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
PITCH

© Siemens AG 2008
YAW
VERTICAL STRAIGHTNESS
HORIZONTAL STRAIGHTNESS
Market Requirements
How to achieve positioning accuracy for a machine tool

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

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

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

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

Six errors for each linear axis plus three squareness errors
(3-axes machine tool: 6 + 6 + 6 + 3 = 21 possible errors)

Note: geometric errors may vary with temperature
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

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

Note: There is displacement of the tool both in position and orientation.
Volumetric Error in the Workspace of a 3-Axes Machine…

…is dependent on the individual axes position
Volumetric Compensation System

Priority Market
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
Requirements from the aerospace sector exemplified for the JSF program

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.

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

1. Siemens portion
   - VCS-algorithm
   - Interface

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

3. Characteristics of the machining system
   - Process control
   - Long-term accuracy

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

   Calibration methodology
   (e.g. by OEM or by Solution Partners)

Source: Dörries Scharmann Technologie GmbH

Industry Sector
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**

**Rotary Axes Errors**

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
DEVIAITION [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

Only Precondition
VCS Compile Cycle installed on 840D sl

... by VCS Compile Cycle for SINUMERIK 840D solution line
Interpolation of 2 VCS Files
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.

**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

Actual Compensation Value
Δx, Δy, Δz

\[ Δx = (1-a)Δx_1 + aΔx_2 \]
\[ Δy = (1-a)Δy_1 + aΔy_2 \]
\[ Δz = (1-a)Δz_1 + aΔz_2 \]
Volumetric Compensation System

Market Access
Responsibilities of the Partners – Typical workflow

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

Machine Tool Builder

- VCS Compile Cycle
- Sinumerik sl
- VCS Integration
- VCS Installation
- VCS Calibration

End Customer

Sales of VCS Software

Calibration service on request

VCS sales only to Machine tool builders
Calibration service by Solution Partners
Volumetric Compensation System
Solution Partners for Machine Calibration

Renishaw GmbH
Dr. Rainer Krug
Technischer Leiter
T: +49/7127/981-1422
F: +49/7127/981-1550
E: rainer.krug@renishaw.com

Jörg Reichle
Produkt-Spezialist
T: +49/7127/981-1431
F: +49/7127/981-1550
E: joerg.reichle@renishaw.com

Automated Precision Europe BV
John Rohde
Global Product Manager Metrology
Telephone: +44(0)1926 - 490 844
Fax.: +44(0)1926 - 490 844
john.rohde@apisensor.eu
www.apisensor.com

AfM Technology GmbH
Wolfram Meyer
Geschäftsführer
Tel.: +49 7361 889608-0
Fax: +49 7361 889608-99
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

- Theory and Algorithmic Integration in Automation System
- Approval in Machine Tool System
- Measurement Techniques
- Application Know-How
- References
- Support

Sinumerik sl based VCS

Scope of Supply of Machine Tool Builder

Scope of Supply

Siemens VCS Software

Machine Tool Builder

The Road to Success

© Siemens AG 2009 - Subject to modifications
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

**Measuring devices, machine measurement, compensation**
Volumetric Compensation System

Results
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

Realized in a calibration time of 2 days

Color scale:
- 0.0253 - 0.03 mm
- 0.0300 - 0.05 mm
- 0.0500 - 0.20 mm
- 0.2000 - 0.40 mm
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
FAQs
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)

**Manufacturing Environment:**
Temperature controlled manufacturing area

Numerical control, machine tool and manufacturing environment
Portal Milling Machine A
Ballbar Test shows Repeatability

Repeatable Behaviour

VCS can be applied
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
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

Changing Position Error dependent on Temperature

Optimal Compensation with VCS is limited
Volumetric Compensation System

Difference to existing Compensations
Why State-of-the-Art Geometric Error Compensation is limited

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

- 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
  - Pitch
  - Yaw
  - Lin. Positioning
  - Straightness
  - Squareness of the axes
Which SW options are needed in detail?
Software options needed to operate VCS

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

3- and 5-axes cartesian machine tools
Which Compensations are conducted by VCS in detail?
VCS Compensation in Detail for a 3-axes machine tool

1- VCS will correct the TCP position error

2- VCS cannot correct the tool orientation error (rotary axes are not available)

Borderline to existing compensations:
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 cannot correct
- the effect of axis roll, pitch and yaw

3-axes Cartesian machine tools
VCS
Compensation in Detail for a 5-axes machine tool

1- VCS will correct the TCP position error (with active TRAORI and activated tool)
2- TRAORI will correct the tool orientation error caused by the geometric error of rotary axes
3- VCS+TRAORI will correct the tool orientation error caused by the linear axes (for trafo types 24 and 40)

Precondition for optimal results:

- well tuned TRAORI parameters (rotary axes)
- Recommendation: use Cycle 996 to setup TRAORI parameters
- LEC for rotary axes has to be setup independently (not part of Cycle996)
Recommendations for existing conventional compensations

When VCS is going to be used…

β 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:
β For gantry axes LEC must stay active since Master/Slave axes use individual LEC tables
Full Error Compensation by Interaction of VCS and TRAORI

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

Without VCS:

With VCS:

Improvement
-82%

Without VCS:
Example Results
Ballbar Test

Without VCS

With VCS
Example Results
Straightness Error

- **Straightness XX**
  - Without VCS
  - With VCS

- **Straightness YY**
  - Without VCS
  - With VCS