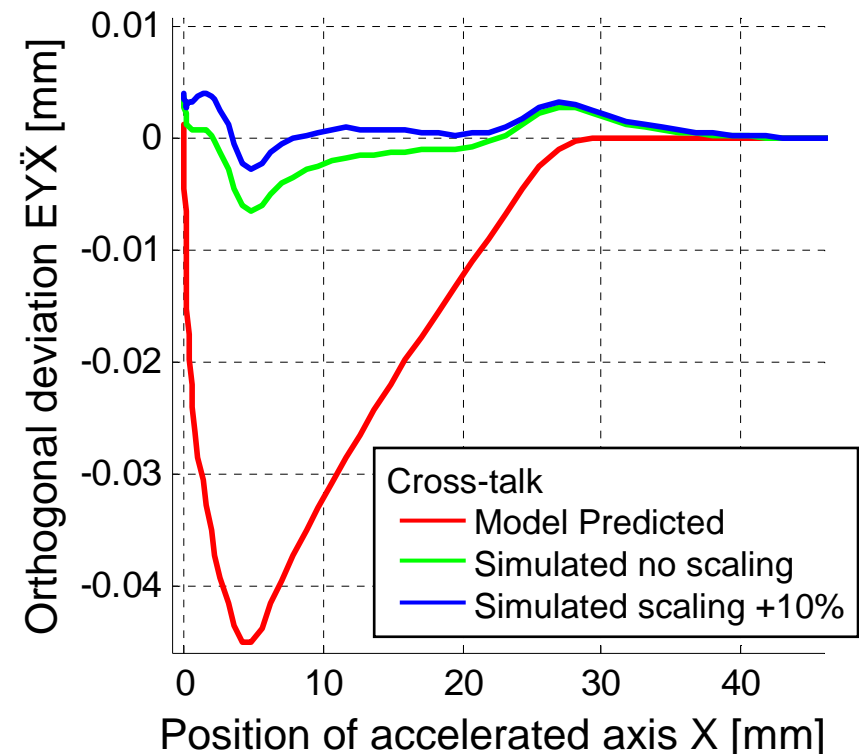
Compensation Procedure for Cross-Talk Error

- Step 1: Measurement of the cross-talk error
- Step 2: Derivation of proportionality factors $EY\ddot{X}/\ddot{X}$
- Step 3: Compensation of the position set-point depending on the nominal acceleration and position



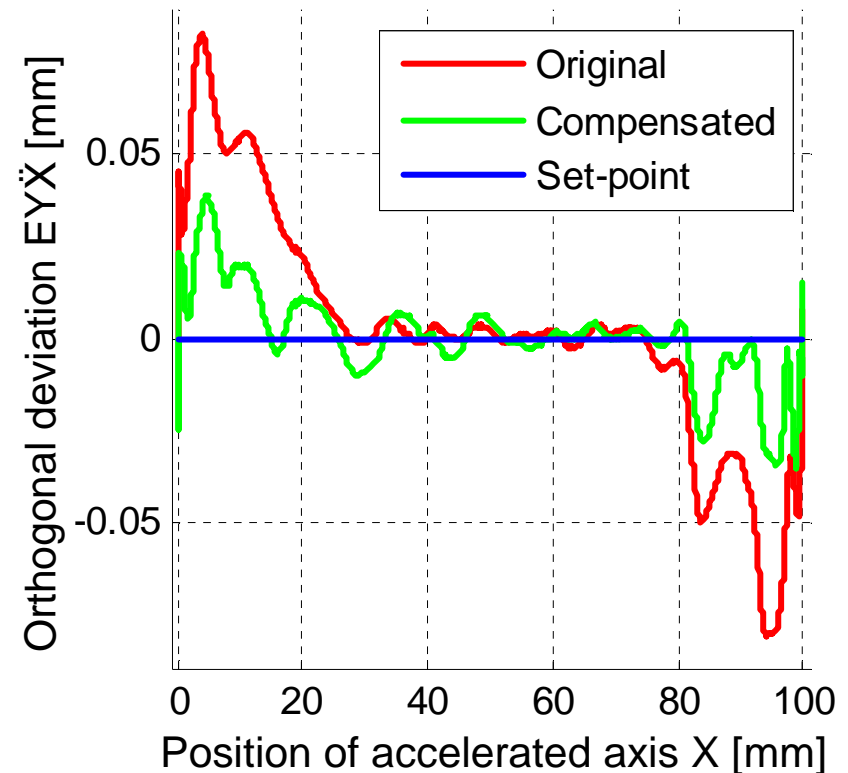
Limited Actuator Dynamics

- 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



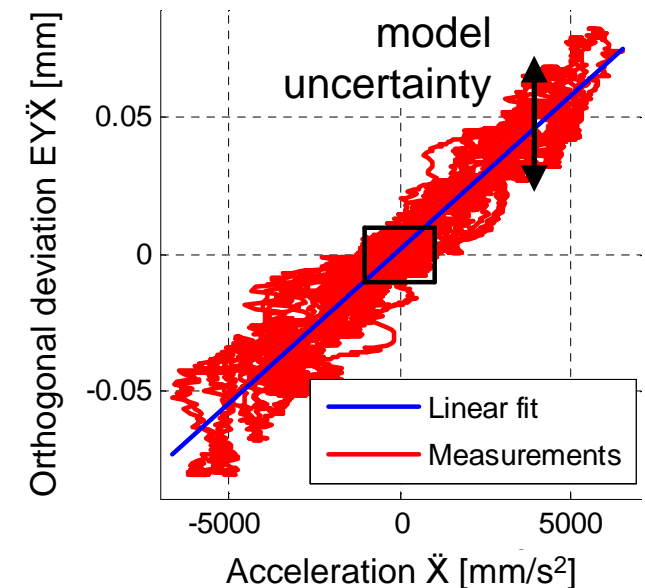
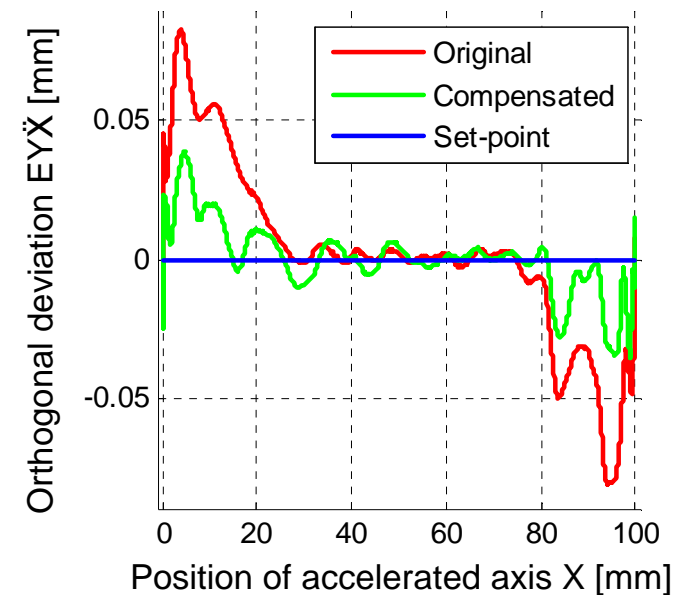
Results and Conclusion

- 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

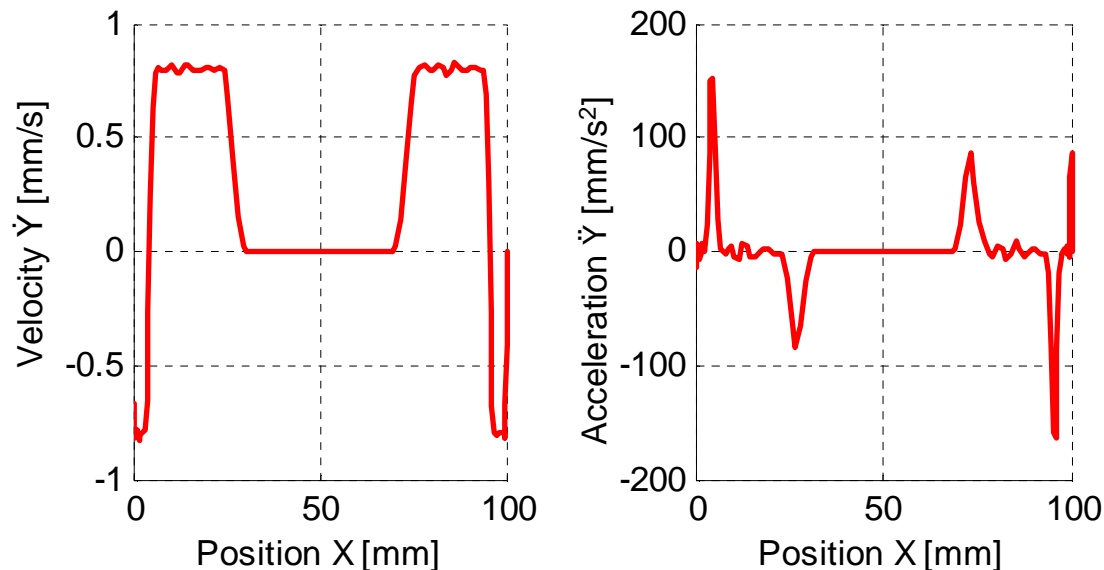
- Further reduction of cross-talk should be possible
- Model uncertainty is about $\pm 20 \mu\text{m}$
- To consider
 - Position control cycle time (4.5 ms)
 - Better inversion of the drive dynamics
 - Dynamics of the compensating axis



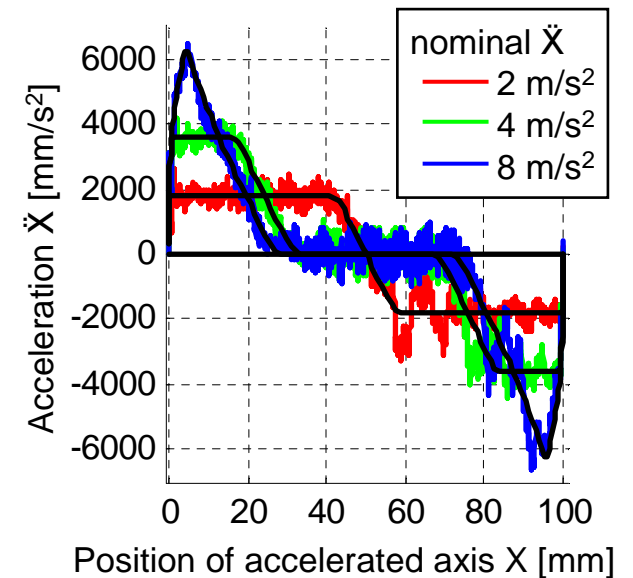
Influence of the Machine Dynamics

- 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:

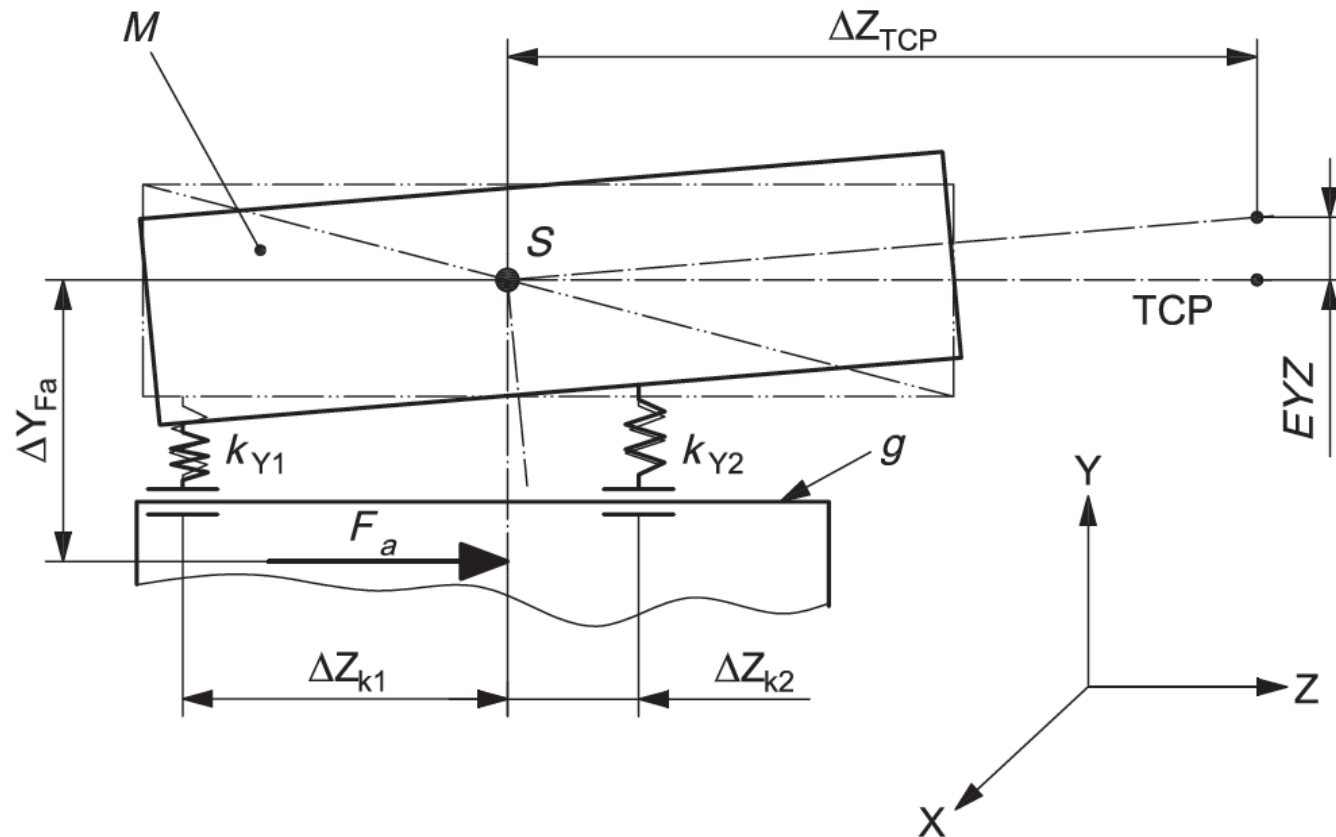
- The orthogonal deviation is reduced by 50% using the proposed compensation strategy.

Thank you for your Attention
Questions ?

Slides

3 Motivation	4 What is Cross-Talk
5 Mathematical Description	6 Countermeasures
7 Measurements	8 How to Model Cross-Talk
9 Position Dependence I	10 Position Dependence II
11 Compensation Procedure	12 Limited Actuator Dynamics
13 Results and Conclusion	14 Discussion
15 Influence of the Machine Dynamics	16 Summary
19 ISO/TR 230-8	20 Cross-Talk Principle
22 Cross-Grid	23 KGM+

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

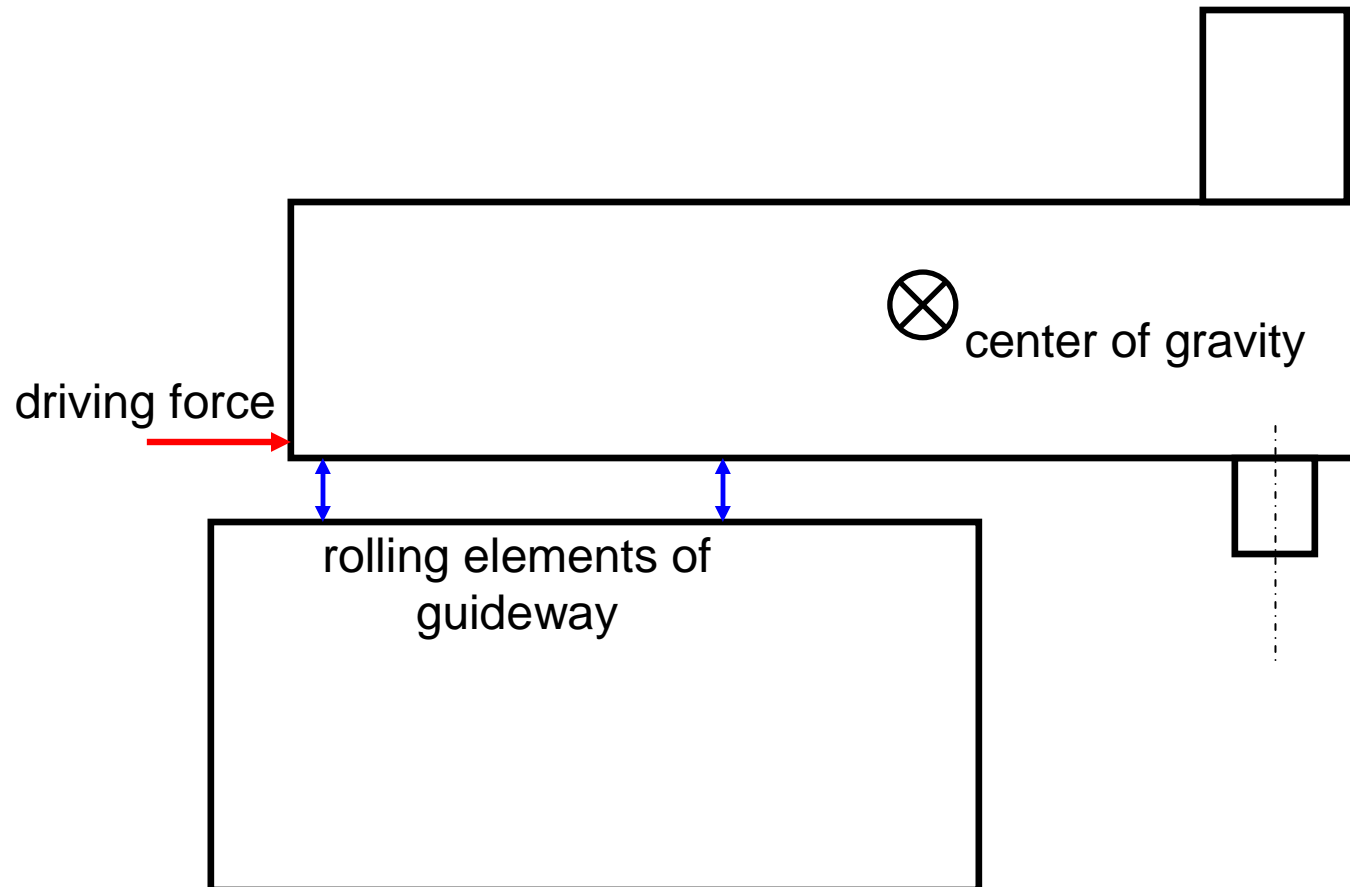


Key

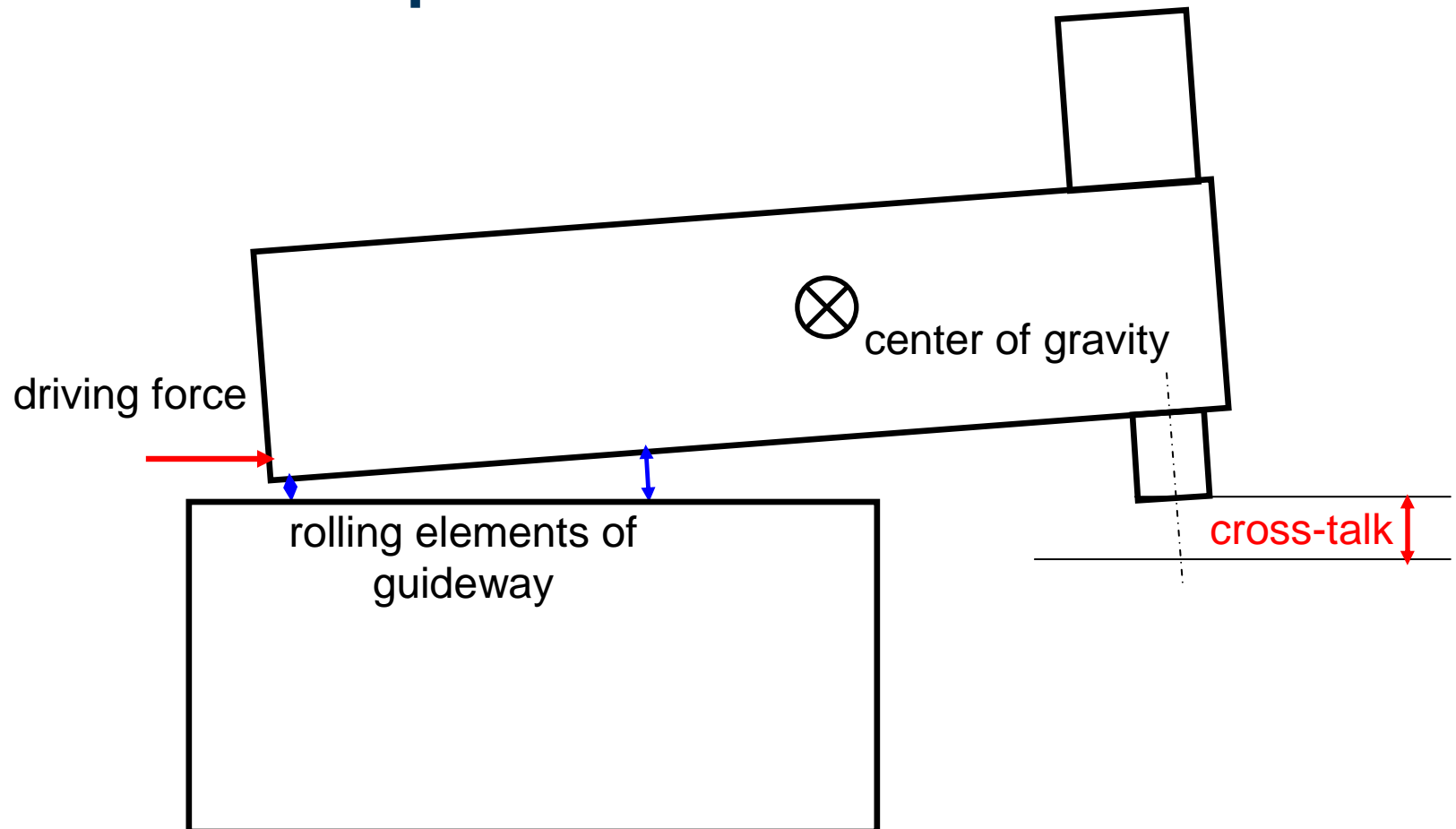
- M* moving mass of the slide
- g* guide-way system
- TCP tool centre point

“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”

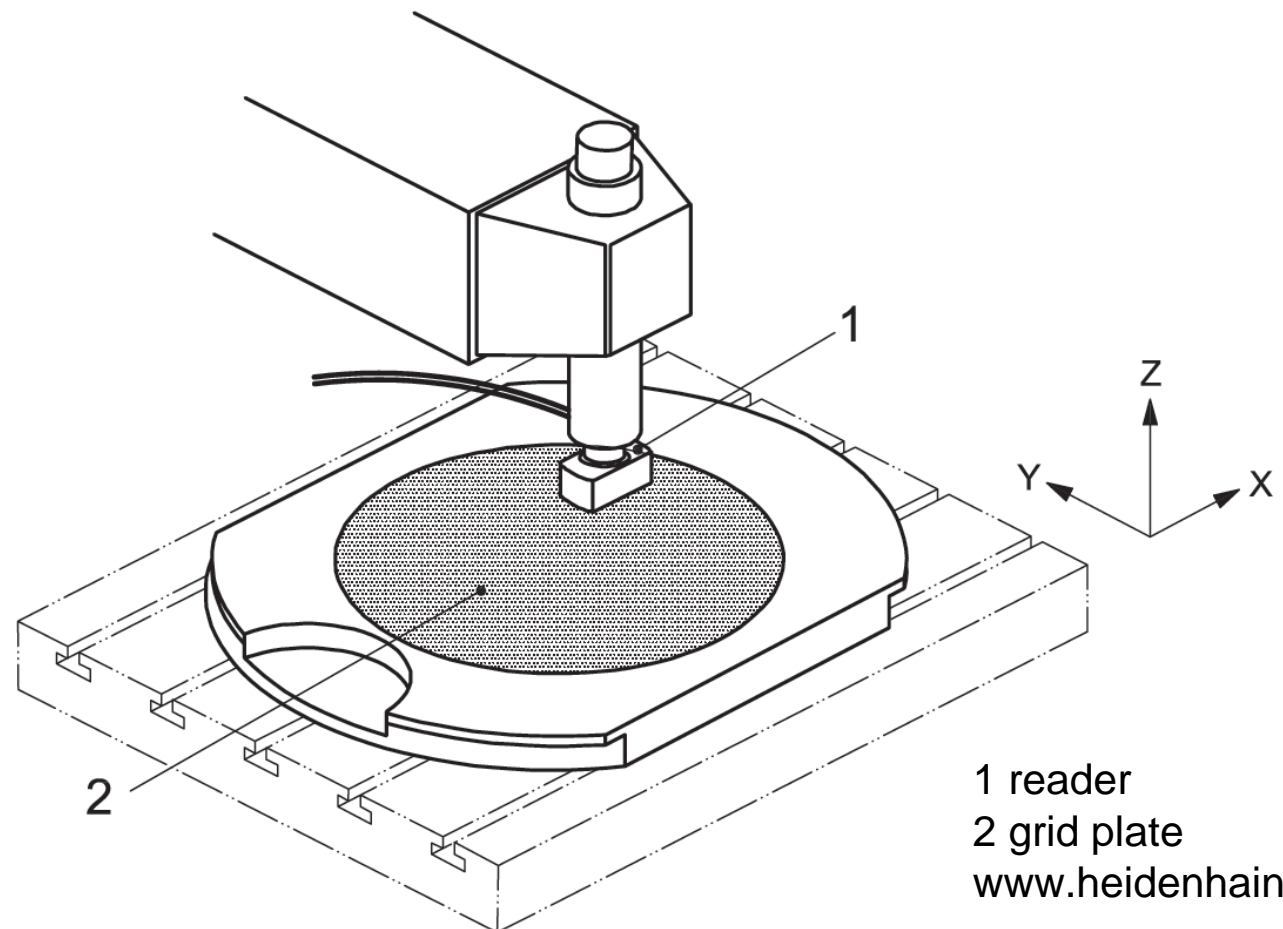
Cross-Talk Principle I

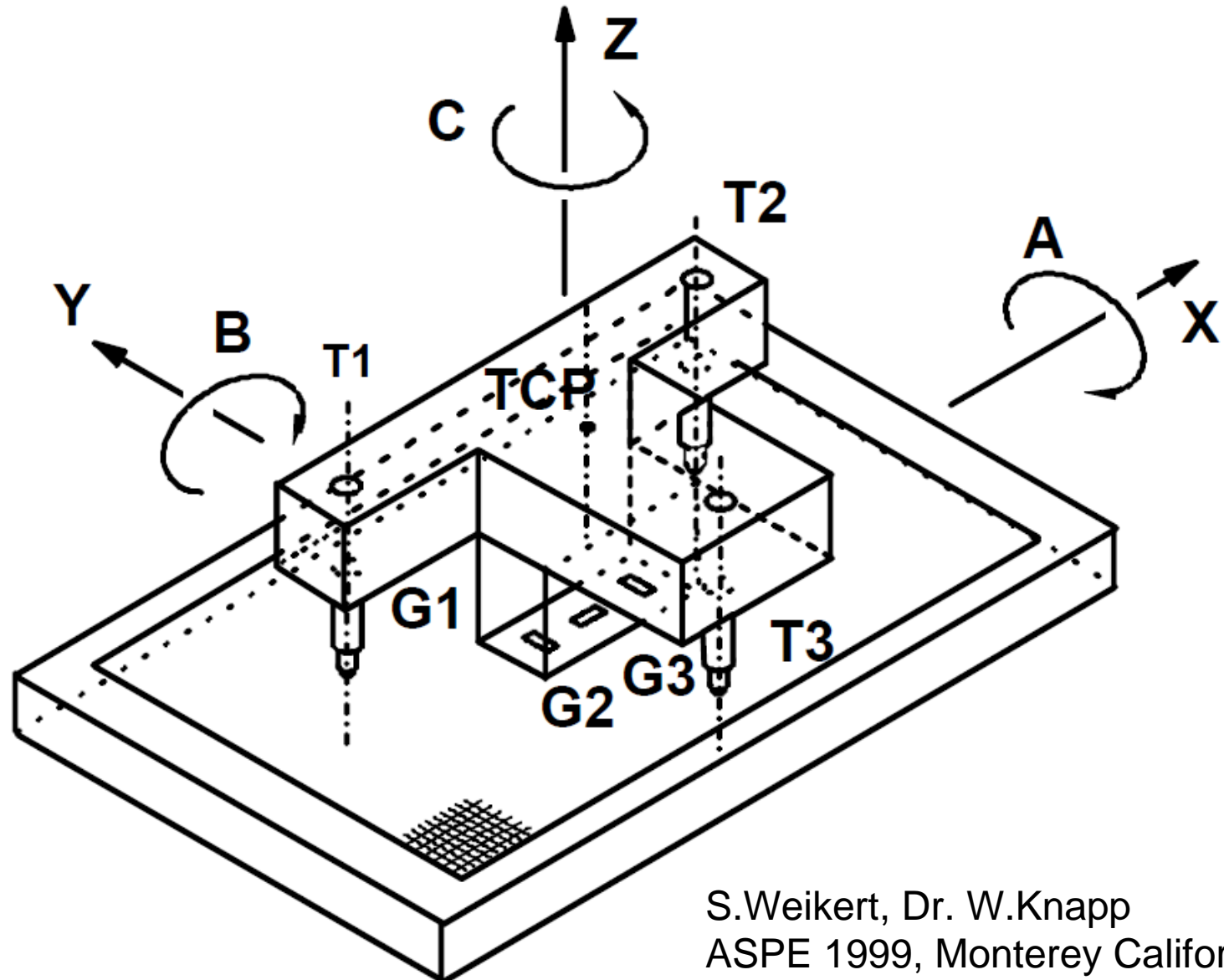


Cross-Talk Principle II



Cross-Grid



KGM+

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ASPE 1999, Monterey California