SIEMENS

Volumetric Compensation System

for SINUMERIK 840D sl

January 2009

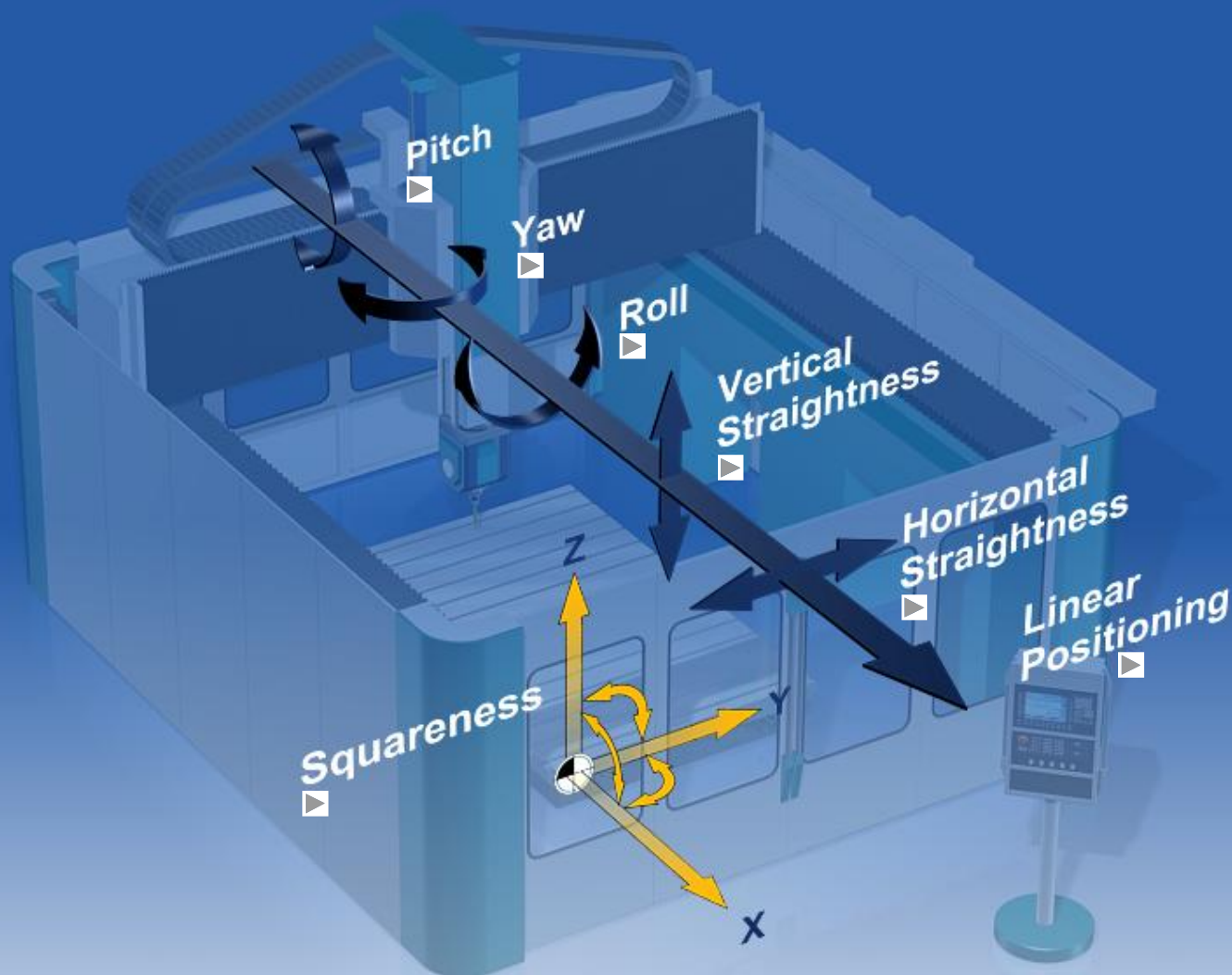## Volumetric Compensation System

§ Geometric Errors

Volumetric Compensation System
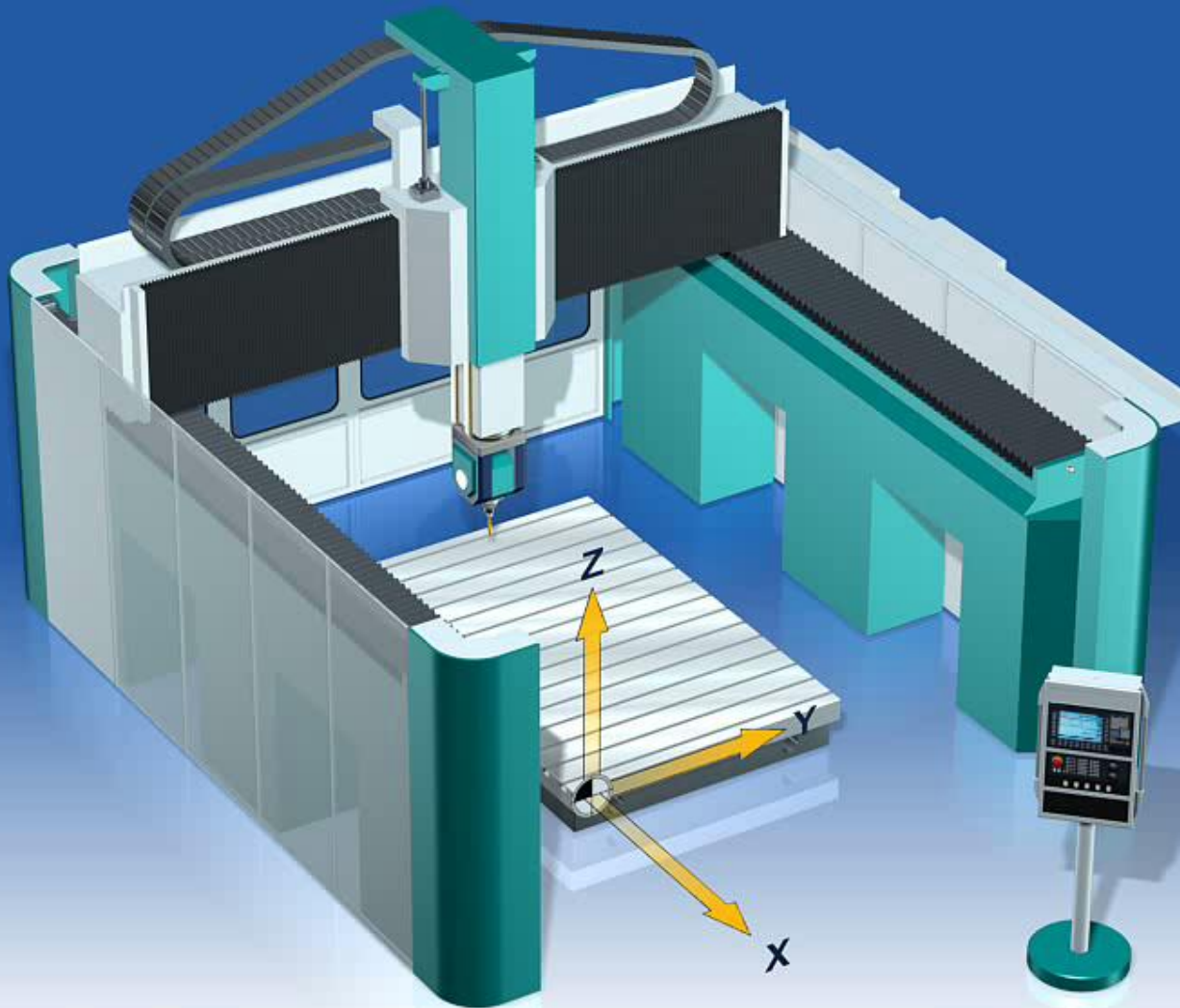# Geometric Errors in Machine Tools

Notice!

If you cannot view the videos, proceed as follows:

1. Start Windows Media Player.

2. Click **Tools**, and then **Options**.

3. Click the **Performance** tab.

4. In the **Video acceleration** section, move the slider all the way to the left to **None**.

5. Click **Apply**, and then click **OK**.
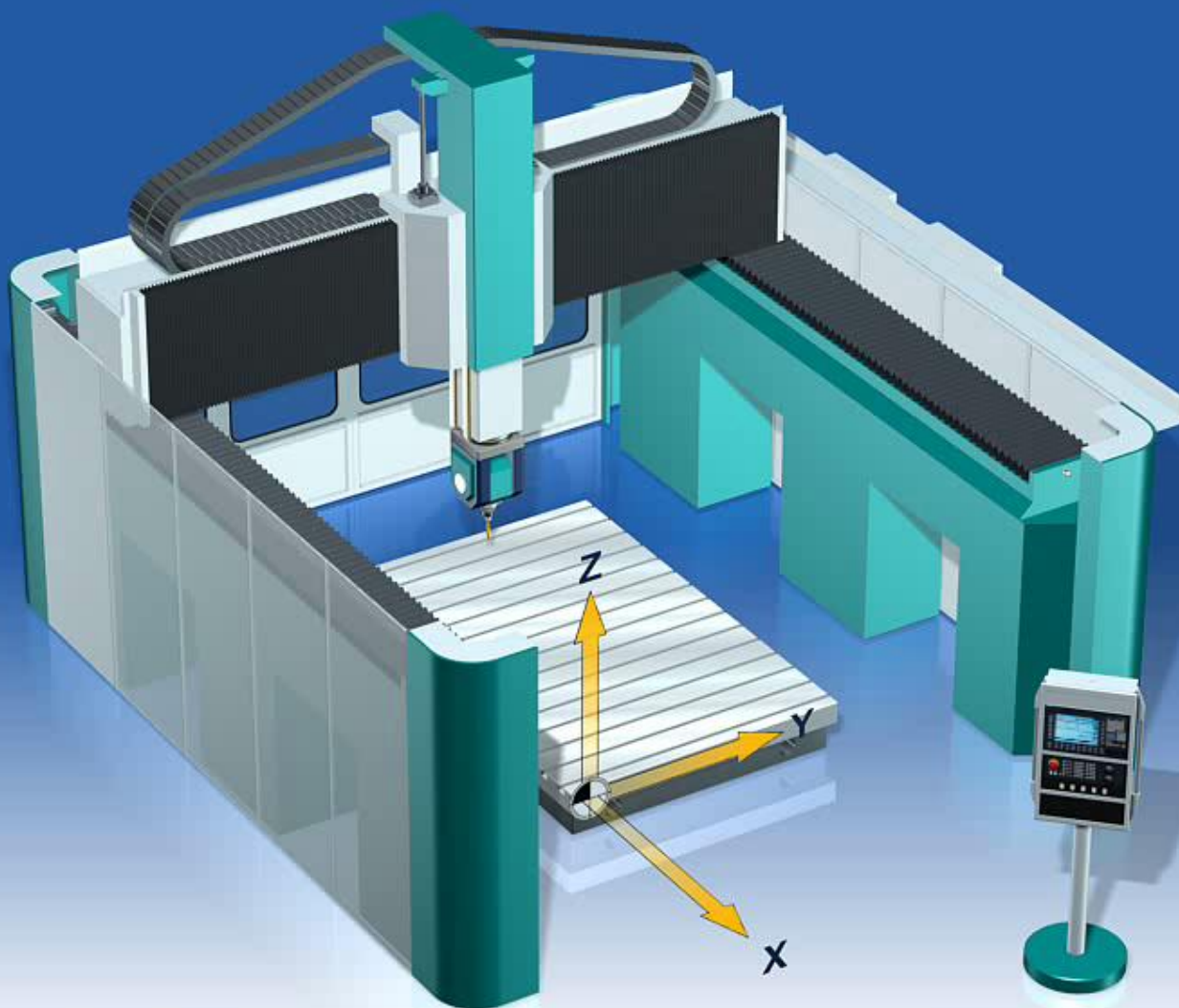
Click here to continue presentation

SINUMERIK 840D sl

PITCH

SINUMERIK 840D sl

Back to master screen

YAW

© Siemens AG 2008

SINUMERIK 840D sl

ROLL

SINUMERIK 840D sl

Back to
master screen

Industry Sector

VERTICAL STRAIGHTNESS

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SINUMERIK 840D sl

Back to
master screen

Industry Sector

09 - Subject to modifications

HORIZONTAL STRAIGHTNESS

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Back to master screen

09 - Subject to modifications

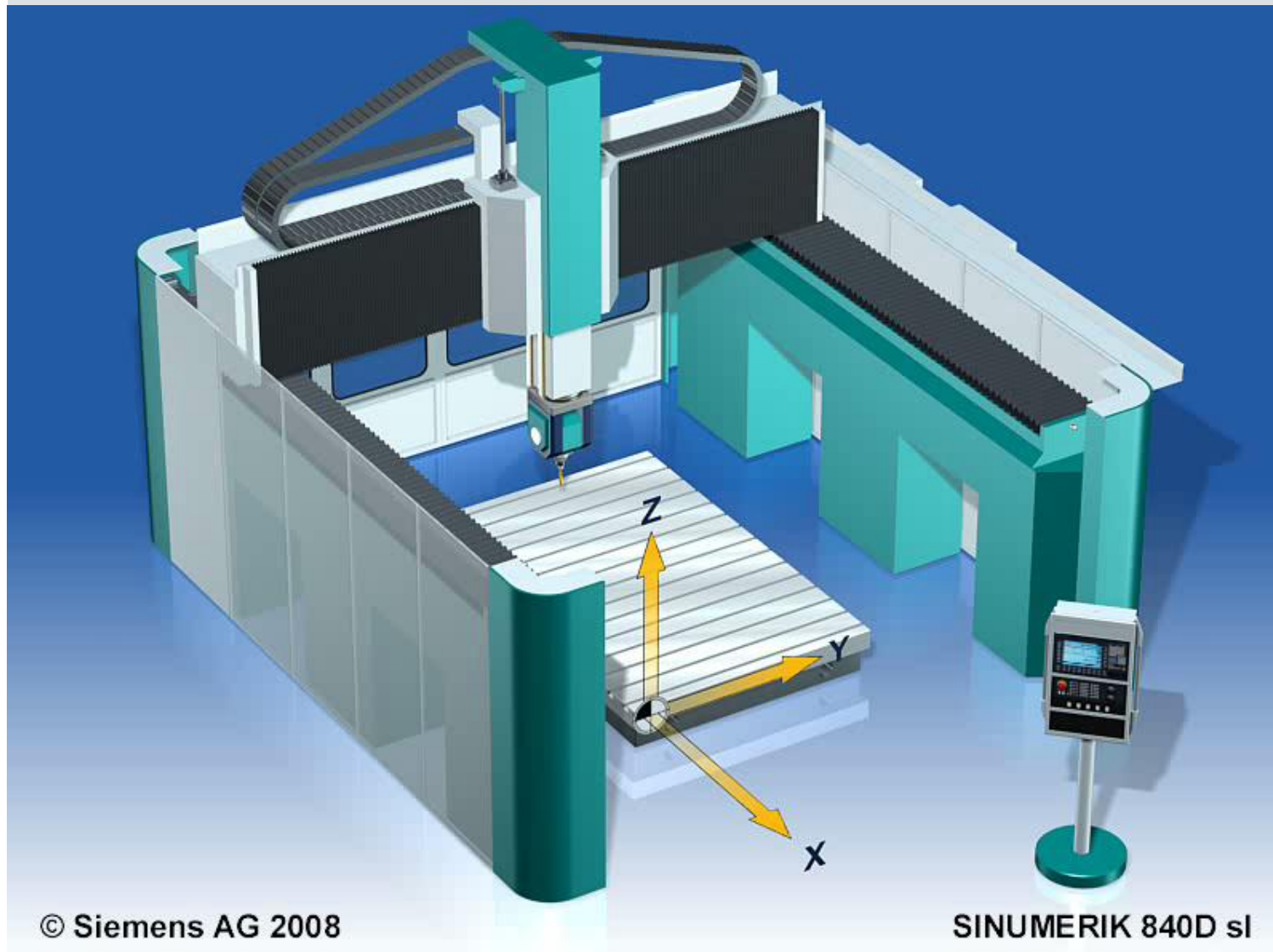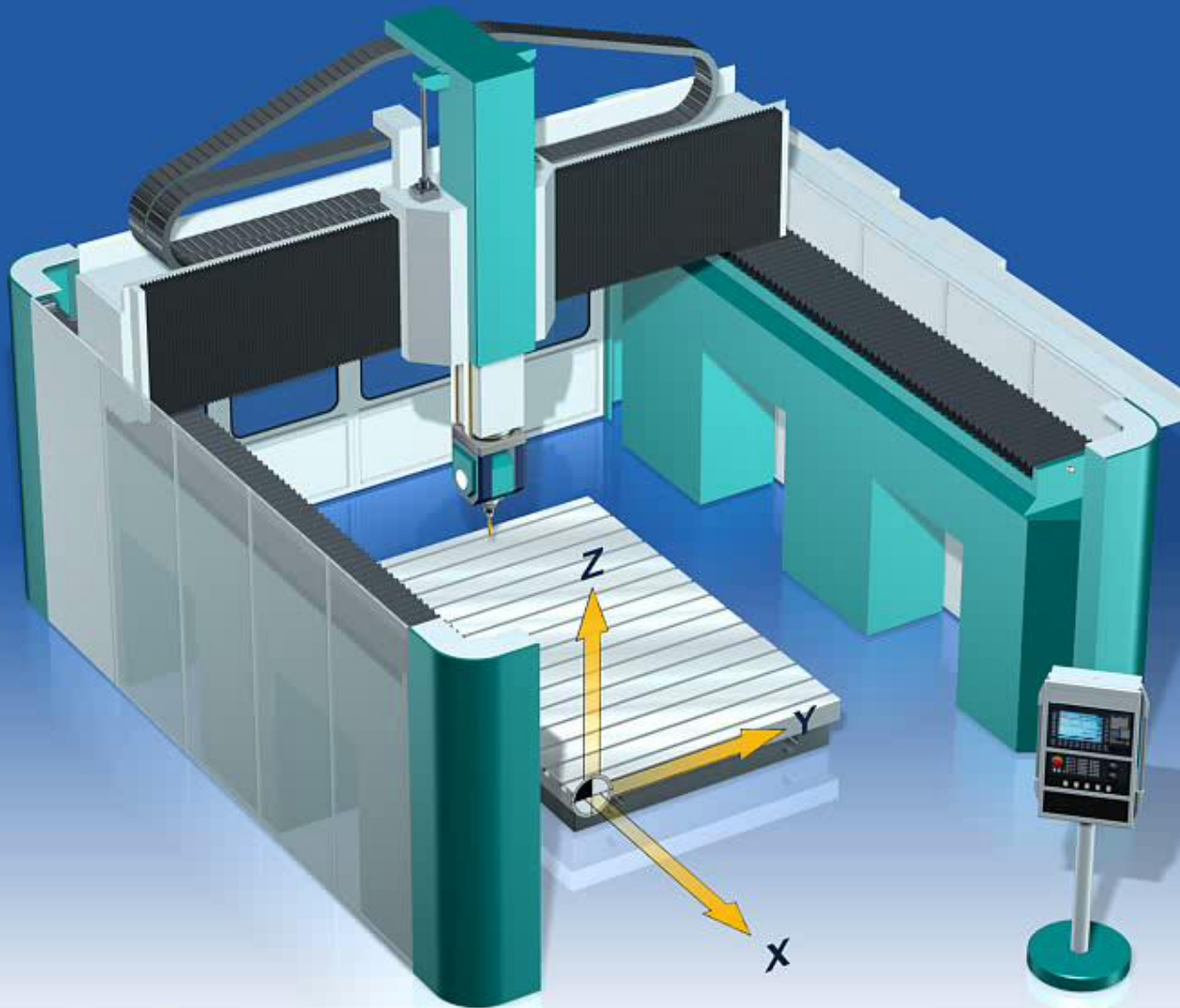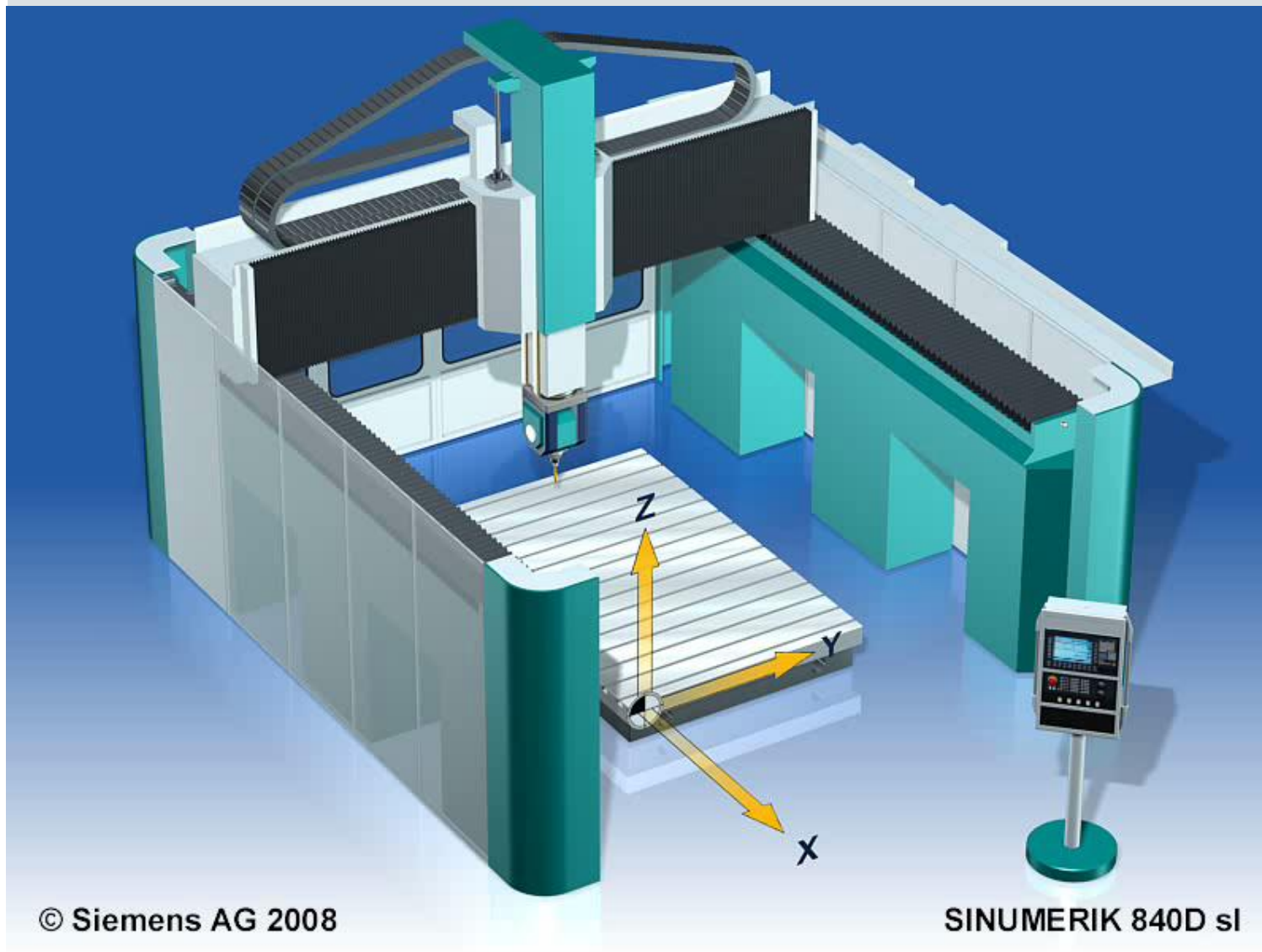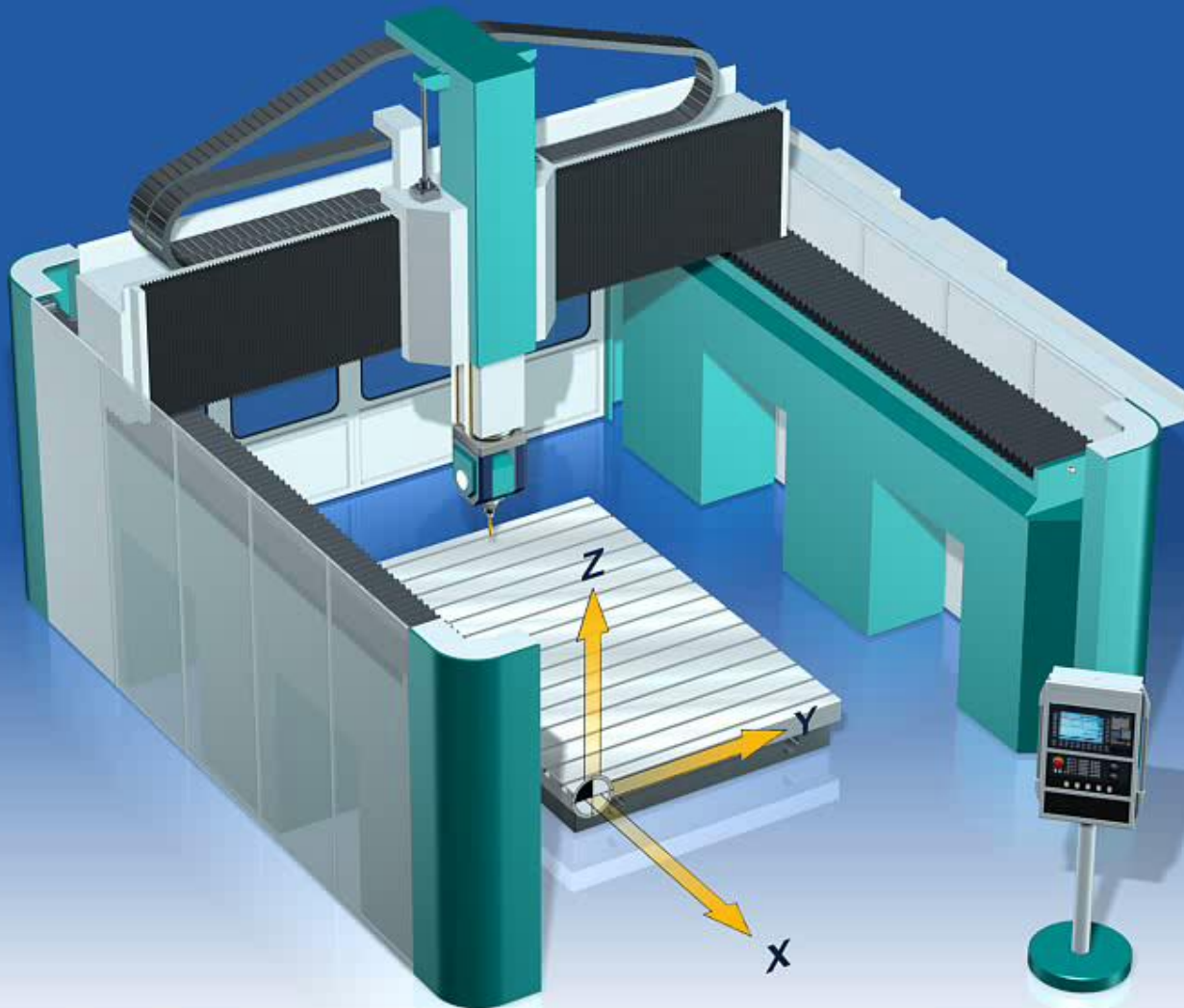# LINEAR POSITIONING

© Siemens AG 2008

SINUMERIK 840D sl

SQUARENESS
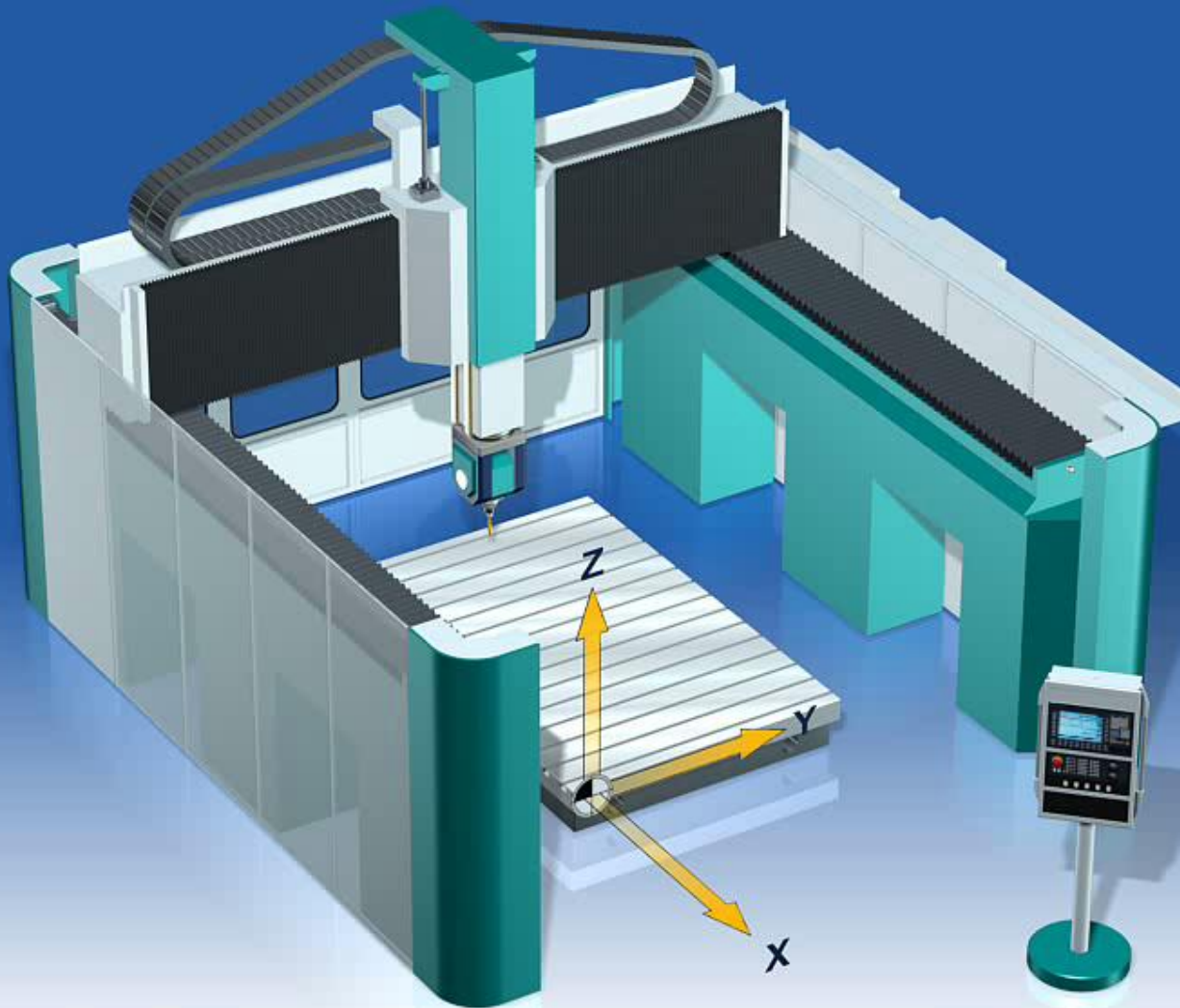
SINUMERIK 840D sl

Back to
master screen

Volumetric Compensation System

§ Market Requirements

How to achieve positioning accuracy for a machine tool

§ **Yesterday:** Mechanical adjustment of machine components and highly-developed craftsmanship

CNC based Compensation VCS
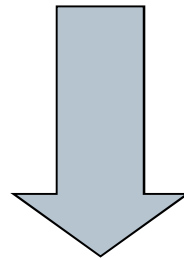
§ **Today:** Mechanical adjustment of machine components and highly-developed craftsmanship combined with CNC based VCS compensation

Yesterday "Scraping"

Today "Programming"

Manufacturing effort

TCP positioning error
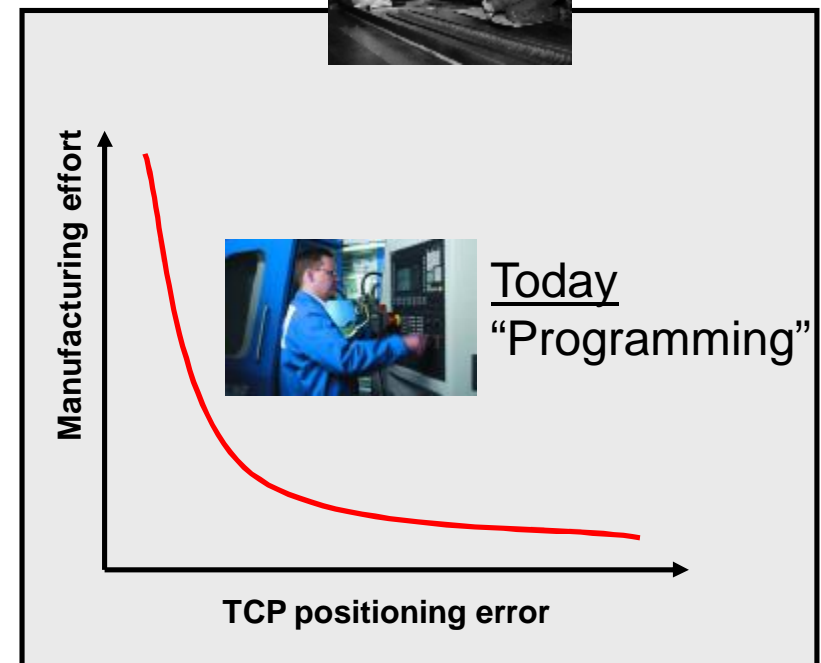
Enhance already accurate machines with CNC based VCS compensation

VCS used in Coordinate Measuring Machines (CMM) since 10 Years

Error Compensation based on the 21 parameter model

§ is proofed and state-of-the-art for coordinate measuring machines (CMM) since 10 Years

§ In CMMs the error compensation algorithms are applied offline after all measured values are taken

§ For NC-controlled machine tools the error compensation has to be done in the interpolation cycle. Thus efficient algorithms and a performand NC are needed.

§ SINUMERIK 840D sl is prepared for this task

Now available for SINUMERIK 840D sl controlled machine tools too

Efficient Laser Measuring Devices are available on the Market

XD Laser
API Automated Precision Inc
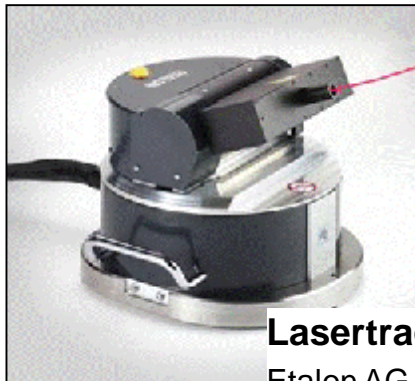
Lasertracer
Etalon AG
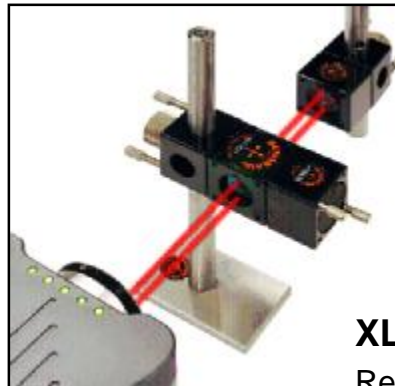
XL-80
Renishaw GmbH

Efficient industrial metrology to determine the 21 geometric errors of a 3-axis machine

§ is available and proofed since few years

§ Complete error determination can be done in one day

§ Related measuring services for machine tools are available by Renishaw, API and Etalon/AfM

§ Siemens is forced to offer compensation for the measured errors within machine tools

Measurement of geometric errors of a machine tool can be done in 1 day

Volumetric Compensation System

§ Objectives

Compensate for the Geometric Errors in a Machine Tool
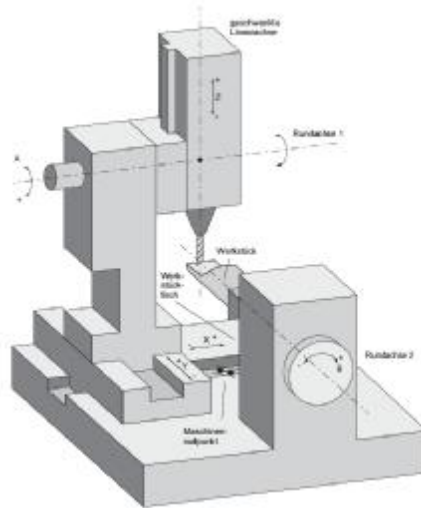
Note:
geometric errors may vary with temperature
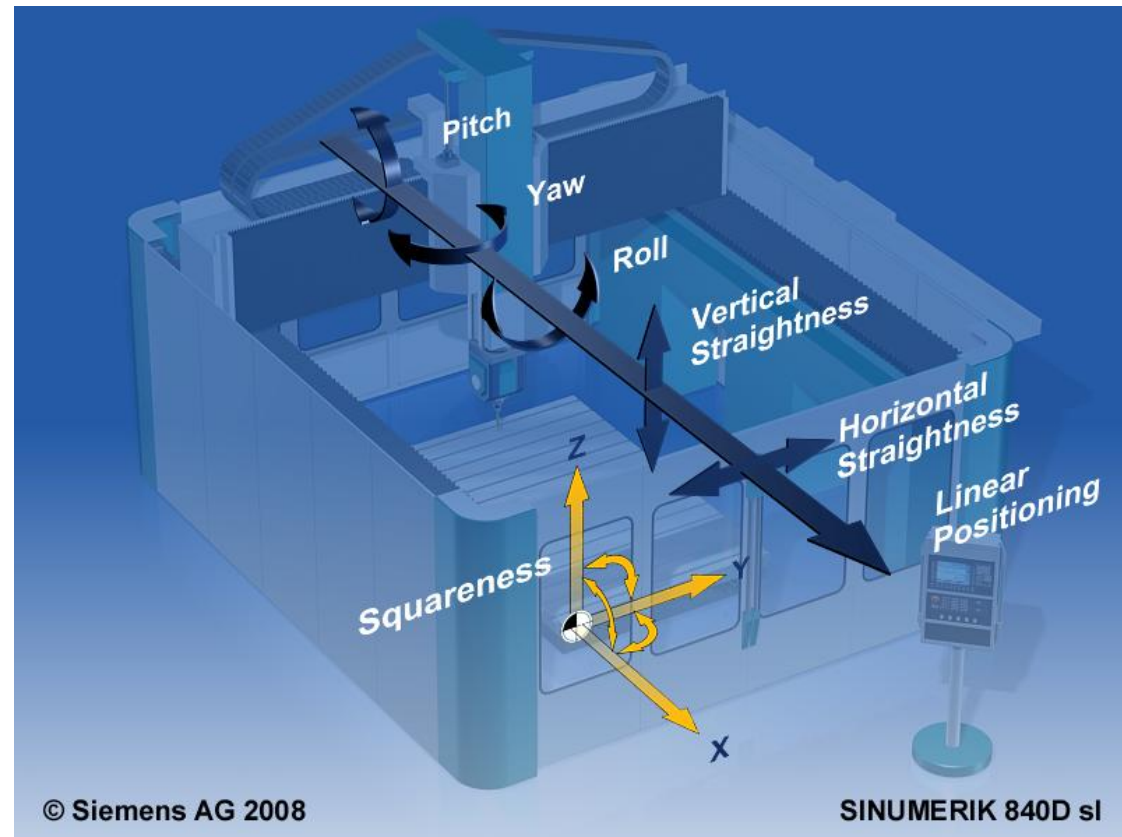
Six errors for each linear axis plus three squareness errors
(3-axes machine tool: 6 + 6 + 6 + 3 = 21 possible errors)

Geometric Errors in a Machine Tool
Positioning Error and Straightness Errors
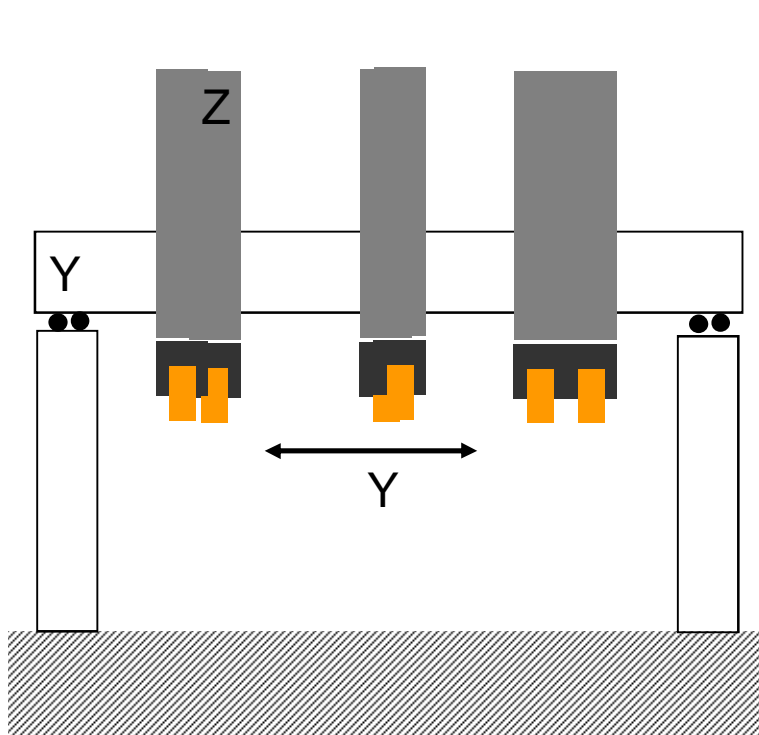
Positioning Error
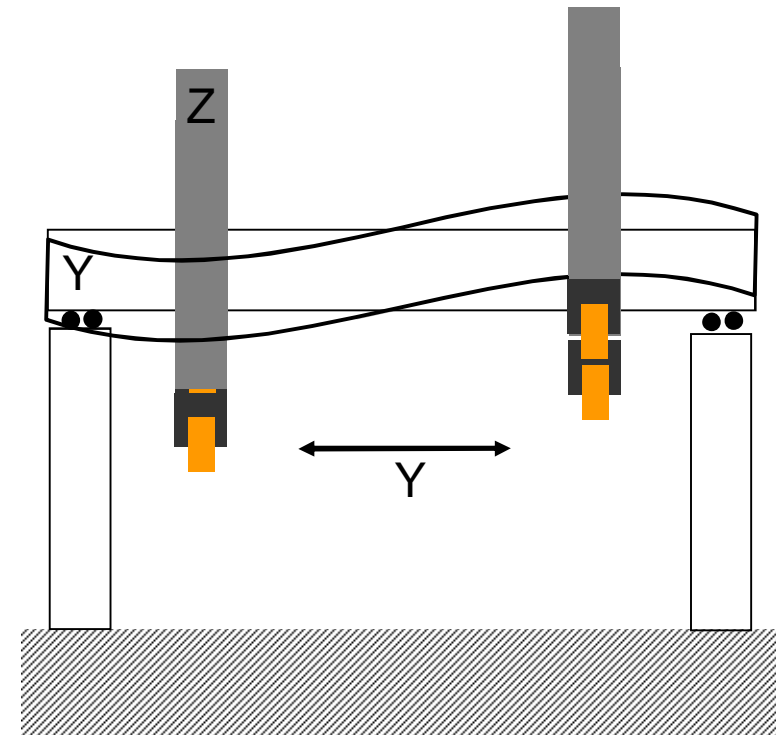
Straightness Error

Different error sources will be overlaped at TCP

Geometric Errors in a Machine Tool
Rotational Errors: Roll, Pitch and Yaw

Pitch Angle

Roll Angle

Yaw Angle
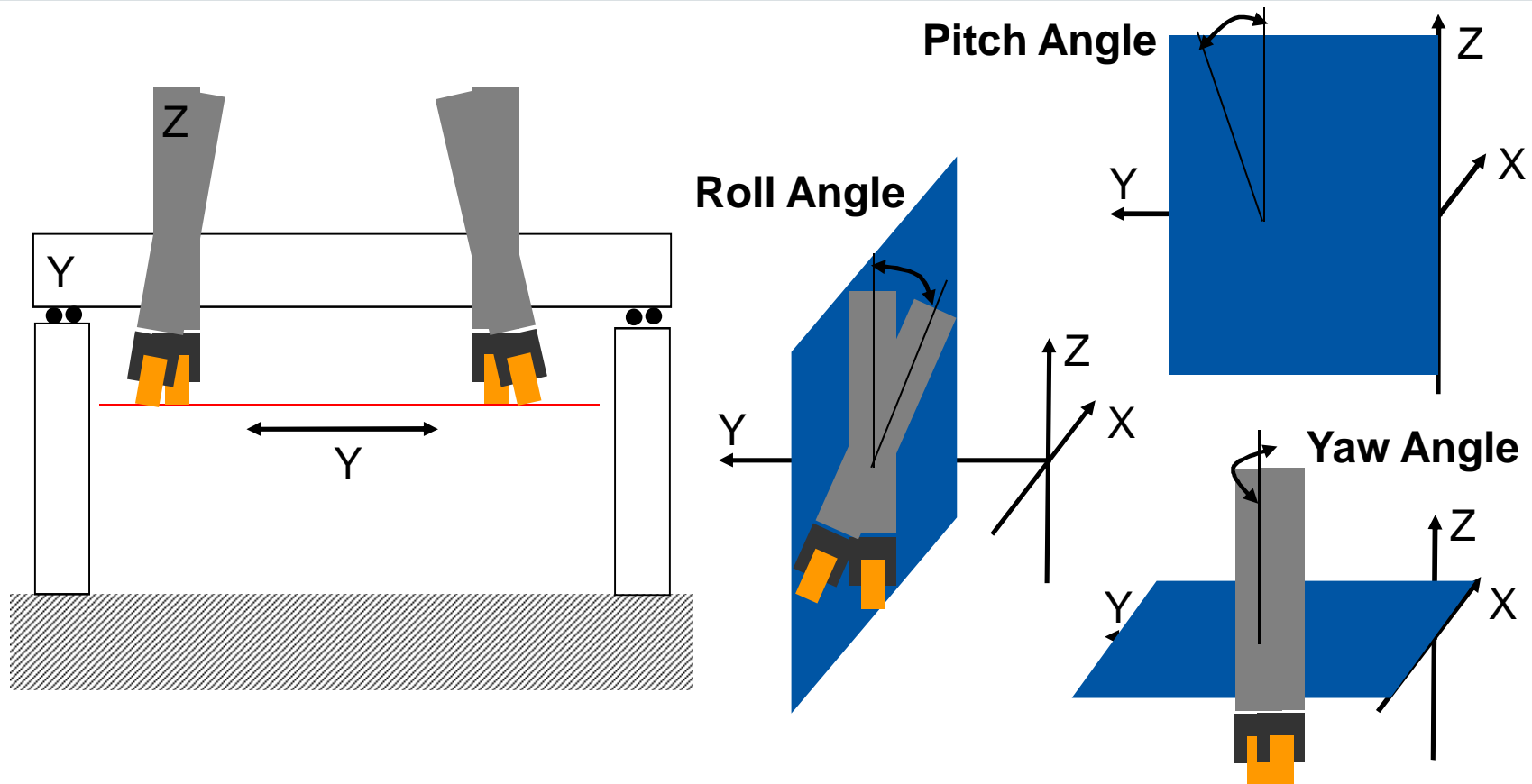
Rotational errors can cause rather big displacements for long arms

Volumetric Compensation System

§ Volumetric Error

The 21 Geometric Errors of a 3-Axes Machine Tool result in a Volumetric Error at the TCP

Resulting Volumetric Error

Programmed tool orientation

$$\begin{pmatrix} A\ 0 \\ B\ 0 \end{pmatrix}$$

Real tool orientation

$$\begin{pmatrix} A\ 0.08 \\ B\ -0.1 \end{pmatrix}$$

Volumetric Error

Programmed tool position

$$\begin{pmatrix} X\ \ 0 \\ Y10 \\ Z\ \ 7 \end{pmatrix}$$

Real tool position

$$\begin{pmatrix} X\ \ 0.03 \\ Y10.17 \\ Z\ \ 6.95 \end{pmatrix}$$

Z

7

10

Y

X
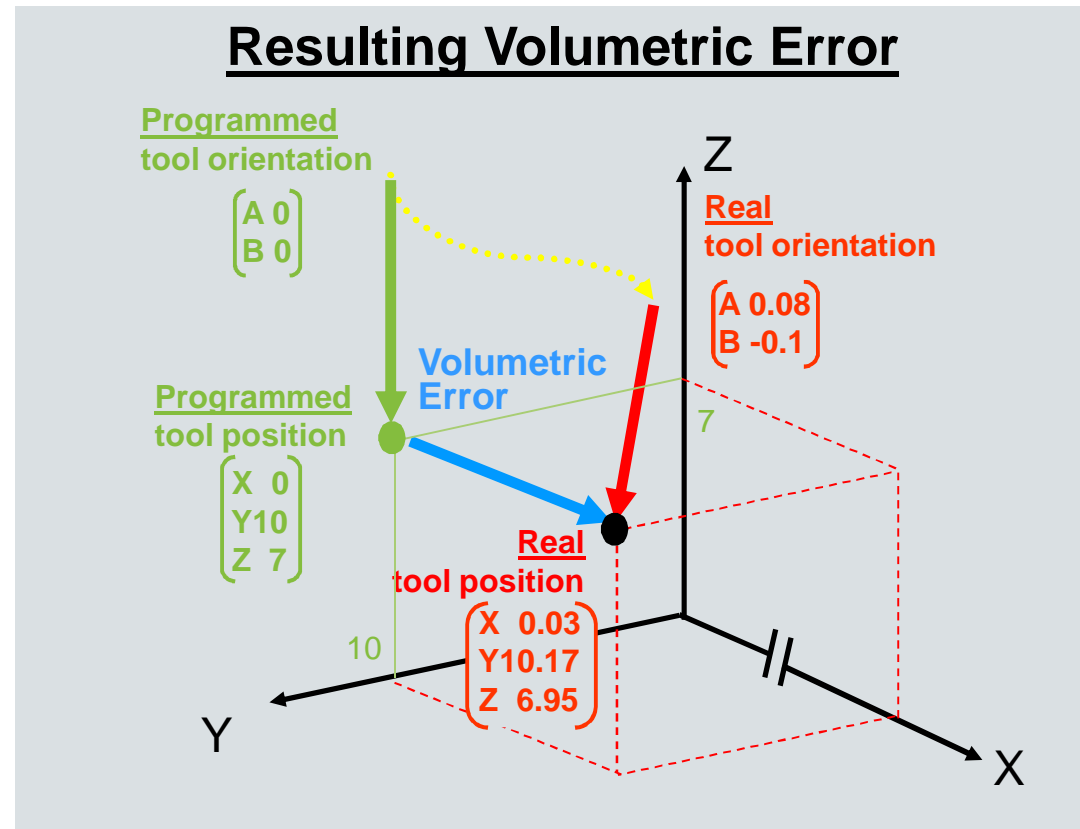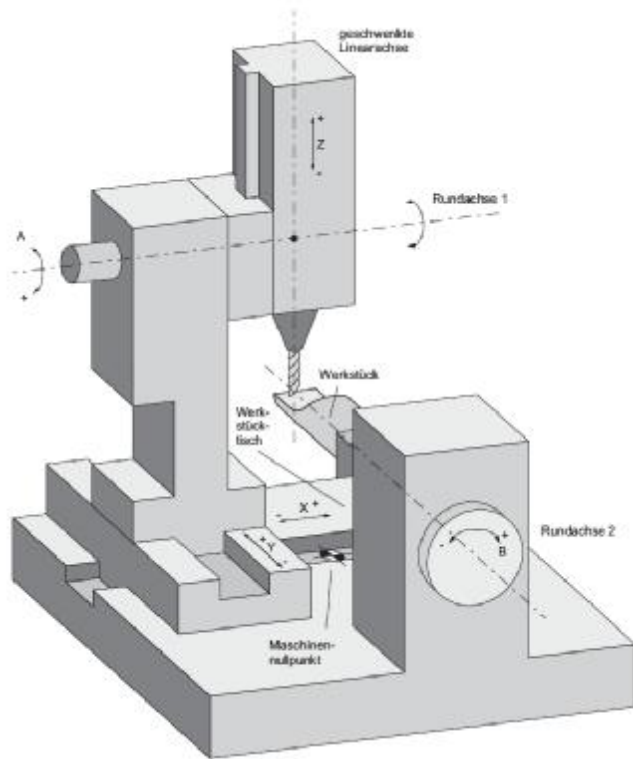
Note: There is displacement of the tool both in <u>position and orientation</u>

Volumetric Error in the Workspace of a 3-Axes Machine…

Vector of Volumetric Error
(as shown in previous slide)
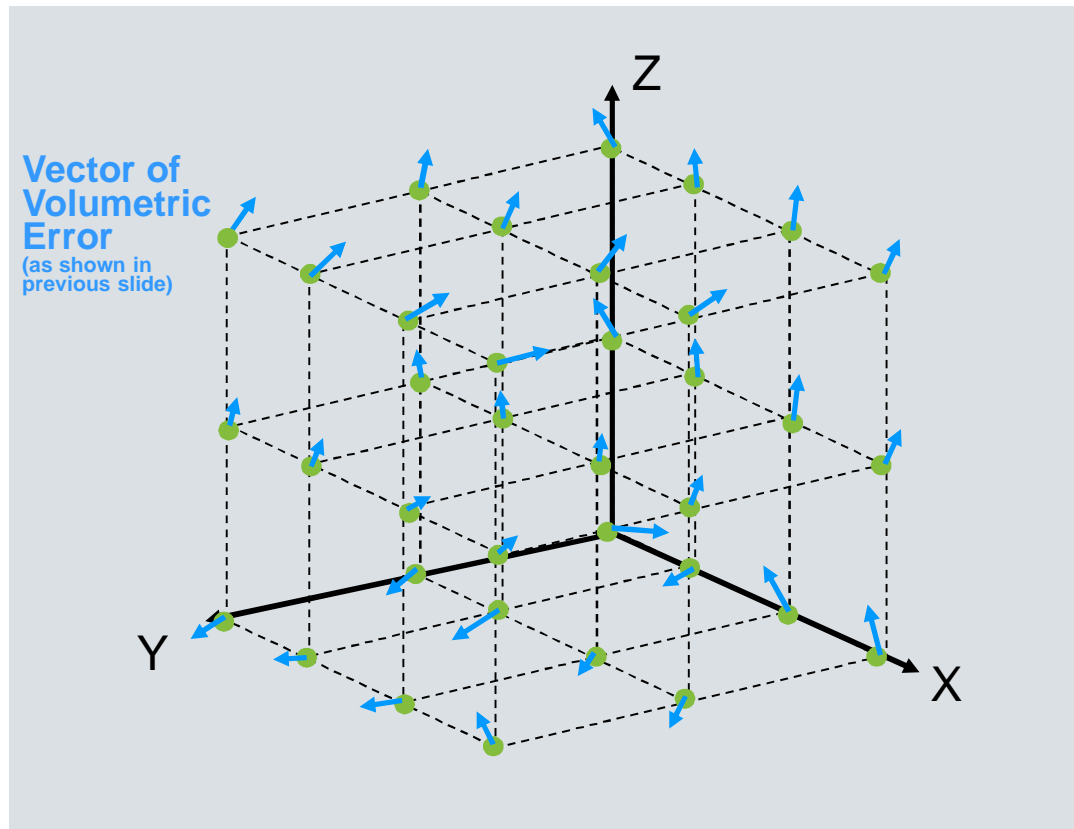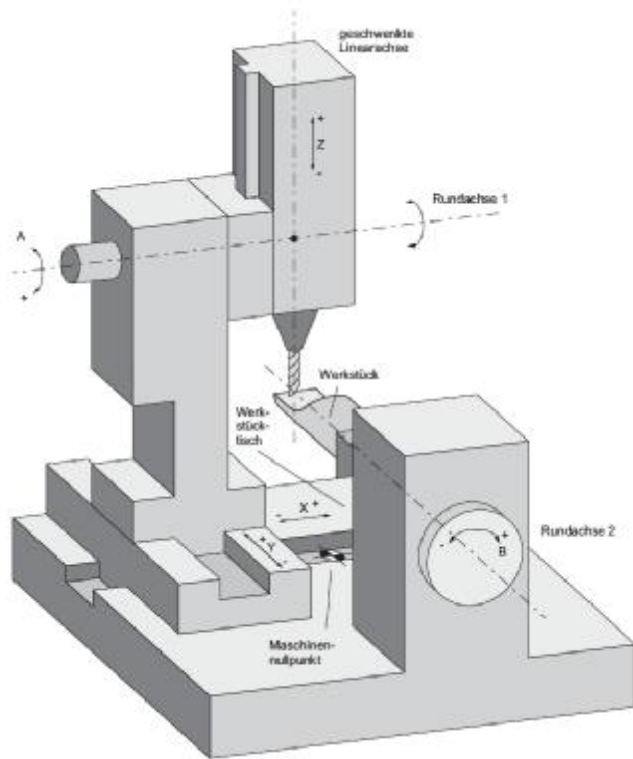
…is dependent on the individual axes position

Volumetric Compensation System

§ Priority Market

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Market Segment and Priority Applications

Example machine tool

Portal milling machine
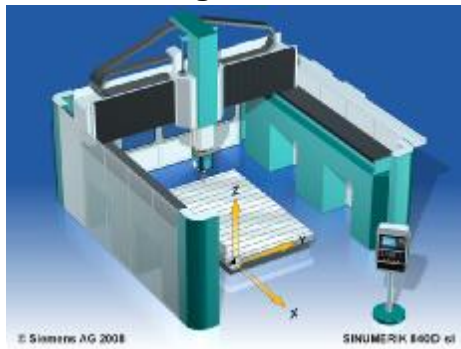
VCS market segment

Aerospace

Requirements:

§ **High machining accuracy requested**
§ **Stable temperature conditions**

Example application

Aerospace

Machining Tasks:

§ **Structural parts**
§ **Drilling of rivet holes**
§ **Engine parts**
§ **etc.**
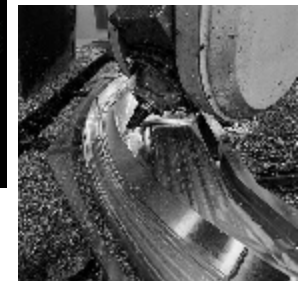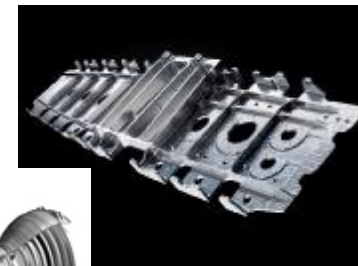
VCS will make accurate portal milling machines even more accurate

Volumetric Compensation System

Industry Sector

2009-01-22   Slide 23/65

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Requirements from the aerospace sector exemplified for the JSF program

Required manufacturing tolerance in the JSF program:
0.05 Millimeter = 50 Micrometer ~ 0.002 Inch

The Joint Strike Fighter (JSF) is a multi-role fighter optimized for the air-to-ground role, designed to affordably meet the needs of the Air Force, Navy and Marine Corps

2009-01-22

Receive an impression of 0.002 Inch

Thickness of a human hair

Thickness of a may beetles wing

Is it possible to reach 0.002 inch accuracy at the workpiece solely based on VCS for Sinumerik 840D sl?
No!! Process know-how and process control in the machining system is needed.

Level of Difficulty

3

Machining system
(e.g. DST and others)
• workpiece temperature
• workpiece twisting
• ambient temperature
• machine heating
• circulation of air
• treatment of chips

Characteristics of the machining system
Process control
Long-term accuracy

2

OEM portion
(e.g. DST and others)
• best quality in machine construction
• Linearity of axis
• repeatability

Machine characteristics

1

Siemens portion
• VCS-algorithm
• Interface

CNC function

CNC-based compensation
VCS

Calibration Know-How
(e.g. by OEM or by Solution Partners)

Calibration methodology

Source: Dörries Scharmann Technologie GmbH

Industry Sector

olumetric Comp

Volumetric Compensation System

§Mode of Action

Compensation of the Tool Center Point (TCP) and Orientation Error (5-axis capability of VCS)

Machine without Errors

Real Machine with Errors

No Compensation applied
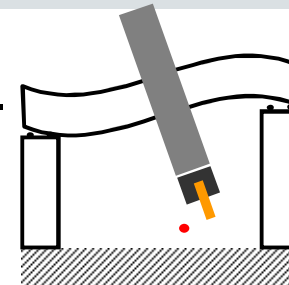
VCS Compensation applied
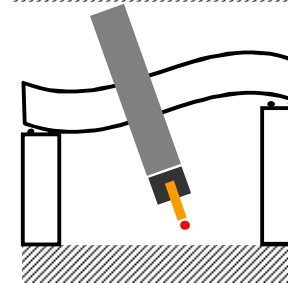
VCS and Orientation Compensation applied
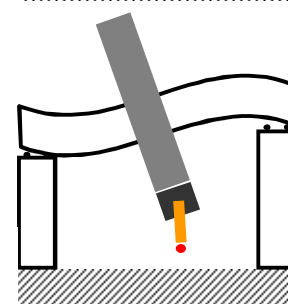
5-axes Cartesian machine tools

Compensation of the Orientation Error in 5-Axes Machines

Linear Axes Errors

Input

VCS

Rotary Axes Errors
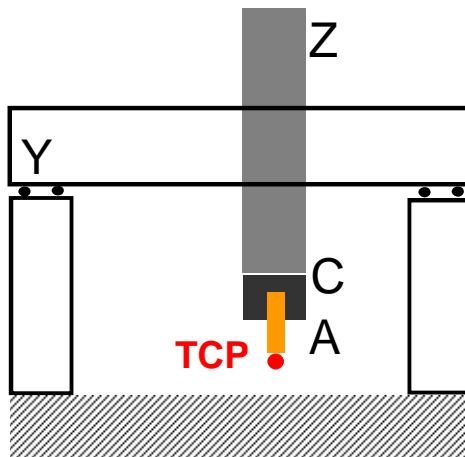
Input

CNC based
Compensation
VCS
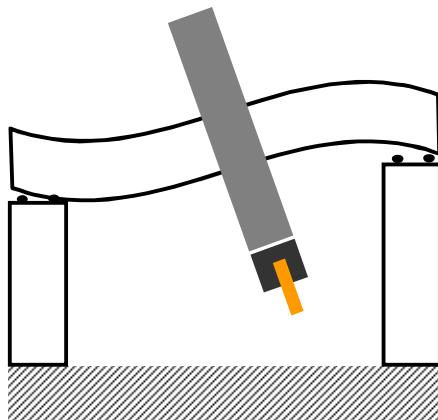
TRAORI
+
LEC
for Rotaries

Compensation of
Tool Center Point (TCP) position error and **Tool orientation** error

VCS and TRAORI must be switched on to enable interaction of VCS and TRAORI
For transformation types 24 and 40 only

Position of the TCP and orientation of the tool will be compensated

Complete Compensation for SINUMERIK-controlled Machine Tools

21 Geometric Errors   +   SINUMERIK 840D sl   =   Higher Accuracy

Errors to be measured by machine tool builder

```
VCS File Format
[XTX]
AXIS_LENGTH [mm]        = 1800
LINEAR_CORRECTION [mm/m] = 0.0
INTERVAL [mm]           = 25
DEVIATION [mm]
GRIDPOINTS = {
-75.0 -0.012193623479
-50.0 0.000000000000
-25.0 0.012193623479
0.0 0.018671152358
25.0 0.016196874983
50.0 0.011456611499
75.0 0.011674987082
```

VCS to be activated by machine tool builder

CNC based
Compensation
VCS

Benfit for machine tool user
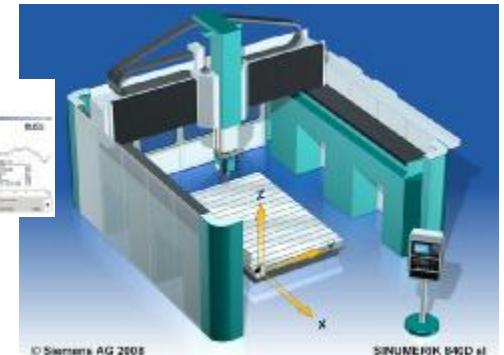
SINUMERIK 840D sl

Only Precondition
VCS Compile Cycle installed on 840D sl

… by VCS Compile Cycle for SINUMERIK 840D solution line

Volumetric Compensation System

§ Interpolation of 2 VCS Files

VCS
Interpolation of 2 VCS Files - Example

VCS can access up to 4 compensation files per channel at a time. VCS provides means to interpolate between two of these compensation files.

Thus VCS can react on changes in the machine geometry dependent on temperature or workpiece weight. To do so VCS requires the actual parameter, e.g. the temperature or weight

Siemens AG 2008   SINUMERIK
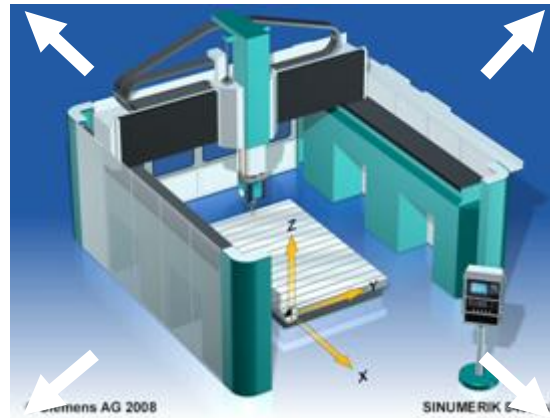
Temperature behaviour of steel

10 micrometer length growth
- per 1 meter steel and
- per 1 degree temperature change

Actual temperature: 23.7 °C

VCS-File 1 20°C	VCS-File 2 25°C
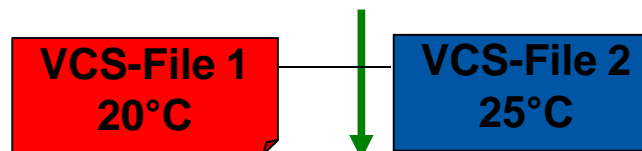
Interpolated VCS compensation

VCS
Interpolation of 2 VCS Files - Example

Challenge:

Geometric Errors of X1 and X2 are different

1.
VCS File

$\Delta x1, \Delta y1, \Delta z1$

2.
VCS File

$\Delta x2, \Delta y2, \Delta z2$

$a=Y/Ymax$ $1-a$

$$\Delta x= (1-a)\Delta x1+a\Delta x2$$
$$\Delta y= (1-a)\Delta y1+a\Delta y2$$
$$\Delta z= (1-a)\Delta z1+a\Delta z2$$

Actual Compensation Value
Dx, Dy, Dz
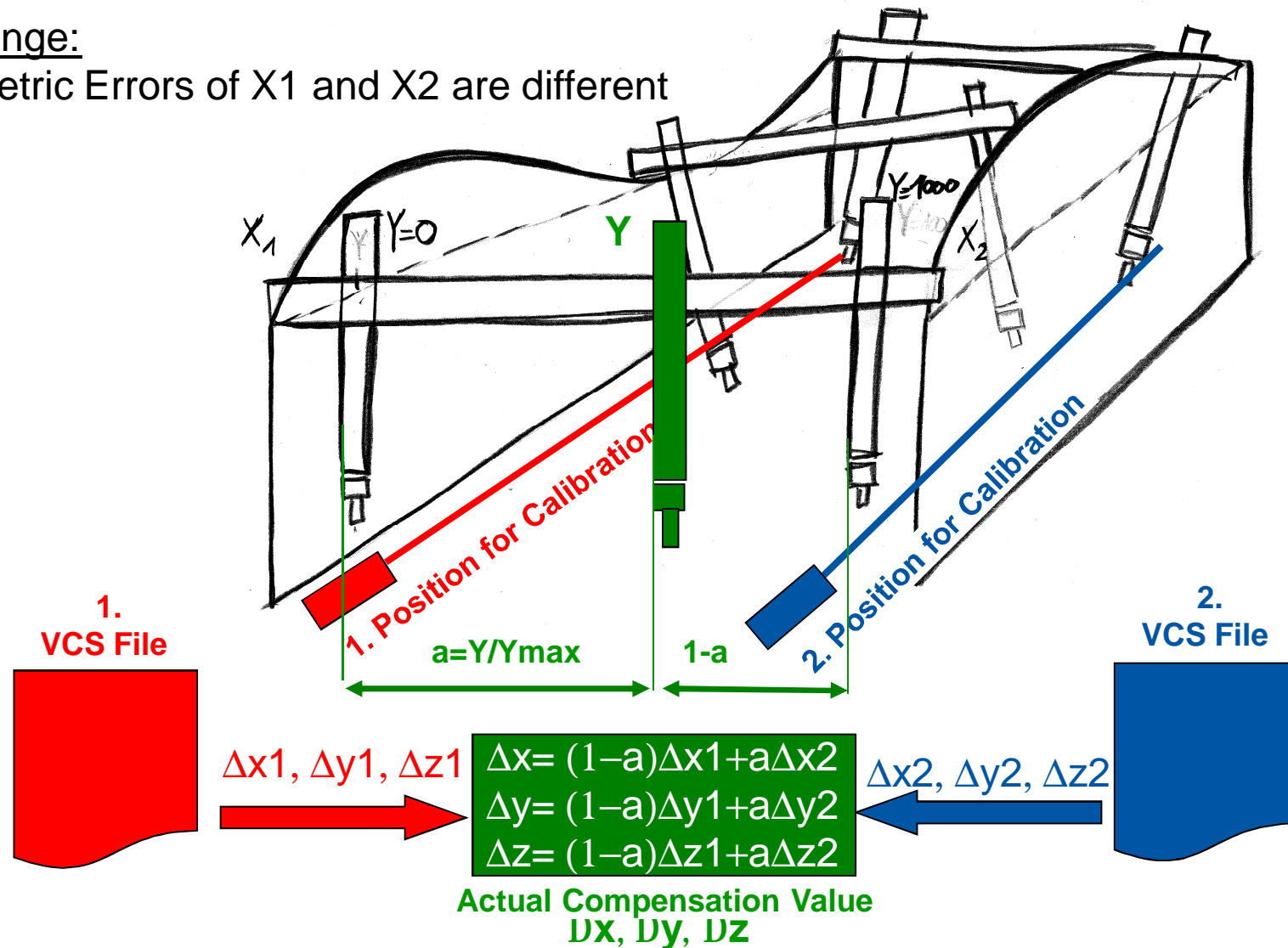
Volumetric Compensation System

§ Market Access

Responsibilities of the Partners – Typical workflow

Siemens
VCS Compile Cycle
Sinumerik sl

Siemens sells the software options and documentation needed to install the volumetric compensation system on SINUMERIK 840D solution line (Calibration service not included)

Sales of VCS Software

Machine Tool Builder
VCS Integration
VCS Installation
VCS Calibration

Calibration service on request

Calibration service provider

API

Renishaw

AfM

Machine equipped with VCS feature

Calibration service on request

End Customer

VCS sales only to Machine tool builders
Calibration service by Solution Partners

Volumetric Compensation System
Solution Partners for Machine Calibration

XL-80
Renishaw GmbH

XD Laser
API Automated Precision Inc

Lasertracer
Etalon AG
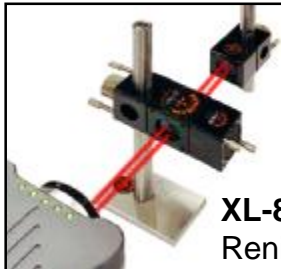
Renishaw GmbH

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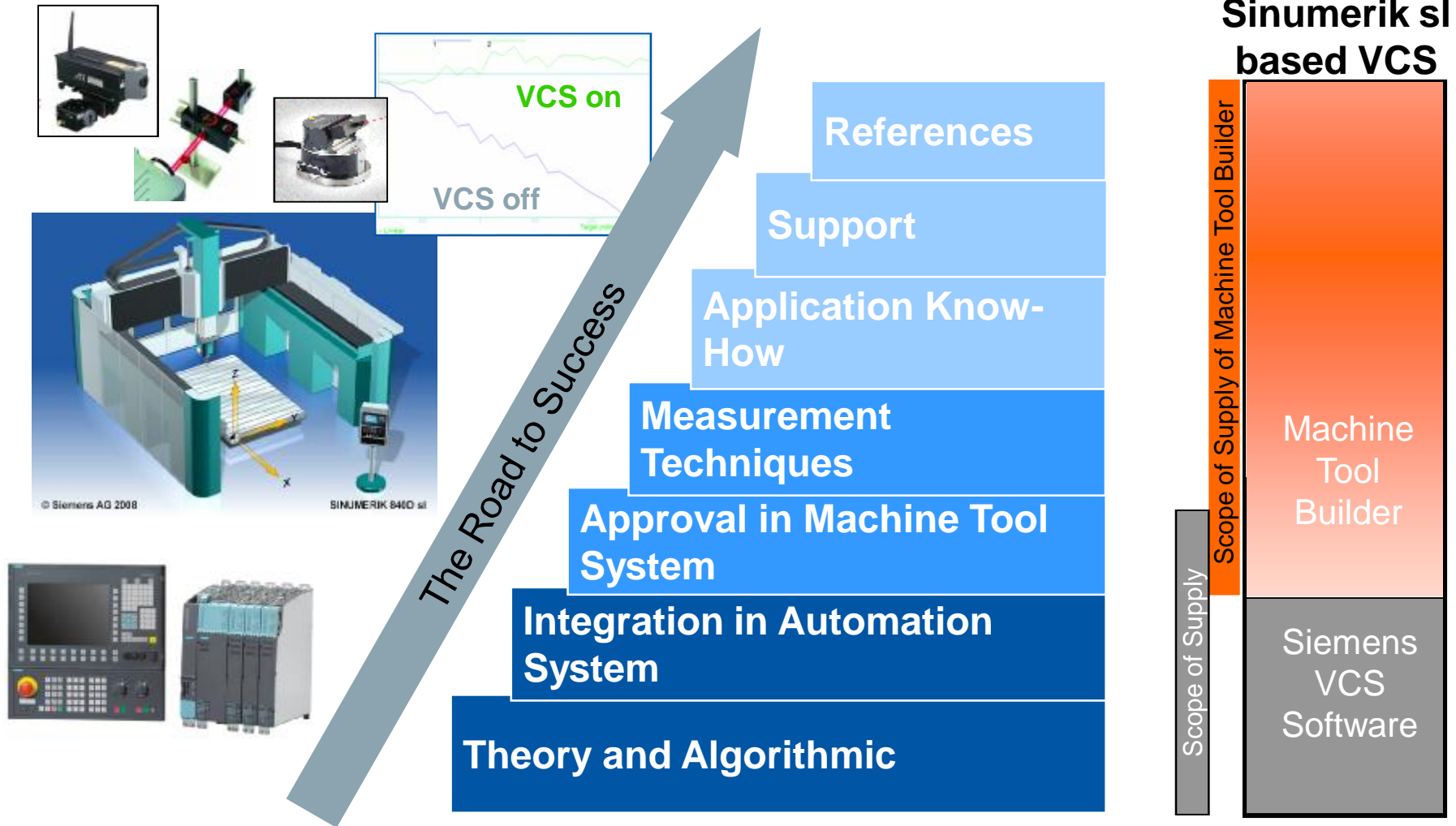E-Mail: w.meyer@afm-tec.de
web: www.afm-tec.de

Etalon AG
Dr.-Ing. Heinrich Iven Schwenke
Vorstand / CTO
Tel: +49.(0)531.5921970
Fax: +49.(0)531.5921979
heinrich.schwenke@etalon-ag.com
www.etalon-ag.com

Calibration service commissioned by machine tool builders or endcustomers

Volumetric Compensation System

§ Set-Up Process

VCS Experience Chain – step by step

VCS on

VCS off

Sinumerik sl based VCS

The Road to Success

References

Support

Application Know-How

Measurement Techniques

Approval in Machine Tool System

Integration in Automation System

Theory and Algorithmic

Scope of Supply of Machine Tool Builder

Scope of Supply

Machine Tool Builder

Siemens VCS Software

Volumetric Compensation System

Industry Sector

SIEMENS

Scope of Supply of Machine Tool Builders (supported by Solution Partners)

Step 1

Define measuring device (Examples only!)

ML10
Source: Renishaw
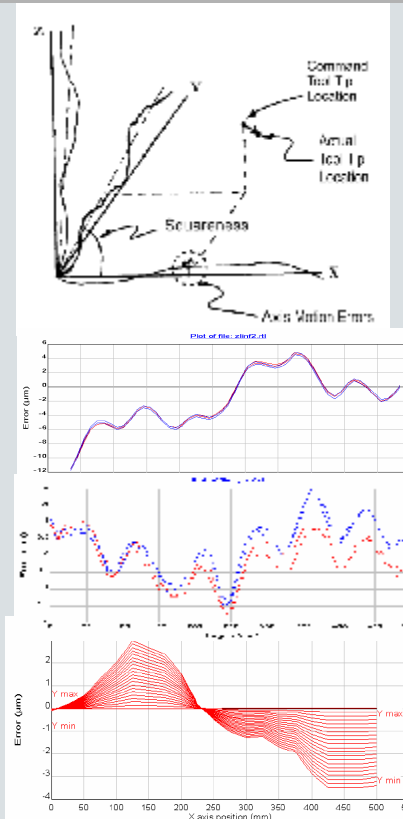
XD Laser
Source: API

Lasertracer
Source: Etalon

Step 2

Machine Geometric Error Measurement

Measurement of the error tables for an individual machine. Generation of Compensation tables

Step 3

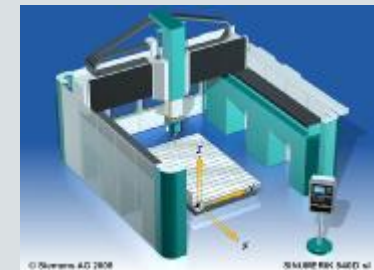**Compensation NC-Part**

Download of the VCS compensation table in NC:

Install
VCS CC

Verification of the VCS Compensation by re-measuring

Interface to NC: Compensation table in VCS-Format

Measuring devices, machine measurement, compensation

Volumetric Compensation System

Industry Sector

SIEMENS
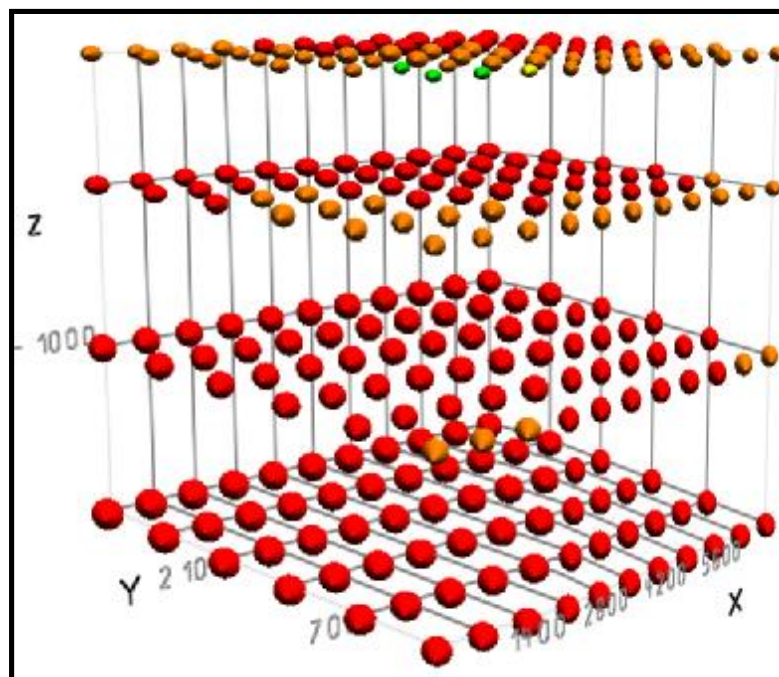
Volumetric Compensation System

§ Results

Volumetric Compensation System

§ More than 10 machine tools compensated successful so far

§ Summary of reference projects available on request

Volumetric Compensation System
Result: Increased Volumetric Accuracy of a Portal Milling Machine
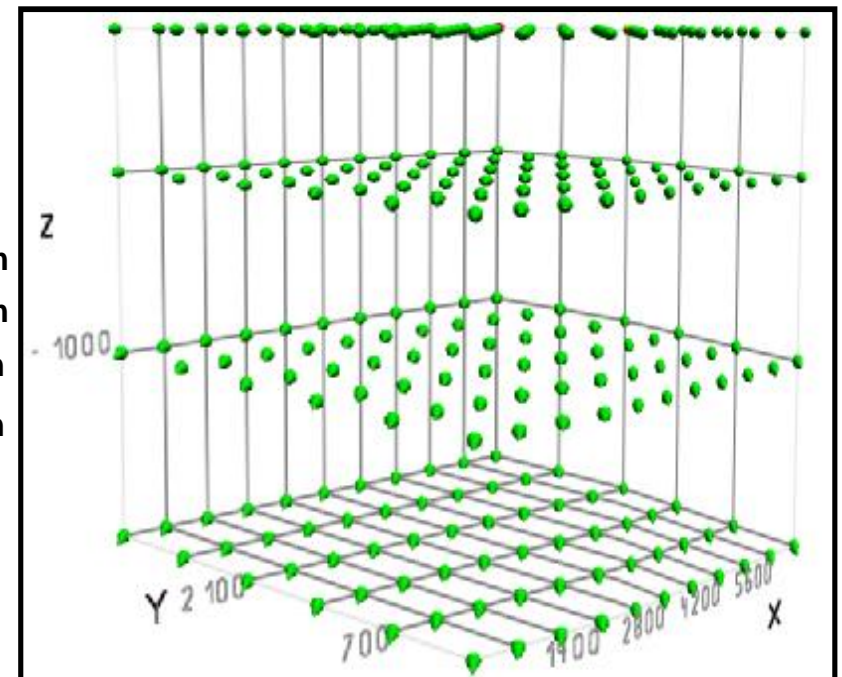
**Volumetric Error with
Standard Compensation**

**Volumetric Error with
Volumetric Compensation System**

Color scale:

0.0253 – 0.03	mm
0.0300 – 0.05	mm
0.0500 – 0.20	mm
0.2000 – 0.40	mm

Realized in a calibration time of 2 days

VCS_Technical_Description_Sales_January_2009_english.ppt

Thank you

SINUMERIK
Volumetric Compensation System

Secure your future
with innovative manufacturing

Name: Dr. Jochen Bretschneider

Department: Industry Sector

Address: MC MT P 3

Phone: +49 (9131) 98-4134

Mail: jochen.bretschneider@siemens.com

Volumetric Compensation System

§ FAQs

Volumetric Compensation System

§ Can I build cheap incorrect machines and VCS will correct?

§ No. High repeatability of the machine is required.

Preconditions for VCS

Numerical Control:

Solutionline: NCU-SW > 01.03.01

VCS Compile Cycle

TRAORI for 5-axis kinematics and optional Cycle 996

Machine Tool:

Cartesian axis configuration

High repeatability of linear positioning
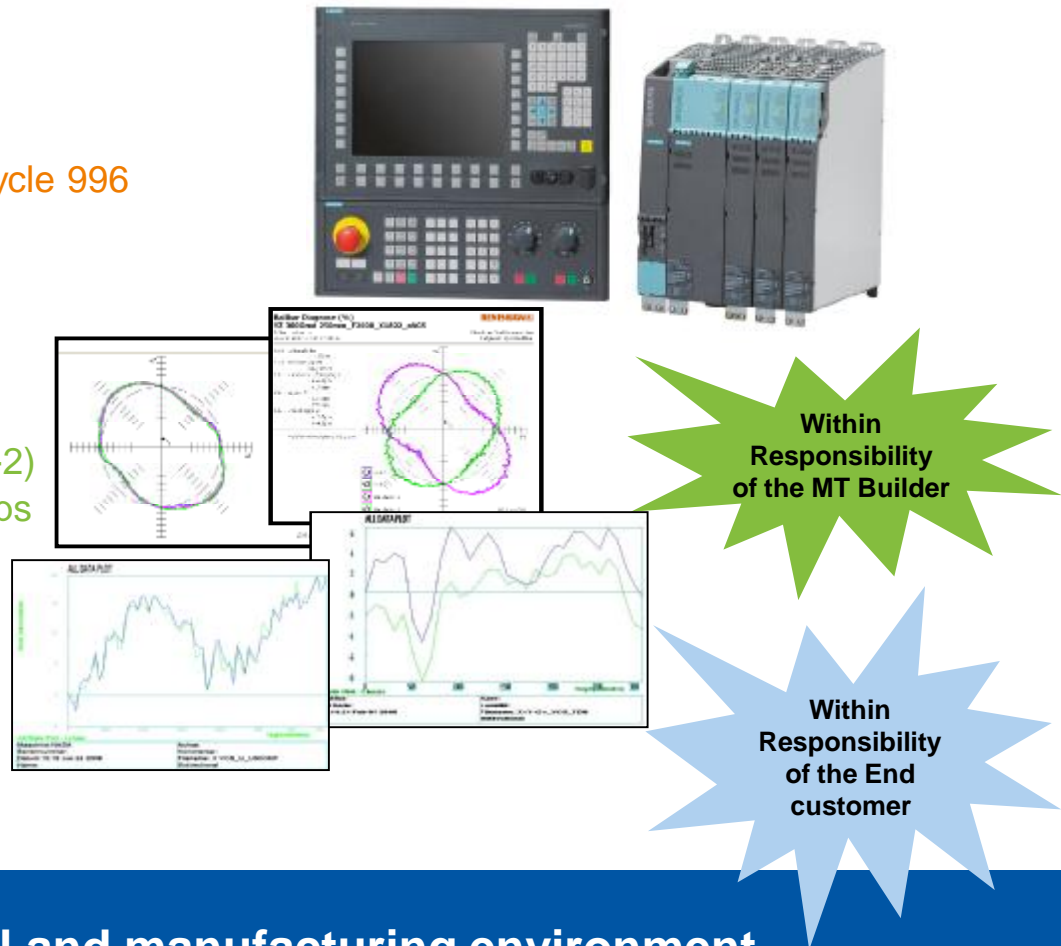
(basis: standard laser measurement ISO 230-2)

High responsiveness of the axes for microsteps

High linear behaviour of the axes

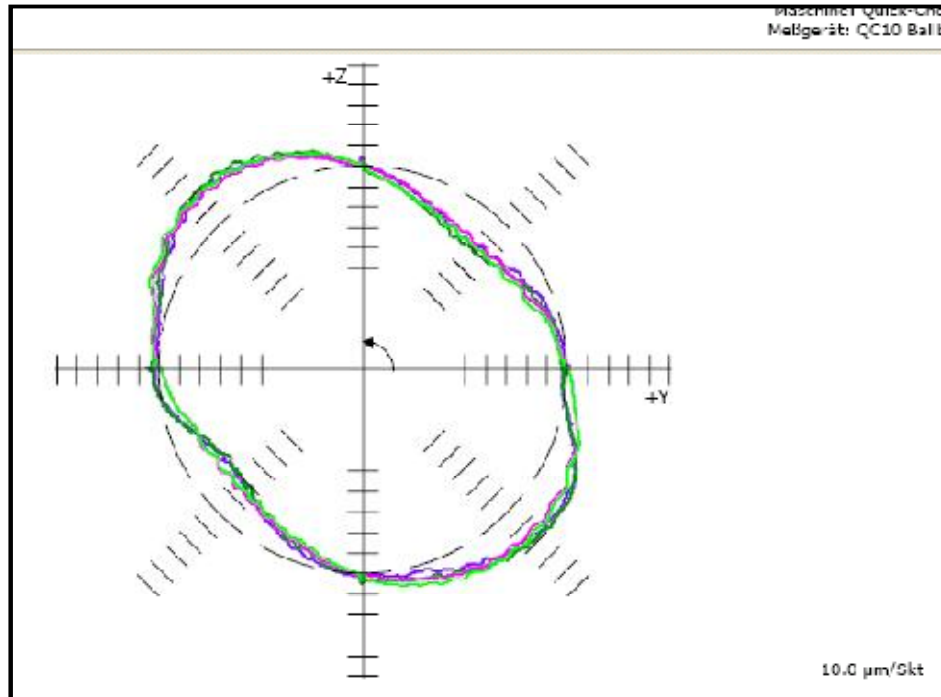(basis: standard circularity test ISO 230-4)

Within Responsibility of the MT Builder

Manufacturing Environment:

Temperature controlled manufacturing area

Within Responsibility of the End customer

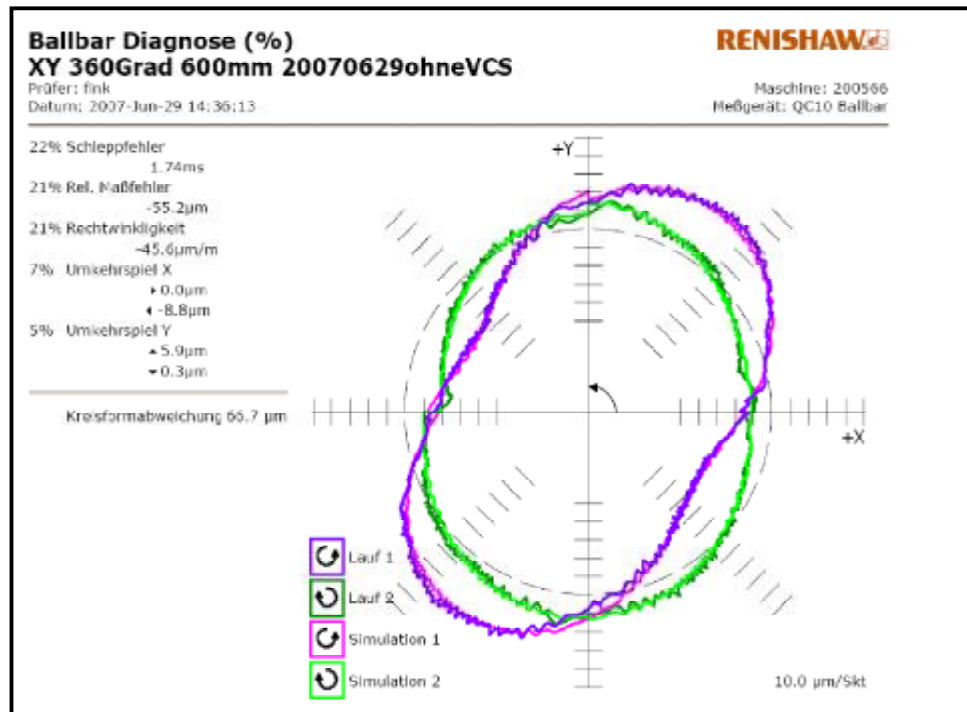**Numerical control, machine tool and manufacturing environment**

Portal Milling Machine A
Ballbar Test shows Repeatability

Repeatable Behaviour

VCS can be applied

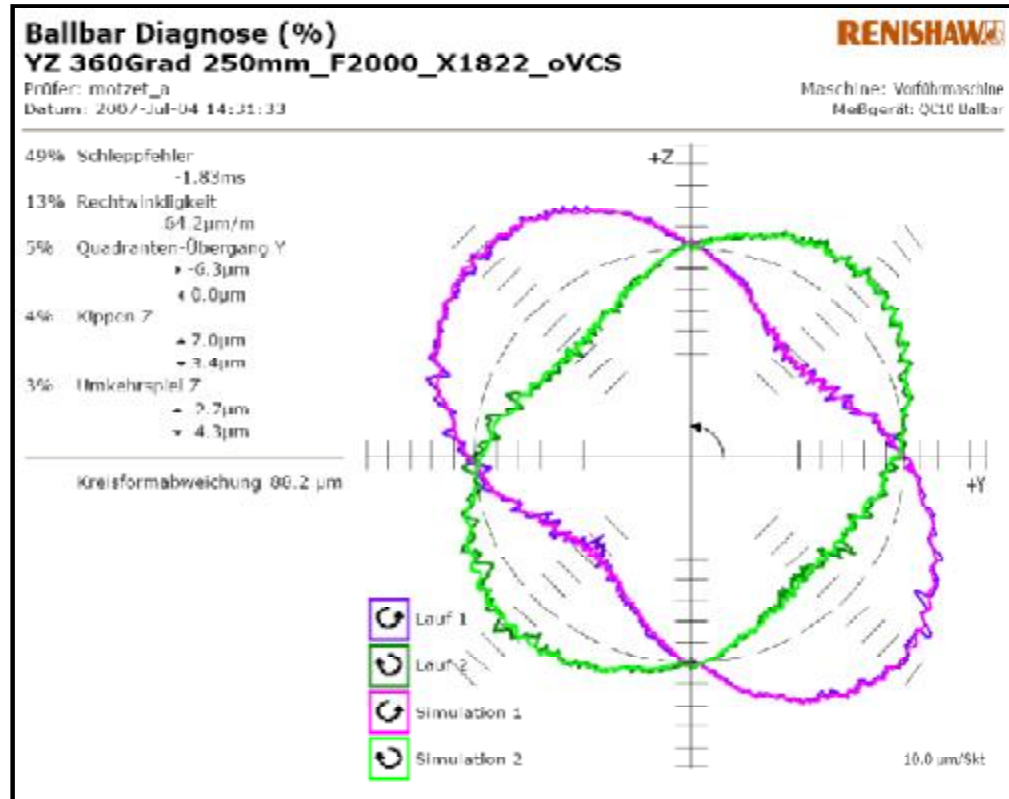Volumetric Compensation System

Industry Sector

Portal Milling Machine B
Ballbar Test shows less Repeatability

Already not Repeatable Behaviour

VCS should not be applied

Portal Milling Machine C
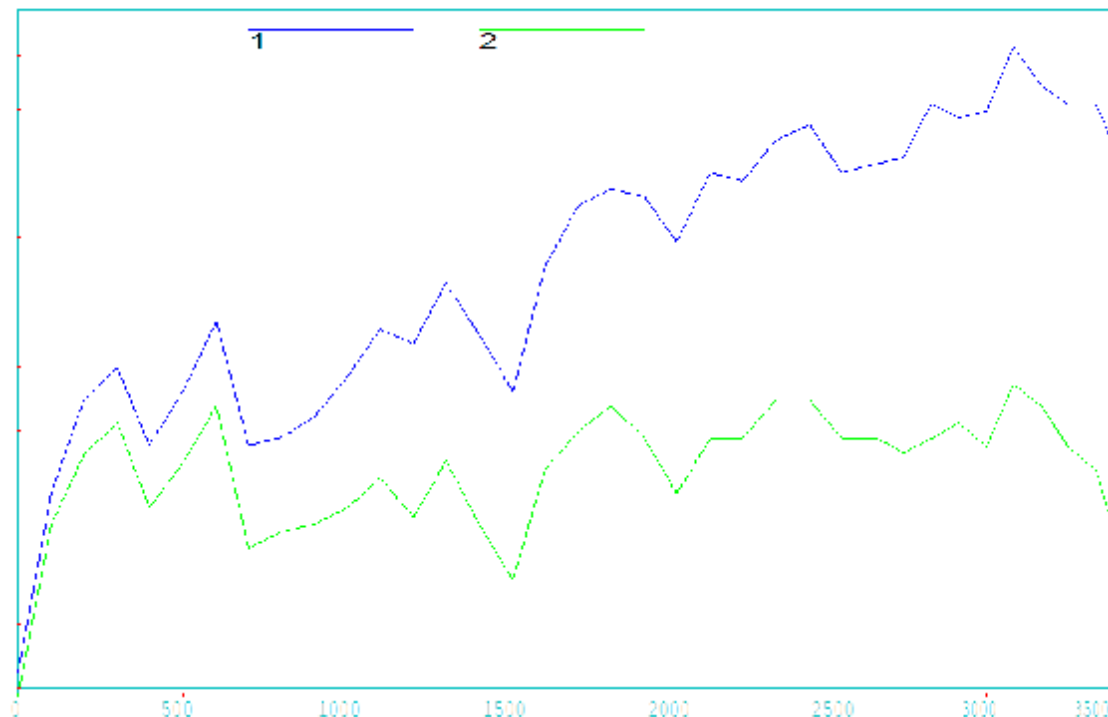# Ballbar Test does not show Repeatability

Not Repeatable Behaviour

VCS cannot be applied

Volumetric Compensation System

§ Influence of changing Temperature
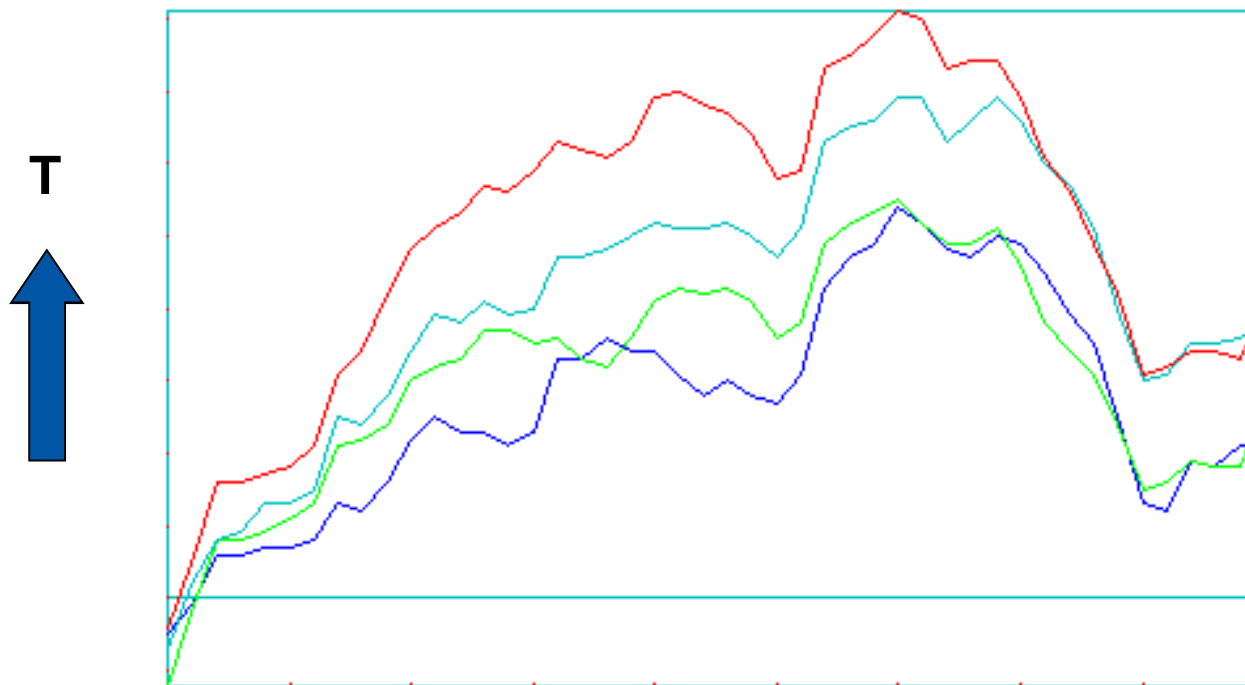
Influence of Ambient Temperature

Changing Shape of Rotational Error dependent on Temperature

Optimal Compensation with VCS is limited

Volumetric Compensation System
Position Error caused by Solar Radiation

T ↑

Changing
Position Error
dependent on
Temperature

Optimal Compensation with VCS is limited

Volumetric Compensation System

§ Difference to existing Compensations

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Why State-of-the-Art Geometric Error Compensation is limited

Leadscrew Error Compensation
Pitch Error Compensation

➡

only compensates
- Linear Positioning Error

Cross Error Compensation
Beam Sag Compensation

➡

only compensates

- Linear Positioning Error
- Straightness Error
- Squareness Error

VCS is needed !

an easy to handle compensation system to compensate for all 21 geometric errors

➡

to completely compensate
- Roll   - Lin. Positioning
- Pitch ⊕ - Straightness
- Yaw   - Squareness
of the axes

Siemens principle:
"We push INNOVATION – to shape the future "

Volumetric Compensation System

§ Which SW options are needed in detail?

Software options needed to operate VCS

Machine Tool	SW-Modul	Set-Up
3-Axes Machine Tool	§ VCS Compile Cycle § Option Temperature Compensation § LEC (for Gantry Machine Tools)	§ Installation of VCS CC on Sinumerik 840D sl by OEM or Siemens § Set-Up of VCS CC by OEM or Solution Partner § Set-Up of LEC by OEM
Additionally needed for: **5-Axes Machine Tool**	§ Option TRAORI § Option Cycle996 (included in VCS package) § LEC for Rotary Axes	§ Installation TRAORI and Cycle996 and Set-Up by OEM or Siemens § Set-Up of LEC by OEM

3- and 5-axes <u>cartesian</u> machine tools

Volumetric Compensation System

§ Which Compensations are conducted by VCS in detail?

VCS
Compensation in Detail for a <u>3-axes machine tool</u>

1- **VCS will correct the TCP position error**

2- **VCS <u>cannot</u> correct the tool orientation error**
   (rotary axes are not available)

<u>Borderline to existing compensations:</u>

LEC only can correct

§ the effect of the axis positioning error

CEC in principle can correct

§ the effect of the axis position, straightness and squareness errors

LEC or CEC <u>cannot</u> correct

§ the effect of axis roll, pitch and yaw

LEC = Leadscrew Error Compensation

CEC = Cross Error Compensation

Beam Sag Compensation

3-axes <u>Cartesian</u> machine tools

VCS
Compensation in Detail for a <u>5-axes machine tool</u>

1- VCS will correct the TCP position error
(with active TRAORI and activated tool)

2- TRAORI <u>will</u> correct the tool orientation error caused by the geometric error of rotary axes

3- VCS+TRAORI <u>will</u> correct the tool orientation error caused by the linear axes (for trafo types 24 and 40)

<u>Precondition for optimal results:</u>

§ well tuned TRAORI parameters (rotary axes)

§ <u>Recommendation:</u> use Cycle 996 to setup TRAORI parameters

§ LEC for rotary axes has to be setup independently (not part of Cycle996)

5-axes <u>Cartesian</u> machine tools

Recommendations for existing conventional compensations

When VCS is going to be used…

§ All existing compensations as LEC and/or CEC can remain active, but can be switched off as well. VCS can be superposed to existing LEC / CEC compensation.

Recommendation:

§ For gantry axes LEC must stay active since Master/Slave axes use individual LEC tables

Our Recommendations

Full Error Compensation
by Interaction of VCS and TRAORI

Ideal

Real

No head errors
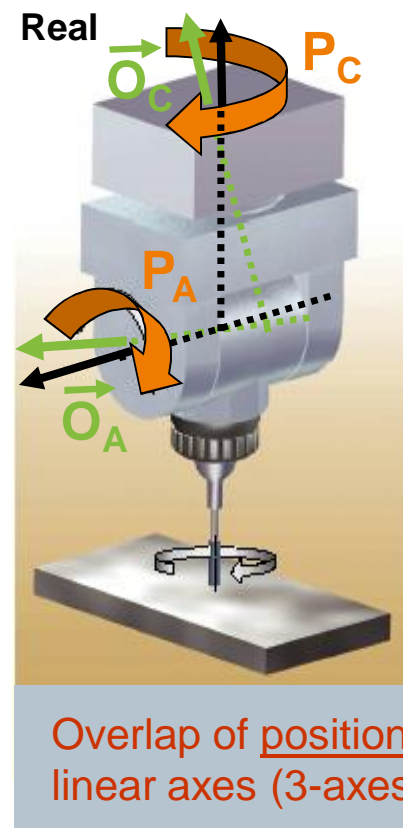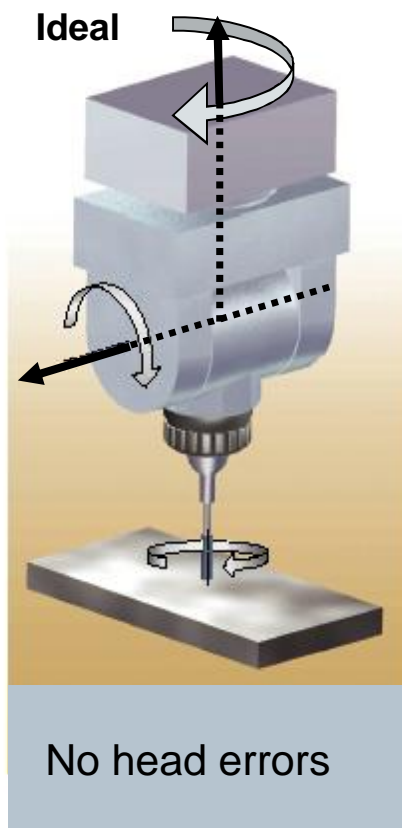
Geometric errors of rotary axes:
§ Positioning error
§ Offset
§ Inclination
§ Displacement

Resulting error of rotary axes at TCP:
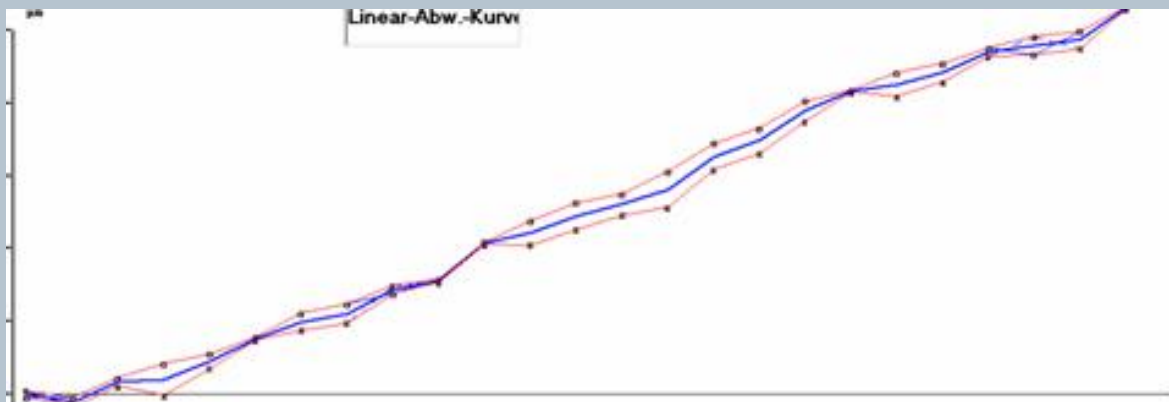§ Positioning error
§ Orientation error

Overlap of positioning and orientation error of the tool caused by linear axes (3-axes kinematics) and rotary axes (2-axes head)
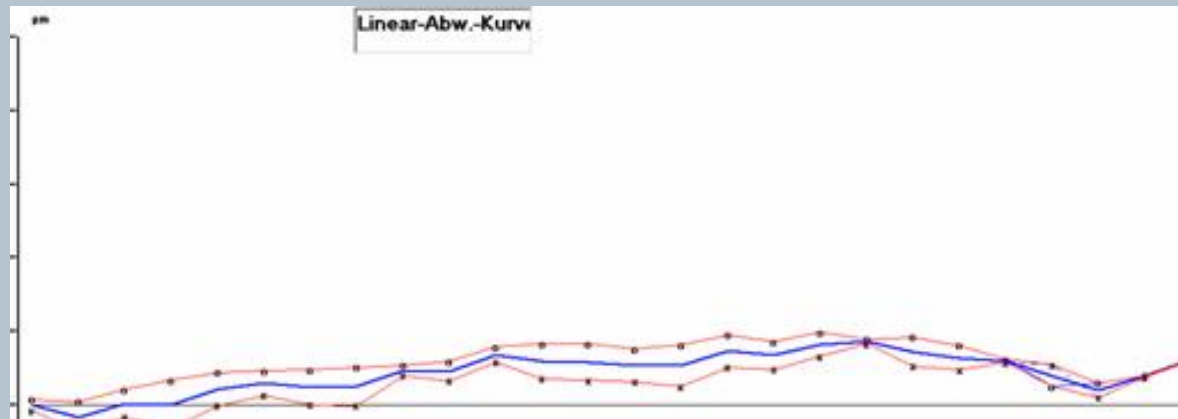
Geometric errors of the rotary head can be compensated by TRAORI and LEC for the rotary axes

Volumetric Compensation System

§ Some more Results
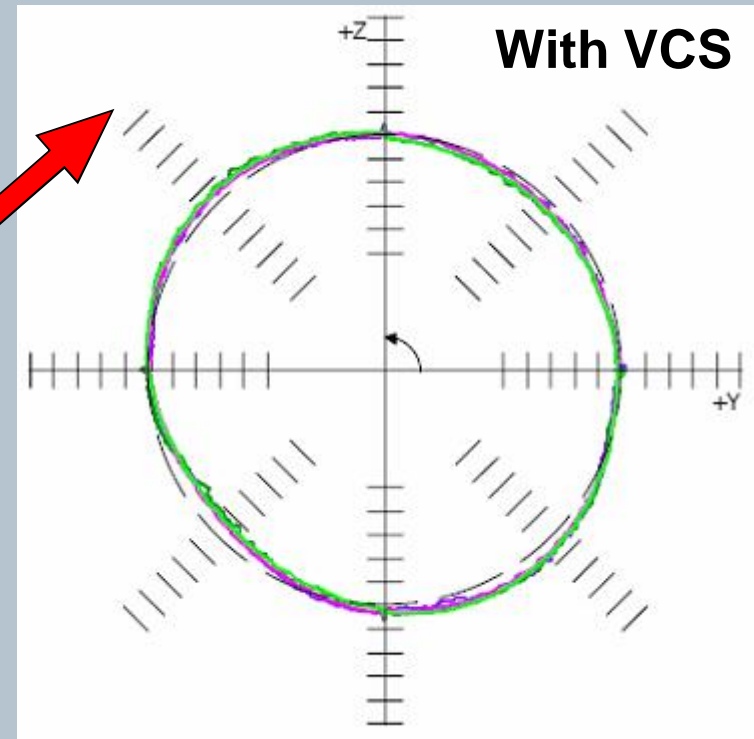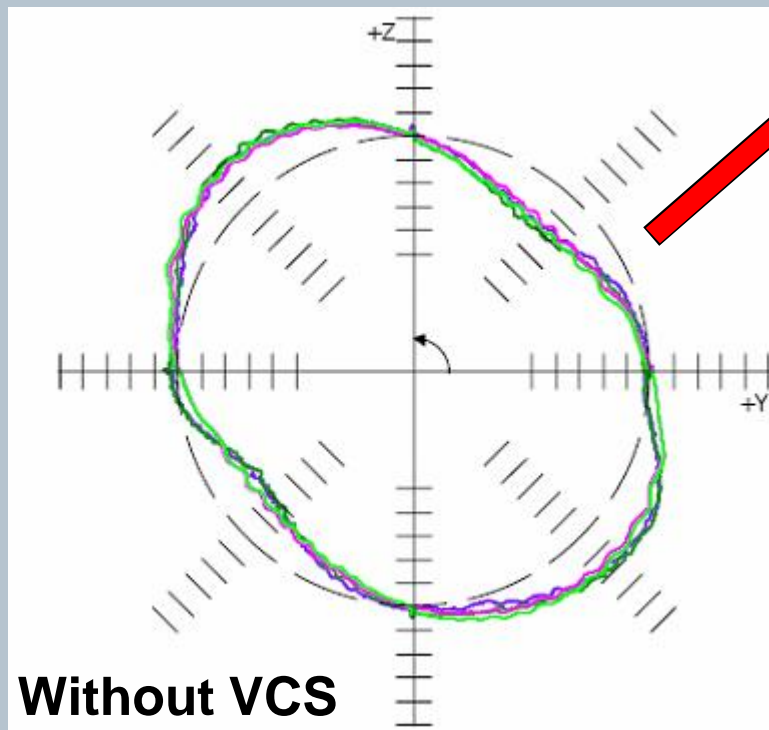
Example Results
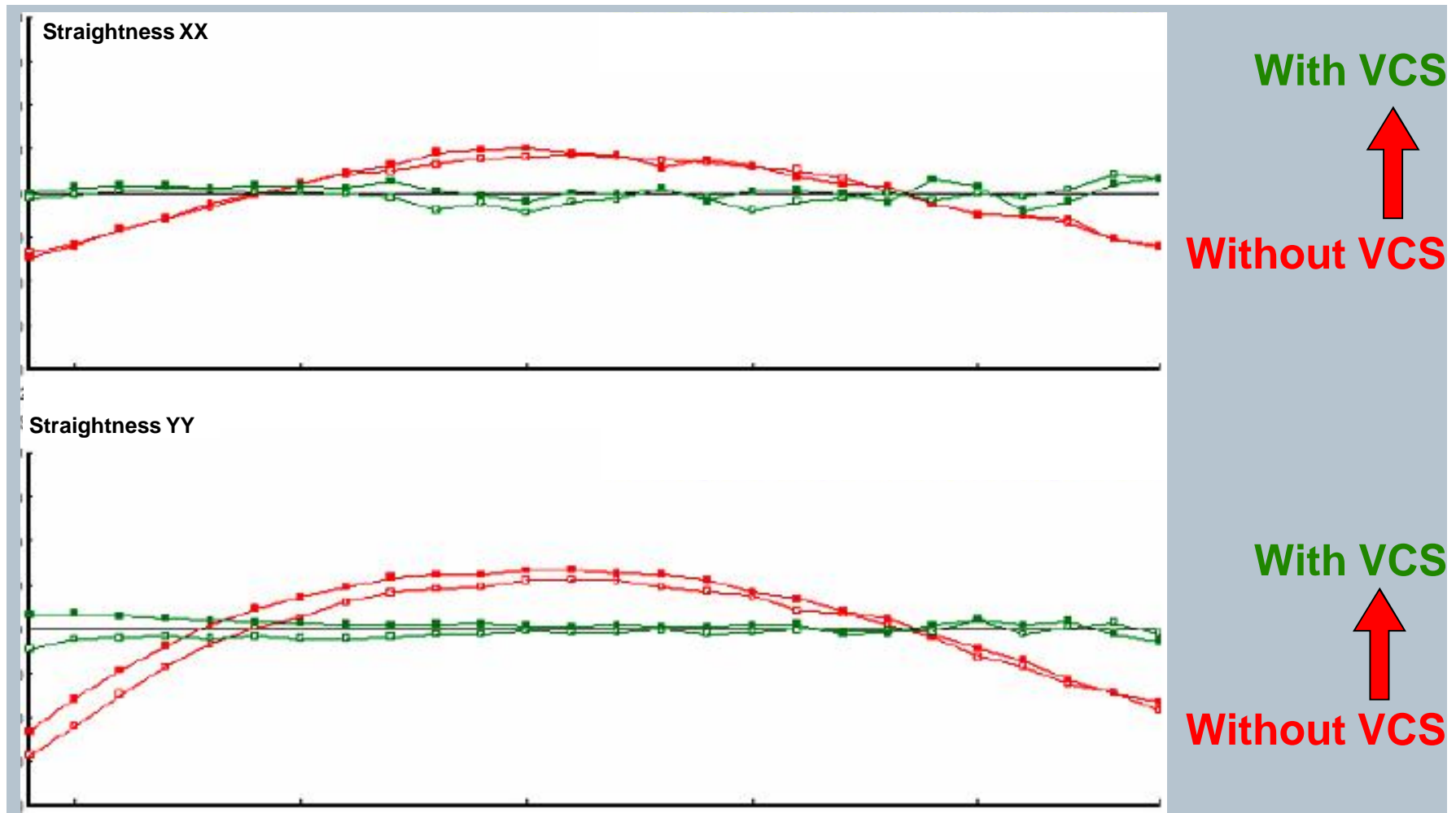# Position Accuracy

With VCS:

Improvement
-82%

Without VCS:

Example Results
Ballbar Test

With VCS

Without VCS

Example Results
Straightness Error

Straightness XX

With VCS

Without VCS

Straightness YY

With VCS

Without VCS