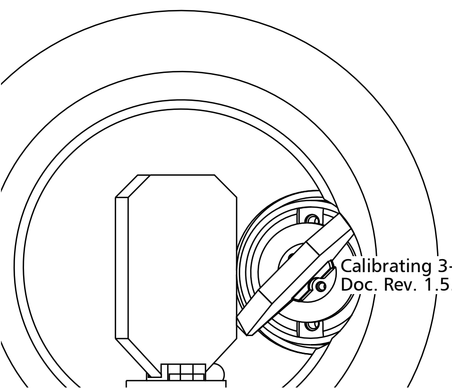
# Calibrating 3-Axis Laser Scan Systems

Application Notes
with Supplementary Information on
Calibrating 2-Axis Laser Scan Systems



SCANLAB GmbH
Siemensstr. 2a
82178 Puchheim
Germany

Tel.+49 (89) 800 746-0
Fax+49 (89) 800 746-199

info@scanlab.de
www.scanlab.de

# Contents

# 1 About this Manual

This manual describes a procedure for adjusting and calibrating 3-Axis Laser Scan Systems, see Figure 2, Page 12 (brief: “3D Calibration”).

Goal of the procedure is optimized precision of 3D laser focus positioning in 2D Configuration and/or 3D Configuration.

> **Caution!**
>
> Read and observe all safety notices in this manual!
>
> SCANLAB accepts no liability for damages or consequential losses resulting from non-observance of this manual, in particular the safety notices contained herein.

## 1.1 Target Group

This manual is primarily aimed at engineers, who define the calibration procedure for a 3-Axis Laser Scan System, in particular persons who develop and use their own RTC DLL-based or CalibrationLibrary DLL-based user programs for the calibration procedure.

Engineers or technicians who use the laserDESK 3D calibration wizard for calibration are largely guided through the calibration steps by the laserDESK 3D calibration wizard: laserDESK supports the steps from Chapter 5 ”Optimizing Correction Files (“Calibration Steps”)”, Page 55 (this chapter is not relevant in this case). However, the other chapters can be useful even when using the laserDESK 3D calibration wizard.

## 1.2 Related Documents

For specifications and details on how to use the respective system components and software tools, refer to the corresponding manuals.

- RTC4 Manual
- RTC5 Manual
- RTC6 Manual
- laserDESK Help
- CalibrationLibrary Manual
- CorrectionFileConverter Manual
- correXion pro Manual
- Dynamic Focusing Unit Manual
  - Chapter “Technical specifications“
  - Chapter “System-specific properties of the 3-axis system“
- “excelli*SCAN* Scan Heads – Functional Principle of *SCAN*ahead Servo Control and Operation by RTC6 Boards” Manual
- xy Scan-System Manual
  - Chapter “Technical specifications“
- Data sheet “Characteristics of the 3-Axis Configuration“
  - See Figure 1, Page 7
- Laser Manual

## 1.3 Manufacturer

SCANLAB GmbH
Siemensstr. 2a
82178 Puchheim
Germany
Tel. +49 (89) 800 746-0
Fax +49 (89) 800 746-199
info@scanlab.de
www.scanlab.de

Example

## Characteristics of the 3-Axis Configuration

The technical specifications listed here refer to a 3-axis configuration consisting of a vario*SCAN* II dynamic focusing unit, an XY scan head without an F-Theta objective and the denoted correction file. If you want to use the vario*SCAN* II in other optical configurations, please contact SCANLAB.

| **Focusing Unit** | |
|---|---|
| Product | vario*SCAN*$_{de}$ II 20i FT |
| Type | 20-20-A |
| SCANLAB article number | 145712 |

| **XY Scan System** | |
|---|---|
| Product | *SCAN*cube III 10 |
| SCANLAB article number | 124399 |
| Aperture diameter | 5 mm |
| Calibration angle | ±0.408 rad optically (1) |
| Maximum range for control values | ±503316 bit |

| **Correction File (*.ctb or *.ct5)** | D3_3013 |
|---|---|

| **Optical Performance** | |
|---|---|
| Working wavelength | 1064 mm |
| Back focal length | - mm |
| Distance A (working distance) (2) | 382 mm |
| Distance B (between vario*SCAN* II and XY scan head) (3) | 30 mm |
| ctb image field calibration (Kxyz_ctb) (4)<br>– in XY<br>- 16 bit:<br>- 20 bit:<br>– in Z<br>- 16 bit:<br>- 20 bit: | <br><br>317 bit/mm<br>5072 bit/mm<br><br>317 bit/mm<br>5072 bit/mm |
| Scan volume (X x Y x Z) | 160 mm x 160 mm x 154 mm |
| Reference Point (X, Y, Z) | (0 mm / 0 mm / 8.23 mm) |

(1) The scan angle needed to reach the specified volume is typically smaller than the calibration angle.
(2) See figure 'Setup of the 3-axis scan configuration' in Part 1 of the Manual.
(3) See figure 'Setup of the 3-axis scan configuration' in Part 1 of the Manual.
(4) Notes on image field calibration, see Application Note "Calibrating a 3-Axis Laser Scan System"

3-Axis Configuration
varioSCAN$_{de}$ II 20i FT #145712, SCANcube III 10 #124399, correction file D3_3013
February 16, 2024

1

Data sheet "Characteristics of the 3-Axis Configuration".

Example: "Datasheet_145712_varioSCAN_de_II_20i_FT_Setup_124399+D3_3013_2024-02-16_en.pdf".

## 1.4 Glossary

| | |
|---|---|
| 2-Axis Laser Scan System | See Chapter 17 "Appendix K: Calibrating 2-Axis Laser Scan Systems", Page 140. |
| 3-Axis Laser Scan System | See Chapter 2 "About 3-Axis Laser Scan Systems", Page 12 and Figure 2, Page 12. |
| 2D Working Field | • With 2D Configurations: 2D Image Field<br>• With 3D Configurations: 2D Image Field in a z plane<br>Specified by the typical Image Field side length. |
| 2D Configuration | • 3-Axis Laser Scan System with Correction File, no F-Theta objective<br>The Dynamic Focusing Unit ensures that the laser focus is always in one plane. Enables 2D laser application. |
| 2D Correction File | Correction File with 2D Correction Table. |
| 2D Correction Table | Correction Table with 2D data. Umbrella term for:<br>• 2D-`ct5`-Correction Table<br>• 2D-`ctb`-Correction Table |
| 3D Configuration | • 3-Axis Laser Scan System with Correction File, with F-Theta objective<br>• 3-Axis Laser Scan System with Correction File, no F-Theta objective<br>The Dynamic Focusing Unit shifts the laser focus to several planes. Enables 3D laser application. |
| 3D Correction File | Correction File with 3D Correction Table. |
| 3D Correction Table | Correction Table with 3D data. Umbrella term for:<br>• 3D-`ct5`-Correction Table<br>• 3D-`ctb`-Correction Table |
| 3D Working Volume | • With 3D Configurations: 3D Image Field<br>Specified by the typical side length of the Image Field as well as the maximum focus shift in z direction. |
| API | Abbreviation of Application Programming Interface. Program part (for example, of CalibrationLibrary DLL) which is available for other programs for connecting to the system (for example, functions of the CalibrationLibrary DLL). |

| | |
|---|---|
| BFL | Back Focal Length.<br>See Average Back Focal Length (Dynamic Focusing Unit), Page 18. |
| Correction File | File in SCANLAB format `*.ctb` or `*.ct5`. Contains the Correction Table(s).<br>See Chapter 7 "Appendix A: About Correction Files", Page 95. |
| Correction Table | Relevant information inside the Correction File. |
| ct5-Correction File | File in SCANLAB format `*.ct5`. |
| ct5-Correction Table | Correction Table of the ct5-Correction File:<br>• 3D-ct5-Correction Table<br>• 2D-ct5-Correction Table |
| ctb-Correction File | • File in SCANLAB format `*.ctb`. |
| ctb-Correction Table | Correction Table of the ctb-Correction File:<br>2D-ctb-Correction Table<br>3D-ctb-Correction Table |
| D2_xxxx.*-Correction File | For 2-Axis Laser Scan Systems.<br>For correction of x, y Control Values in accordance with the respective system configuration.<br>See Chapter 7 "Appendix A: About Correction Files", Page 95. |
| D3_xxxx.*-Correction File | For 3-Axis Laser Scan Systems.<br>For correction of x, y, z Control Values in accordance with the respective system configuration.<br>See Chapter 7 "Appendix A: About Correction Files", Page 95. |
| Defocus | Shift of focal point set with the RTC command **set_defocus**, parallel to the z axis, relative to the focus position according to the z control value. |
| Dynamic Focusing Unit | See Chapter 2 "About 3-Axis Laser Scan Systems", Page 12 and Figure 2, Page 12. |
| fiberSYS | 3D scan system from SCANLAB. Consists of at least: xy module, integrated dynamic focusing system, integrated pre-focus optics.<br>See also Figure 6, Page 37. |
| Gain Error | Incorrect scaling of 2D Working Field axes.<br>Relates to galvanometer scanner position control. Linear effect. |
| GUI | Graphical User Interface. |
| Image Field | Synonym: working field. |

| | |
|---|---|
| laserDESK<br>XML configuration file | See Figure 39, Page 116. |
| Non-Linearity | 2D Working Field distortion that cannot be attributed to linear effects (such as Gain Error, Offset Error and Skew Error).<br>Relates to galvanometer scanner position control. Linear effect. |
| Offset Error | 2D Working Field offsets with respect to the null position.<br>Relates to galvanometer scanner position control. Linear effect. |
| Positioning Speed | Synonym: jump speed. |
| ReadMe File | See Section "About ReadMe Files", Page 100. |
| Reference Point | See Section "Appendix F: About the Reference Point", Page 112. |
| RTC Manual | Generic term for: RTC4 Manual, RTC5 Manual, RTC6 Manual. |
| *SCAN*ahead Servo Control | Equipment feature of certain SCANLAB scan systems (= "SCANahead Systems"), essentially based on an ISB as a servo board for the 2 galvanometer scanner with corresponding firmware and parameterization.<br>Refer to "excelliSCAN Scan Heads – Functional Principle of SCANahead Servo Control and Operation by RTC6 Boards" Manual. |
| *SCAN*ahead System | SCANLAB scan system with SCANahead Servo Control, for example, excelli*SCAN* series.<br>Compare to Tracking Error System. |

| | |
|---|---|
| SCANcalc | SCANLAB app, see website www.scanlab.de. |
| Serial-Number-Specific Correction File | Surcharge. Takes Non-Linearity and Skew Error into account. See Chapter 7 "Appendix A: About Correction Files", Page 95. |
| Skew Error | Tilt of the 2D Working Field axis compared to the ideal 2D Working Field axis. |
| Tracking Error | Time difference between the planned and actual reaching of a certain mirror position at constant speed. |
| Tracking Error Servo Control | The "conventional" servo control of Tracking Error Systems. |
| Tracking Error System | SCANLAB scan system with conventional control (1st generation) = with Tracking Error and without preprocessing.<br>For example, intelli*SCAN* III.<br>Compare to SCANahead System. |
| vario*SCAN* | Umbrella term for all types of vario*SCAN*, vario*SCAN* II and vario*SCAN* FLEX. |
| x, y, z Control Values | Set position parameter values for RTC commands in bit. These must be calculated by the user program based on the Cartesian set position coordinate values in the 2D Working Field or 3D Working Volume in mm, with the help of calibration factors $K_{xy}$, Kz. |
| x, y, z Output Values | The values outputted by the RTC Board to the axes of the scan system (bit values after all corrections; these can be read out from the RTC Board by RTC command **get_value**, see Chapter 10 "Appendix D: Notes on Relevant RTC Commands", Page 106 and RTC Manual). |

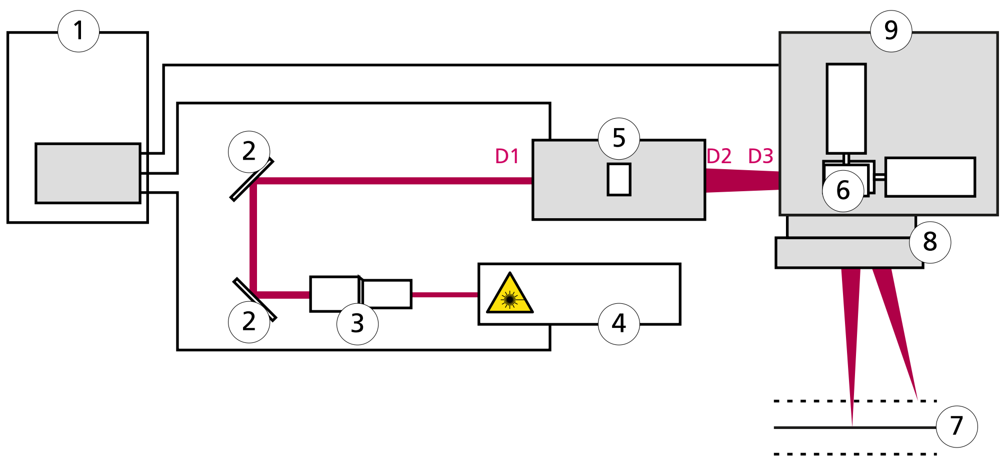
# 2 About 3-Axis Laser Scan Systems

3-Axis Laser Scan Systems, see Figure 2, Page 12, and Table 1, Page 13 allow:

- 2D laser applications in a 2D Working Field ("2D Configuration")
- 3D laser applications in a 3D Working Volume ("3D Configuration")

**Notes**

- This manual also contains information on SCANLAB products in which the 3 axes are factory-integrated in a shared housing – in deviation from the illustration in Figure 2, Page 12, for example,
  - powerSCAN
  - fiberSYS
  - intelli*WELD*




**Legend**

1. PC with User Program, RTC Board, `D3_xxxx.*`-Correction File
2. Adjustment Mirror
3. Beam Expander
4. Laser
5. Dynamic Focusing Unit = 1 axis
6. Mirror
7. Laser focus in working plane or processing volume
8. F-Theta Objective
9. xy Scan System = 2 axes

2

3-Axis Laser Scan System. See also Table 1, Page 13.

Table 1 System components

| System Component | Typical? | Optional? | From SCANLAB? | Comment |
|---|---|---|---|---|
| PC | yes | no | no | – |
| User Program | yes | no | no | – |
| RTC Board | yes | no | yes | *Option "3D" must be enabled.* |
| `D3_xxxx.*`-Correction File | yes | no | yes | For correction of x, y, z Control Values in accordance with the respective system configuration. |
| Adjustment Mirror | yes | no | no | – |
| Beam Expander | yes | yes | no | – |
| Laser | yes | no | no | – |
| Dynamic Focusing Unit | yes | no | yes | Device with a moving optical component for focal length variation and therefore, also for dynamic variation of the focus position of the laser beam along the beam direction.<br>= 1 axis.<br>Includes, for example, the following SCANLAB products:<br>vario*SCAN*, vario*SCAN* II, vario*SCAN* FLEX or excelli*SHIFT*. |
| Mirror | yes | no | yes | Moving. Synonym: deflection mirror, scan mirror. See also note on xy Scan System. |
| F-Theta Objective | yes | yes | yes | For focusing the laser beam on a working plane. |
| xy Scan System | yes | no | yes | = 2 axes (due to the 2 Mirror).<br>Includes, for example, the following SCANLAB products:<br>intelli*SCAN*, excelli*SCAN*. |

## 2.1 Calibration-Relevant Parameters (Alphabetical)

- See also worksheet Work Sheet Process Parameters, Page 121.

**Calibration-relevant Parameter**

| Calibration-relevant Parameter | **2D Working Field Size (Typical)** |
|---|---|
| Definition(s), Explanation(s) | • Side length in x direction and y direction for z = 0<br>• Value is specified by SCANLAB |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter “System-specific properties of the 3-axis system“<br>• Dynamic Focusing Unit Manual, Chapter “Technical specifications“<br>• Data sheet “Characteristics of the 3-Axis Configuration”<br>– In row “Scan volume (X x Y x Z)”: X × Y<br>• laserDESK XML configuration file, XML tag `scan_field` |
| Comment(s) | • For some system configurations, SCANLAB specifies the length and width of a *rectangular* 2D Working Field.<br>• Value only applies together with the SCANLAB-supplied Correction File (not: 1to1-Correction File). Together with adapted Correction Files (created during Chapter 5 ”Optimizing Correction Files (“Calibration Steps”)”, Page 55), changed values may apply, see for example, Chapter 5.1.2 ”Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective”, Page 65 or Chapter 5.5 ”Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients”, Page 79. |
| References | – |

| Calibration-relevant Parameter | ABC Coefficients |
|---|---|
| Definition(s), Explanation(s) | • The term summarizes:<br>– A Coefficient<br>– B Coefficient<br>– C Coefficient<br>• The ABC Coefficients are saved in the Correction File |
| Source(s) | • ReadMe File<br>(16-bit value if not otherwise specified)<br>• Correction File header (read out with CorrectionFileConverter > **Show File Header**) (CorrectionFileConverter shows 16-bit values)<br>• Query by RTC command **get_head_para**<br>The possible bit resolution depends on the RTC Board:<br>– RTC4 board consistently 16-bit values<br>– RTC5 board consistently 16-bit values<br>– RTC6 board ≤ SW-V.1.11.0 consistently 16-bit values<br>– RTC6 board SW-V ≥ 1.12.0 consistently 16-bit values or consistently 20-bit values |
| Comment(s) | • For the Dynamic Focusing Unit, the Parabolic Function, Page 16 determines the relationship between Focus Length Value l and z Output Value $z_{out}$.<br>Focus Length Value l:<br>– Has no unit<br>– Corresponds to the focal length difference between the specified point (x, y, z) and point (0, 0, 0).<br>• For systems with F-Theta objective, this corresponds to the distance of the set position from the z = 0 plane (as the F-Theta objective keeps the focus in the xy plane).<br>• Systems without F-Theta objective require an adaptation in z for the variation of (x, y).<br>– See also Chapter 8 "Appendix B: Determining Focus Length Values", Page 103 |
| References | – |

Table 2 Parabolic Function

| $z_{out} = A + B \times l + C \times l^2$ | |
|---|---|
| $z_{out}$ | z Output Value |
| A | A Coefficient |
| B | B Coefficient |
| C | C Coefficient |
| l | Focus Length Value |
| Important: *Consistently* use either 16-bit values or 20-bit values in the formula! | |
| See also Table 9 Calculating z output value for the Dynamic Focusing Unit, Page 105. | |

| Calibration-relevant Parameter | Allowed Laser Power (Dynamic Focusing Unit) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter “Technical specifications“ |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Allowed Laser Power (xy Scan System) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • xy Scan-System Manual, Chapter “Technical specifications“ |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Allowed Output Density (xy Scan System) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • xy Scan-System Manual, Chapter “Technical specifications“ |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Aperture (Dynamic Focusing Unit) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter “Technical specifications“ |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Aperture (xy Scan System) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • xy Scan-System Manual, Chapter “Technical specifications“<br>• |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Average Back Focal Length (Dynamic Focusing Unit) |
|---|---|
| Definition(s), Explanation(s) | • BFL<br>• Technical feature of, for example, vario*SCAN* |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter “System-specific properties of the 3-axis system“<br>• Data sheet “Characteristics of the 3-Axis Configuration” |
| Comment(s) | • Is needed for calculation of Rayleigh Length<br>• Is needed for estimating Beam Diameter ($1/e^2$) for varioSCAN and excelliSHIFT by Rule of Thumb |
| References | – |

| **Calibration-relevant Parameter** | **Beam Diameter (Focal Plane)** |
|---|---|
| Definition(s), Explanation(s) | • $D_{focus}$<br>• Synonym: laser spot diameter |
| Source(s) | • SCANcalc, Page 11<br>• Only with vario*SCAN* and excelli*SHIFT* (not: fiberSYS):<br>You can estimate Beam Diameter (Focal Plane) ($1/e^2$) according to Table 3, Page 19. |
| Comment(s) | • See also Rayleigh Length. |
| References | – |

Table 3 Beam Diameter ($1/e^2$) for vario*SCAN* and excelli*SHIFT* by Rule of Thumb

| $D_{focus} = M^2 \times k \times \lambda \times (f / D2)$ | |
|---|---|
| $D_{focus}$ | Beam Diameter ($1/e^2$) for varioSCAN and excelliSHIFT by Rule of Thumb |
| $M^2$ | Beam quality (depending on the laser) |
| k | Correction factor. Ideally 1.27. In reality usually 1.5…2.0. Typical values for Gaussian beams, depending on the D3 / D2 ratio:<br>D3 / D2 — k<br>2 — 1.30<br>1.5 — 1.42<br>1.25 — 1.58<br>1 — 1.87<br>0.9 — 2.05<br>0.75 — 2.43<br>If [Dynamic Focusing Unit aperture diameter / D1] < D3 / D2, then k is determined by this ratio (at the Dynamic Focusing Unit input). |
| $\lambda$ | laser wavelength |
| f | • Systems with F-Theta objective: Focal Length (F-Theta Objective)<br>• Systems without F-Theta objective: Average Back Focal Length (Dynamic Focusing Unit) |
| D2[a] | Beam diameter at Dynamic Focusing Unit exit, defined as:<br>[Internal Beam Expansion Factor (Dynamic Focusing Unit) × D1] |
| D1 | Beam diameter at Dynamic Focusing Unit beam input. |
| D3[b] | xy Scan System aperture. |

(a) D2 elsewhere referred to as “$D_g$”.

(b) D3 elsewhere referred to as “$D_a$”.

| Calibration-relevant Parameter | Calibration Angle (xy Scan System)<br>– Only relevant for Special Case: No "Standard" D2-Correction File `D2_xxxx.*` Available – |
|---|---|
| Definition(s), Explanation(s) | • ± Scan angle for 96% of the maximum (minimum) control value.<br>With 16-bit protocol ±31,457 bit. With 20-bit protocol ±503,316 bit.<br>Specified in rad (optical angle) or degrees (mechanical angle), see below. |
| Source(s) | • Only for SCANLAB customers without D2-"Standard"-Correction File `D2_xxxx.*`<br>xy Scan-System Manual > Chapter "Technical Specifications" > Control > Row "Calibration" > Value in unit rad (optical angle)<br>Example: "±0.408 rad with ±503316 Bit" |
| Comment(s) | • For most SCANLAB customers as well:<br>– `*_ct5_ReadMe.txt` \| `*_ReadMe.txt` > Row "Scan Angle Calibration:"<br>• In unit degrees (mechanical angle)<br>• Example: "Scan Angle Calibration: +/- 11.7 degrees mech.<br>– CorrectionFileConverter and *.`ct5` opened<br>> Field 'Calibration Angle [mech. degrees]'<br>• In unit degrees (mechanical angle)<br>• Example: "11.700" (this value is to be interpreted as "± value")<br>• Calibration Angle (xy Scan System) frequently specified by SCANLAB are: 10.0°, 10.7°, 11.0°, 11.7° (each mechanical angles).<br>• degrees (mechanical angle) to rad (optical angle) conversion<br>degrees (mechanical angle) $\times$ 2 $\times$ $\pi$ / 180° = rad (optical angle)<br>Example: 11.7° (mechanical angle) $\times$ 2 $\times$ 3.14 / 180° = 0.408 rad (optical angle)<br>• rad (optical angle) to degrees (mechanical angle) conversion<br>rad (optical angle) $\times$ 180° / $\pi$ / 2 = degrees (mechanical angle)<br>Example: 0.408 rad (optical angle) $\times$ 180° / 3.14 / 2 = 11.7° (mechanical angle) |
| References | – |

| Calibration-relevant Parameter | Calibration Factor $K_{xy}$ |
|---|---|
| Definition(s), Explanation(s) | • $K_{xy}$<br>• Synonyms: K_xy, K = K_xy = K_z<br>• Process parameter relating to xy Scan System<br>• [bit / mm], see Table 10, Page 109<br>• See Chapter 11 "Appendix E: About Calibration Factors", Page 109<br>• Value is specified by SCANLAB |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter "System-specific properties of the 3-axis system"<br>• Data sheet "Characteristics of the 3-Axis Configuration"<br>• ReadMe File provided with the SCANLAB `D3_xxxx.*`-Correction File<br>– See Table 10 Specifications of calibration factors (16-bit value or 20-bit value) in various ReadMe Files, Page 109<br>• Correction File header (read out with CorrectionFileConverter) |
| Comment(s) | • In system configurations with Dynamic Focusing Unit the following applies:<br>– Do not change the SCANLAB-specified values for Calibration Factor Kz and Calibration Factor $K_{xy}$. Otherwise, inaccuracies may result.<br>• SCANLAB specifies calibration factors as 16-bit values or as 20-bit values, see also Chapter 11 "Appendix E: About Calibration Factors", Page 109.<br>• These values specified by SCANLAB should not be changed in system configurations with a Dynamic Focusing Unit.A change in this case can lead to inaccuracies. |
| References | Calibration Factor Kz |

| **Calibration-relevant Parameter** | **Calibration Factor Kz** |
|---|---|
| Definition(s), Explanation(s) | • Kz<br>• Synonyms: K_xy, K = K_xy = K_z<br>• Process parameter relating to Dynamic Focusing Unit<br>• [bit / mm], see Table 10, Page 109<br>• See Chapter 11 "Appendix E: About Calibration Factors", Page 109<br>• Value is specified by SCANLAB |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter "System-specific properties of the 3-axis system"<br>• Data sheet "Characteristics of the 3-Axis Configuration"<br>• Dynamic Focusing Unit Manual, Chapter "Technical specifications"<br>• ReadMe File provided with the SCANLAB `D3_xxxx.*`-Correction File<br>– See Table 10 Specifications of calibration factors (16-bit value or 20-bit value) in various ReadMe Files, Page 109<br>• Correction File header (read out with CorrectionFileConverter) |
| Comment(s) | • In system configurations with Dynamic Focusing Unit the following applies:<br>– Do *not* change the SCANLAB-specified values for Calibration Factor Kz and Calibration Factor $K_{xy}$. Otherwise, inaccuracies may result.<br>• SCANLAB specifies calibration factors as 16-bit values or as 20-bit values, see also Chapter 11 "Appendix E: About Calibration Factors", Page 109. |
| References | Calibration Factor $K_{xy}$ |

| Calibration-relevant Parameter | Damage Threshold (xy Scan System) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • xy Scan-System Manual, Chapter "Technical specifications" |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Defocus Value d |
|---|---|
| Definition(s), Explanation(s) | • d<br>• See Chapter 6.3.1 "Estimating the Defocus Value and Checking the Beam Diameter", Page 91 |
| Source(s) | • – |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Distance B |
|---|---|
| Definition(s), Explanation(s) | • The intended mechanical distance between<br>– beam exit of the Dynamic Focusing Unit in the delivery state<br>– beam entrance of the xy Scan System<br>• See Figure 5, Page 36, (7)<br>• Value is specified by SCANLAB |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter "System-specific properties of the 3-axis system"<br>• Data sheet "Characteristics of the 3-Axis Configuration"<br>• laserDESK XML configuration file, XML tag `distance_b` |
| Comment(s) | • For non-specification-compliant values, see Page 38<br>• In the laserDESK XML configuration file you can identify the associated Correction File (specified values for Working Distance A \| Working Distance A' \| Distance B exclusively apply to this Correction File). |
| References | – |

| Calibration-relevant Parameter | Focal Length (F-Theta Objective) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter "System-specific properties of the 3-axis system"<br>• Data sheet "Characteristics of the 3-Axis Configuration"<br>• ReadMe File<br>• laserDESK XML configuration file, XML tag `focus_distance`<br>• Systems without F-Theta objective also:<br>– ReadMe File<br>– Correction File header (read out with CorrectionFileConverter) |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Internal Beam Expansion Factor (Dynamic Focusing Unit) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter "Technical specifications"<br>• Data sheet "Characteristics of the 3-Axis Configuration" |
| Comment(s) | • – |
| References | – |

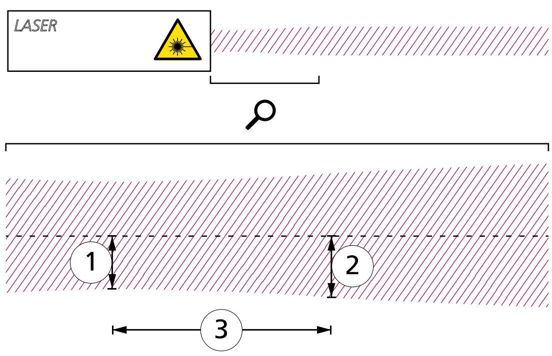
| Calibration-relevant Parameter | Laser Frequency (Repetition Rate) |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • Laser Manual |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Maximum Focus Shift in z Direction (±) |
|---|---|
| Definition(s), Explanation(s) | • $z_{min}$<br>• $z_{max}$<br>• Max. control value $z_{max}$ and min. control value $z_{min}$ for which the delivered Correction File has been calculated, see also Figure 5, Page 36<br>• Value is specified by SCANLAB |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter "Technical specifications"<br>• Dynamic Focusing Unit Manual, Chapter "System-specific properties of the 3-axis system"<br>• Data sheet "Characteristics of the 3-Axis Configuration"<br>– In row "Scan volume (X x Y x Z)": Z divided by 2<br>• ReadMe File<br>• laserDESK XML configuration file, XML tag `z_range` (= $z_{max} - z_{min}$) |
| Comment(s) | • This value must be checked or redefined after a change (and corresponding generation of a new Correction File) of:<br>– A Coefficient<br>(in Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65)<br>– ABC Coefficients<br>(in Chapter 5.5 "Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients", Page 79)<br>• Value only applies together with the SCANLAB-supplied Correction File (not: 1to1-Correction File). Together with adapted Correction Files (created during Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55), changed values may apply, see for example, Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65 or Chapter 5.5 "Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients", Page 79. |
| References | – |

| Calibration-relevant Parameter | Maximum Jump Speed for Marking Test Patterns |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • laserDESK XML configuration file, XML tag `jump_speed`<br>– Value applies to the *entire* 3-Axis Laser Scan System! |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Maximum Marking Speed for Marking Test Patterns |
|---|---|
| Definition(s), Explanation(s) | • – |
| Source(s) | • laserDESK XML configuration file, XML tag `mark_speed` |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | **Rayleigh Length** |
|---|---|
| Definition(s), Explanation(s) | • $z_R$<br>• See Figure 3, Page 27. |
| Source(s) | • You can use SCANcalc to calculate the actual Rayleigh Length for xy Scan Systems.<br>• Rayleigh Length can be calculated with formula:<br>$$z_R = \frac{\left(\pi \times \left[\frac{D_{focus}}{2}\right]^2\right)}{M^2 \times \lambda}$$<br>– laserDESK XML configuration file, XML tag `rayleigh_length` is a theoretical value that is obtained with $M^2 = 1$ |
| Comment(s) | • Rayleigh Length is dependent on:<br>– Beam quality $M^2$<br>– Beam diameter (see also Beam Diameter (Focal Plane))<br>– Aperture<br>– Laser wavelength<br>– Focal length of the objective<br>– For systems without F-Theta objective also on the Dynamic Focusing Unit Back Focal Length |
| References | – |




**Legend**

1. Smallest beam radius (waist)
2. Waist, increased by factor $\sqrt{2}$
3. Rayleigh Length

3

Rayleigh Length.

| Calibration-relevant Parameter | Reference Point Coordinates |
|---|---|
| Definition(s), Explanation(s) | • For the typical location of the Reference Point in 2D Working Field or 3D Working Volume, see Figure 37, Page 112.<br>• Reference system for the Reference Point Coordinates is the SCANLAB Reference Coordinate System, Page 33.<br>• Cartesian coordinate values<br>• SCANLAB specifies Reference Point Coordinates for every `D3_xxxx.*`-Correction File.<br>• SCANLAB calculates Reference Point Coordinates as follows:<br>– Dynamic Focusing Unit is brought to its neutral position[a] when the reference point coordinates (with loaded and assigned `D3_xxxx.*`-Correction File) are commanded<br>– by such that the Dynamic Focusing Unit is brought to its neutral position when controlled with them and the `D3_xxxx.*`-Correction File, and the laser beam – after correct adjustment – is focused on the Reference Point in the 2D Working Field or 3D Working Volume. |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter “System-specific properties of the 3-axis system“<br>• Dynamic Focusing Unit Manual, Chapter “Technical specifications“<br>• Data sheet “Characteristics of the 3-Axis Configuration”<br>• ReadMe File<br>• laserDESK XML configuration file, XML tag `reference_point` |
| Comment(s) | • – |
| References | – |

(a) The neutral position is the center travel position of the Dynamic Focusing Unit which it moves to after z output value $z_{out} = 0$ has been commanded by the control.

| **Calibration-relevant Parameter** | **Stepper Motor Value (Dynamic Focusing Unit)** |
|---|---|
| Definition(s), Explanation(s) | • Synonym(s):<br>– Position of the focusing optics<br>• Refers to:<br>– vario*SCAN* 40 FLEX<br>– power*SCAN* II 50i<br>– power*SCAN* II 70i |
| Source(s) | • – |
| Comment(s) | • Dynamic Focusing Unit Manual, Chapter “System-specific properties of the 3-axis system“<br>• Dynamic Focusing Unit Manual, Chapter “Technical specifications“<br>• Data sheet “Characteristics of the 3-Axis Configuration” |
| References | – |

| Calibration-relevant Parameter | Stretch Factor (x Direction) |
|---|---|
| Definition(s), Explanation(s) | • Sx<br>• SCANLAB D3_xxxx.*-Correction Files contain one value each for Stretch Factor (x Direction) Sx and Stretch Factor (y Direction) $S_y$. They are used to compensate for pyramidal 2D Working Field changes (or linear z-dependent scaling effects outside the z = 0 plane), see also Figure 20, Page 74. |
| Source(s) | • Read out by RTC command **get_table_para** from the currently used Correction File<br>• ReadMe File<br>• Systems without F-Theta objective: also in ReadMe File |
| Comment(s) | • – |
| References | – |

| Calibration-relevant Parameter | Stretch Factor (y Direction) |
|---|---|
| Definition(s), Explanation(s) | • $S_y$<br>• SCANLAB D3_xxxx.*-Correction Files contain one value each for Stretch Factor (x Direction) Sx and Stretch Factor (y Direction) $S_y$. They are used to compensate for pyramidal 2D Working Field changes (or linear z-dependent scaling effects outside the z = 0 plane), see also Figure 20, Page 74. |
| Source(s) | • Read out by RTC command **get_table_para** from the currently used Correction File<br>• ReadMe File<br>• Systems without F-Theta objective: also in ReadMe File |
| Comment(s) | • – |
| References | – |

| **Calibration-relevant Parameter** | **Tracking Error (Dynamic Focusing Unit)** |
|---|---|
| Definition(s), Explanation(s) | • t_tracking_z |
| Source(s) | • laserDESK XML configuration file, XML tag `tracking_error_z`<br>• See Chapter 4 "Configuring and Mechanically Adjusting the 3-Axis Laser Scan System", Page 35 |
| Comment(s) | • For typical values, see Table 5, Page 51. |
| References | Tracking Error (xy Scan System) |

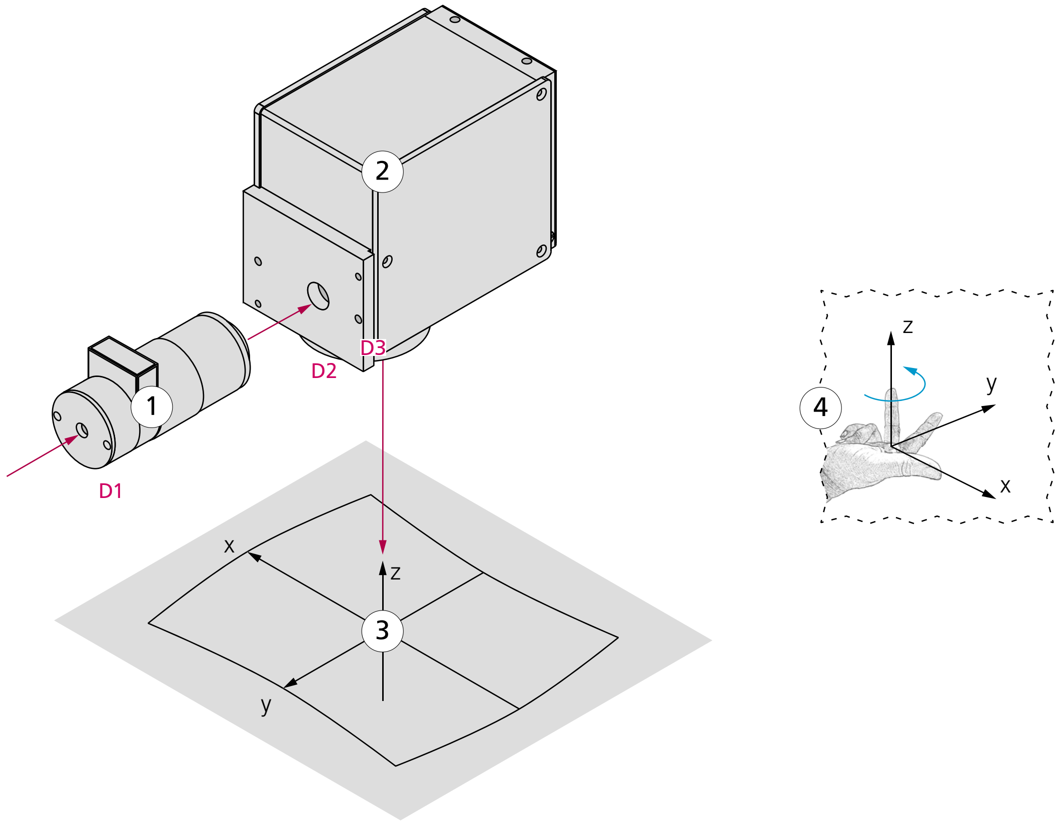
| **Calibration-relevant Parameter** | **Tracking Error (xy Scan System)** |
|---|---|
| Definition(s), Explanation(s) | • t_tracking_xy |
| Source(s) | • xy Scan-System Manual, Chapter "Technical specifications"<br>• laserDESK XML configuration file, XML tag `tracking_error_xy` |
| Comment(s) | • With intelli*SCAN*, t_tracking_xy values may be dependent on the tuning |
| References | Tracking Error (Dynamic Focusing Unit) |

| Calibration-relevant Parameter | Working Distance A |
|---|---|
| Definition(s), Explanation(s) | • Distance after adjustment<br>– from working plane for control value z = 0<br>– to the center of the beam entrance opening of the xy Scan System<br>• See Figure 5, Page 36, (6)<br>• Value is specified by SCANLAB |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter “Technical specifications“<br>• Dynamic Focusing Unit Manual, Chapter “System-specific properties of the 3-axis system“<br>• Data sheet “Characteristics of the 3-Axis Configuration”<br>• Systems without F-Theta objective also:<br>– ReadMe File<br>– Correction File header (read out with CorrectionFileConverter)<br>• laserDESK XML configuration file, XML tag `working_distance_a` |
| Comment(s) | • In the laserDESK XML configuration file you can identify the associated Correction File (specified values for Working Distance A \| Working Distance A’ \| Distance B exclusively apply to this Correction File). |
| References | Working Distance A’ |

| Calibration-relevant Parameter | Working Distance A’ |
|---|---|
| Definition(s), Explanation(s) | • For some products, Working Distance A’ is specified due to design instead of Working Distance A:<br>Distance after adjustment<br>– from working plane for control value z = 0<br>– to the center of the beam entrance opening of the xy Scan System<br>• See Figure 6, Page 37, (5)<br>• Value is specified by SCANLAB |
| Source(s) | • Dynamic Focusing Unit Manual, Chapter “System-specific properties of the 3-axis system“<br>• Data sheet “Characteristics of the 3-Axis Configuration” |
| Comment(s) | • In the laserDESK XML configuration file you can identify the associated Correction File (specified values for Working Distance A \| Working Distance A’ \| Distance B exclusively apply to this Correction File). |
| References | Working Distance A |

## 2.2 About the SCANLAB Reference Coordinate System

**SCANLAB Reference Coordinate System**




- Axis orientation in the coordinate system also corresponds to the axis orientation with RTC boards.
- Definition of the xyz reference system:
  - y axis points in the opposite direction of the entering beam
  - z axis points in the opposite direction of the emerging beam
  - x axis direction is defined by the right-handedness of the coordinate system (4)

**Legend**

1. Dynamic Focusing Unit
2. xy Scan System
3. Coordinate Origin (0|0|0)
4. Right-handed Coordinate System

4

SCANLAB Reference Coordinate System.

# 3 Safety

**Caution!**

When setting up or operating a 3-Axis Laser Scan System hazards with the risk of damage to health are posed:

- Laser radiation
- Poisonous vapors produced during the laser process
- Heat
- Electrical current

Consequences include: eye injuries, skin injuries, burn injuries, damages to the respiratory system.

Make sure that all necessary and prescribed safety measures are observed.

**Observe the typical safety measures:**

- Design the 3-Axis Laser Scan System such that, both in normal operation and during commissioning or maintenance, hazards mentioned under Caution! are minimized.
- Perform a risk analysis of your laser setup! Take suitable design measures, depending on the laser type, laser power and application.
- Make sure that all users are trained in the respective activities on the 3-Axis Laser Scan System and in particular, in safe handling of laser radiation.
- Make sure that all users are equipped with the necessary personal protective equipment.

**Observe as a user:**

- Always wear suitable laser safety goggles, appropriate to the laser wavelength and laser power
- Never look into the laser beam
- Do not hold any body parts in the laser beam
- First power up the control for the xy Scan System, and then switch on the laser
- For adjustment work, set the laser power to a minimum value
- Do not set the laser power above the maximum allowed value, see manuals for the system components
- Switch the laser off when the laser beam is not needed
- Observe all applicable regulations on laser safety

# 4 Configuring and Mechanically Adjusting the 3-Axis Laser Scan System

Requirements specified in this chapter are prerequisite for:(1)

- Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55
- Chapter 6 "(Optional) Carrying out Further Measures", Page 84
- Chapter 16 "Appendix J: Troubleshooting Static Errors in Laser Applications", Page 124

## 4.1 Optical System Configuration

Design the system components, see Figure 2, Page 12, in such a way that the respective desired values can be achieved for the fundamental parameters of the respective laser applications, that is, typically for the following parameters:

- laser wavelength
- Laser power
- Laser repetition rate
- Usable 2D Working Field (3D Working Volume)
- The average laser spot diameter in the 2D Working Field (3D Working Volume)
- The working distance between the 2D Working Field and xy Scan System
- Speed requirements
- Precision requirements

**Procedure**

**(1)** Consult SCANLAB already at the time of designing the 3-Axis Laser Scan System and when selecting the system components. Then SCANLAB can define a suitable package of the relevant system components of the 3-Axis Laser Scan System to meet your project goals.

**(2)** Make sure that the other customer-supplied system components are also suitably designed for your objectives:
- Machine frame
- Workpiece positioning equipment
- Safety devices
- Cooling equipment
- Other SCANLAB-supplied system components, for example,
  - RTC Board
  - Correction Files

**(3)** Compare the technical specifications in the manuals of the system components with the requirements of your goals.

(1) For installation and commissioning, also observe the instructions in the respective manuals.

## 4.2 Ensuring the Proper Mechanical Configuration of System Components

| Relevant Process Parameters |
|---|
| • Working Distance A, Page 32 or Working Distance A', Page 32 |
| • Distance B, Page 23 |

**Goal**

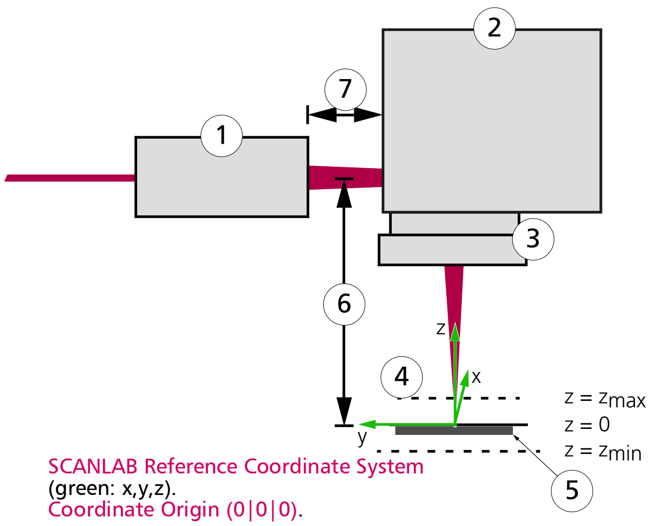
- Mechanically, all system components must be correctly installed and aligned relative to each other.
- Dynamic Focusing Unit and Workpiece (marking substrate) must be brought into the correct position relative to the xy Scan System.

With 3D Configurations, the following applies:

- $z_{max}$ and $z_{min}$ are the values for Maximum Focus Shift in z Direction (±)

With 2D Configurations, the following applies:

- $z_{max} = z_{min} = 0$

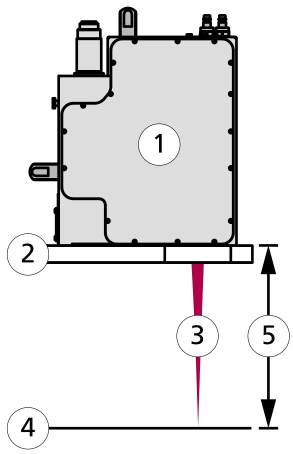



**Legend**

1. Dynamic Focusing Unit
2. xy Scan System
3. F-Theta Objective
4. 3D Working Volume
5. Workpiece (marking substrate)
6. Working Distance A
7. Distance B

5

Working Distance A, Distance B, SCANLAB Reference Coordinate System.




**Legend**

1. fiberSYS
2. Mounting plate
3. Emerging beam
4. Focal plane
5. Working Distance A’

Not to scale.

6

fiberSYS: Working Distance A’.

### 4.2.1 Positioning the Dynamic Focusing Unit Correctly

**Procedure**

**(1)** Install Dynamic Focusing Unit and xy Scan System such that Distance B is maintained.

**(2)** Make sure that the exit-side optical axis of the Dynamic Focusing Unit and the entrance-side optical axis of the xy Scan System coincide.

**(3)** Observe the tolerances for the relative position of the xy Scan System and Dynamic Focusing Unit (relative to the input opening of the Dynamic Focusing Unit):[1]

Tilt........................................................ < 5 mrad

Displacement ..................................... < 0.3 mm

**(4)** With mechanical system design and system set-up, keep as close as possible to the intended relative position.

*The more precise, the better the calibration result later.*

**Notes**

- For Product-specific notes see Table 4, Page 39.
- If you wish to operate Dynamic Focusing Unit and xy Scan System with a non-specification-compliant Distance Bvalue (for example, because of special adapter plates or extensions in the beam path):
  - (a) With your “desired” value, take into account:
    - Due to the beam divergence or beam convergence of the laser beam it has an influence on the beam diameter at the beam entrance of the xy Scan System
    - Requirements on the beam diameter from Chapter 4.4.1 ”Setting Laser Power, Beam Diameter, Beam Divergence”, Page 43 must be met
  - (b) Inform SCANLAB of the “desired” value. SCANLAB checks whether your setup can be operated with it and generates a suitable Correction File on request.

(1) See also the information in Chapter 4.4.2 “Aligning the Beam Position”.

Table 4 Product-specific notes

| SCANLAB Product | Notes |
|---|---|
| vario*SCAN* II | • When setting Distance B, a vario*SCAN* II can be installed in any mounting position, rotated around its own optical axis. |
| vario*SCAN* | • The installation position of vario*SCAN* must always be such that the area marked with the “top“ sticker is facing upwards.[a] This also applies when vario*SCAN* is installed in a housing such as in varioSCAN FLEX and varioSCAN (without stepper motor) in FLEX housing. If this kind of housing is to be installed in the system rotated for example, by 90° around the optical axis of the vario*SCAN*, then the housing must first be opened and vario*SCAN* rotated accordingly in its holder. After the housing installation, the surface marked with the “top“ sticker must be facing upwards. |
| vario*SCAN* FLEX | • The installation position of varioSCAN must always be such that the area marked with the “top“ sticker is facing upwards. This also applies when varioSCAN is installed in a housing such as in varioSCAN FLEX and varioSCAN (without stepper motor) in FLEX housing. If this kind of housing is to be installed in the system rotated for example, by 90° around the optical axis of the varioSCAN, then the housing must first be opened and varioSCAN rotated accordingly in its holder. After the housing installation, the surface marked with the “top“ sticker must be facing upwards.<br>• If this SCANLAB product – as intended – is bolted directly (= without spacing) onto a xy Scan System, then Distance B is defined by SCANLAB and uses this value for generating the associated Correction Files. |
| vario*SCAN* (without stepper motor) in *FLEX* housing | • The installation position of varioSCAN must always be such that the area marked with the “top“ sticker is facing upwards. This also applies when varioSCAN is installed in a housing such as in varioSCAN FLEX and varioSCAN (without stepper motor) in FLEX housing. If this kind of housing is to be installed in the system rotated for example, by 90° around the optical axis of the varioSCAN, then the housing must first be opened and varioSCAN rotated accordingly in its holder. After the housing installation, the surface marked with the “top“ sticker must be facing upwards.<br>• If this SCANLAB product – as intended – is bolted directly (= without spacing) onto a xy Scan System, then Distance B is defined by SCANLAB and uses this value for generating the associated Correction Files. |

Table 4 Product-specific notes (cont'd.)

| SCANLAB Product | Notes |
|---|---|
| intelli*WELD* | • Dynamic Focusing Unit and xy Scan System are already installed in a common housing. SCANLAB takes into account the Distance B specified by this housing design when generating the associated Correction Files. |
| power*SCAN* II | • Dynamic Focusing Unit and xy Scan System are already installed in a common housing. SCANLAB takes into account the Distance B specified by this housing design when generating the associated Correction Files. |
| excelli*SHIFT* | • SCANLAB recommends a Distance B between excelli*SHIFT* and xy Scan System of ≤ 500 mm. |

(a) The mechanical mounting of the vario*SCAN* is optimized for the described installation position. Permanently error-free operation in a different installation position cannot be guaranteed.

### 4.2.2 Positioning Marking Substrates Correctly

**Procedure**

**(1)** Position the marking substrates to be processed with control value z = 0 in this z = 0 working plane. For the steps described in Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55, you must bring the surface of marking substrates partly into the z = 0 working plane and partly into different z working planes. Make sure that the position of the marking substrates can be set accordingly.

**(2)** With systems without an F-Theta objective:
If the z = 0 working plane is to have a different distance from xy Scan System, inform SCANLAB of this value of Working Distance A.
SCANLAB can then check whether your system can be operated with this Working Distance A and calculate a corresponding Correction File for this value, if desired.[1]

**(3)** Surfaces parallel to the z = 0 plane, which are to be processed with a z control value, must be parallel to the underside of the xy Scan System (perpendicular to the z axis of the SCANLAB Reference Coordinate System).
The achievable calibration precision is dependent on the deviations.

Tilting of the marking substrate surface (for example, due to a tilted workpiece support) *cannot* be compensated for by the procedure described in Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55.

**(4)** When positioning marking substrates in the 3D Working Volume of the 3-Axis Laser Scan System take care about the orientation of the x axis and y axis of the SCANLAB Reference Coordinate System, see Figure 5, Page 36.[2]

(1) For systems with an F-Theta objective:
Working Distance A adaptation is not possible.

(2) This alignment of the coordinate axes corresponds to the alignment used by the RTC Boards. For an illustration of the reference system in the intelli*WELD* relative to its housing, see the associated manual. The reference system only differs from SCANLAB Reference Coordinate System in Figure 5, Page 36 for some customer-specific SCANLAB special systems, see the respective manual.

## 4.3 Improving Thermal Conditions

In general, measures must be taken to improve the thermal conditions for 3-Axis Laser Scan Systems. Typical goals of such measures are:

- Dissipation of excess heat during operation
  - to prevent temporary or permanent failures of system components[1]
- Temperature stabilization of system components
  - to prevent errors in the 2D Working Field or 3D Working Volume[2]

The specific measures depend on:

- Respective system components used
- Requirements of the respective laser application

**Procedure**

**(1)** Tie the system components to the machine frame well thermally

**(2)** Keep thermal environmental conditions constant

**(3)** If available, switch on water cooling and/or air cooling on the 3-Axis Laser Scan System already before calibration and standard operation[3]

**(4)** Allow the 3-Axis Laser Scan System to warm up before calibration and standard operation

(1) Exceeding a critical temperature can lead to the failure of an xy Scan System or a Dynamic Focusing Unit, for example.

(2) Thermal changes of system components can have an impact on their mechanical, electrical and optical properties and can therefore, also lead to an offset and/or Gain Error in the 2D Working Field.

(3) Optionally, the Dynamic Focusing Unit and xy Scan System are equipped with corresponding cooling channels.

## 4.4 Beam Parameters and Laser Control

In this Chapter:



### 4.4.1 Setting Laser Power, Beam Diameter, Beam Divergence

| Relevant Process Parameters |
|---|
| • Internal Beam Expansion Factor (Dynamic Focusing Unit), Page 24 |
| • Allowed Laser Power (Dynamic Focusing Unit), Page 17 |
| • Input Aperture (Dynamic Focusing Unit), Page 18 |
| • Allowed Laser Power (xy Scan System), Page 17 |
| • Allowed Output Density (xy Scan System), Page 17 |
| • Damage Threshold (xy Scan System), Page 23 |
| • Aperture (xy Scan System), Page 18 |

**Procedure**

**(1)** Collimate the laser beam entering the Dynamic Focusing Unit.(1)

**(2)** Make sure that the laser beam is not directed at system components (for example, to Mirror) with excessive laser power density.
Otherwise, damage to system components or errors in the laser application may occur.

**(3)** Make sure that vignetting of the laser beam cannot occur.
Otherwise, damage to system components or errors in the laser application may occur.

**(4)** When adjusting the laser power, beam diameter and beam divergence, observe:
- Make sure that the maximum allowed laser powers, laser densities and damage thresholds specified for the system components are not exceeded
- Correspondingly, avoid beam diameters and beam expansion factors that are too low
- If relevant, also observe beam convergence of the laser beam

**(5)** Make sure that the laser beam is not so significantly expanded that vignetting of the laser beam occurs:
- Correspondingly, avoid beam diameters and beam expansion factors that are too high.
- If relevant, also observe beam divergence of the laser beam

**(6)** Observe the specified internal beam expansion factor and the specified input aperture of the Dynamic Focusing Unit.

**(7)** Observe the specified apertures of the xy Scan System.

**Notes**

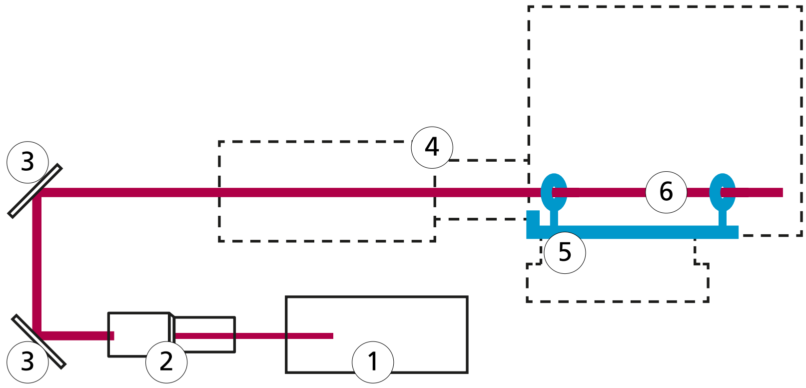
- For many system configurations, an appropriately designed beam expander is required to set the beam diameter and beam divergence.
- Collimation modules for fiber lasers are available from SCANLAB. SCANLAB checks whether these are suitable for the lasers used.

(1) Generally, SCANLAB designs Dynamic Focusing Unit and Correction File for a collimated input beam. In particular, the laser beam entering excelli*SHIFT* must be collimated as accurately as possible.

### 4.4.2 Aligning the Beam Position

**Prerequisites**

- At the beam path between the laser and the Dynamic Focusing Unit, 2 Adjustment Mirror are installed. Thus, you can adjust the position and alignment of the incoming laser beam, see Figure 7, Page 45.
  If the Dynamic Focusing Unit and xy Scan System are not directly connected by an adapter (or for example, by a FLEX housing) at the time of installation:
  - It may be necessary that additional Adjustment Mirrors and temporarily an Adjustment aid in the beam input between the Dynamic Focusing Unit and xy Scan System need to be installed. Thus, you can also optimally align the laser beam with the beam entrance of the xy Scan System.
- The laser beam needs to be correctly aligned with the optical axes of the Dynamic Focusing Unit and xy Scan System: the laser beam should be tilt-free and centered on the entrance apertures of the Dynamic Focusing Unit and xy Scan System.
  With a Gaussian laser beam profile, the following maximum tolerances for the beam position apply to most applications (relative to the optical axis of the Dynamic Focusing Unit):
  Tilt of the laser beam .......................... < 5 mrad
  Displacement ..................................... < 0.3 mm
- For lasers with a top hat rectangular beam profile: the setting may need to be even more precise.
- The laser beam must be adjusted as accurately a possible to prevent vignetting and errors in the 2D Working Field or 3D Working Volume. In addition: The greater the precision during adjustment, the better the calibration result. Avoid vignetting in particular when using lasers with very high laser powers. If necessary, reduce the beam diameter to a suitable value.
- For beam adjustment, an Adjustment aid with 2 pinholes or with 2 cross-hairs rotated by 45° is needed.
  - The Adjustment aid must be designed such that you can ascertain whether the above-mentioned tolerances can be observed.
  - Apertures and the distance between the 2 pinholes must be selected appropriately.
  - For some laser wavelengths, cross-hairs are more suitable than pinholes.
- Laser must be:
  - Without fiber adapter
  - Without collimation module




**Legend**

1. Laser
2. Beam Expander (optional)
3. Adjustment Mirror
4. Removed during beam adjustment: Dynamic Focusing Unit and xy Scan System
5. Adjustment aid
6. Target beam axis

7

Aligning the laser beam.

**Procedure**

- Case A: Dynamic Focusing Unit and xy Scan System are installed separately
- Case B: Dynamic Focusing Unit and xy Scan System are connected with a mechanical adapter after installation

(a) Case A: Dynamic Focusing Unit and xy Scan System are installed separately

(1) With the Dynamic Focusing Unit and xy Scan System removed, secure the Adjustment aid in the place of the xy Scan System so that the pinholes or cross-hairs are on the target beam axis of the xy Scan System, see Figure 7, Page 45.

(2) Proceed with the beam adjustment, for example, using the "Walking the Beam" method. Use the first Adjustment Mirror in the beam path in combination with the first pinhole in the beam path to adjust the laser beam position and the second Adjustment Mirror in combination with the second pinhole to adjust the laser beam angle. As a general rule, several iterations are necessary in which the position and angle are repeatedly adapted in alternation.

(3) Install the Dynamic Focusing Unit.

(4) Adjust the position and alignment of the Dynamic Focusing Unit until the laser beam is running centered through the 2 pinholes or cross-hairs of the Adjustment aid. Leave the 2 Adjustment Mirrors unchanged.

(5) Remove the Adjustment aid again.

(6) Mount xy Scan System.

(b) Case B: Dynamic Focusing Unit and xy Scan System are connected with a mechanical adapter after installation

(1) With the Dynamic Focusing Unit and xy Scan System removed – unlike in Figure 7, Page 45 – secure the Adjustment aid in the place of the Dynamic Focusing Unit so that the pinholes or cross-hairs are on the target beam axis.

(2) Proceed with the beam adjustment, for example, using the "Walking the Beam" method, see step 2 in Case A: Dynamic Focusing Unit and xy Scan System are installed separately.

(3) Remove the Adjustment aid again.

(4) Mount Dynamic Focusing Unit and xy Scan System.

### 4.4.3 Controlling the Laser by RTC Board

| Relevant Process Parameters |
|---|
| • Beam Diameter (Focal Plane), Page 19 |
| • Laser frequency (repetition rate) to obtain separated laser pulses<br>≤<br>[marking speed / Beam Diameter (Focal Plane)] |
| • Laser Power<br>User-defined value. Must fit laser, marking substrate, test pattern, marking speed. |

**Procedure**

**(1)** Make sure that the laser is correctly wired to the intended RTC connector.

**(2)** Make sure that the correct RTC laser mode is set in the user program.

**(3)** Make sure that the laser control signals are appropriately configured, see RTC Manual.

**(4)** With laserDESK: Make sure that the appropriate laser definition file is set.

**(5)** Depending on the marking substrate and laser, it can be advisable to work with separate laser pulses during calibration. Imaging quality and focus position can thus be analyzed optimally. Set the following laser parameters:
- Laser frequency (repetition rate) to obtain separated laser pulses
- Beam Diameter (Focal Plane)
- Laser Power

## 4.5 Controlling Positions of xy Scan System and Dynamic Focusing Unit by RTC Board

| Relevant Process Parameters |
|---|
| • 2D Working Field Size (Typical), Page 15 |
| • Maximum Focus Shift in z Direction (±), Page 25 |
| • Calibration Factor $K_{xy}$, Page 21 |
| • Calibration Factor Kz, Page 22 |

**Goal**

- xy Scan System and Dynamic Focusing Unit are controlled with the correct position values (when controlled by an RTC Board)
- Targeted positions are safely reached in the 2D Working Field or 3D Working Volume

**Procedure**

**(1)** Use a RTC Board with enabled 3D option.

**(2)** Make sure that the xy Scan System and Dynamic Focusing Unit are correctly connected to the RTC Board with the right cables and are supplied with suitable power. For details on this, see the associated manuals.

**(3)** For control, use only a Correction File that is calculated for the system components used and the desired system parameters, see Chapter 4.1 "Optical System Configuration", Page 35.
- Use a `D3_xxxx.*`-Correction File.
- *Do not* use the 1to1-Correction File.
- Make sure that the Correction File is calculated for the Working Distance A and Distance B used, see Chapter 4.2 "Ensuring the Proper Mechanical Configuration of System Components", Page 36.
- See also Chapter 7 "Appendix A: About Correction Files", Page 95.

**(4)** Make sure that the control values in the user program relate to the SCANLAB Reference Coordinate System, see Figure 5, Page 36.

**(5)** In RTC user programs, you have to convert the target positions in mm (in the 2D Working Field or 3D Working Volume) to control values in bits. For this, use Calibration Factor $K_{xy}$, Page 21 and Calibration Factor Kz, Page 22. Note that the calibration factors – depending on the RTC Board, the mode (standard mode, compatibility mode) and the axis to be controlled (xy or z) – can relate to either 20 bits or 16 bits, see Chapter 11 "Appendix E: About Calibration Factors", Page 109.
See also Table 12 Product-specific notes, Page 111.

**(6)** When defining test patterns, observe:
- 2D Working Field Size (Typical)
- Maximum Focus Shift in z Direction (±)

If these values are exceeded, this can cause vignetting of the laser beam and, also damage to the 3-Axis Laser Scan System.

**(7)** Make sure during calibration (= Optimizing Correction Files ("Calibration Steps"), Page 55):
- Offset is set to 0
- Gain remains unchanged

## 4.6 Make Settings for Test Pattern Marking

When marking the test patterns in Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55, the commanded positions must be safely reached.

For this, in your marking software, you need to set the suitable values for:

- Setting Speeds, Page 49
- Setting Delays, Page 50

### 4.6.1 Setting Speeds

| Relevant Process Parameters |
|---|
| • Maximum Jump Speed for Marking Test Patterns, Page 26 |
| • Maximum Marking Speed for Marking Test Patterns, Page 26 |

**Procedure**

**(1)** Set the jump speed for marking test patterns to a low value.

**(2)** Set the marking speed to a value with which all test patterns are marked in suitable quality.

**Notes**

- To mark test patterns, you should set the jump speed to a value far below the maximum possible jump speed (of the xy Scan System *and* Dynamic Focusing Unit). For this purpose, in laserDESK XML configuration file, SCANLAB specifies a maximum jump speed that applies to the *entire* 3-Axis Laser Scan System.
- In the laserDESK XML configuration file, SCANLAB specifies a Maximum Marking Speed for Marking Test Patterns in Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55.

  For good geometric fidelity, the marking speed set in your marking software should always be *below* this value. At the same time, it should be optimally adapted to the requirements of each individual calibration step. SCANLAB can not provide a universal recommendation for a very specific marking speed value as this is dependent, amongst other things, on the laser and marking substrate and on whether or not the marking result focuses on high contrast or separability of individual laser pulses.
- For the actual laser applications, you can re-adapt the speed values to the respective requirements of precision and throughput, after calibration has been completed.
- In the manuals, only the xy Scan System speeds are usually specified in rad/s. These can be converted into mm/s in the 2D Working Field using the focal length of the F-Theta objective or using the working distance. For a 3D Configuration, however, only SCANLAB has the necessary expertise to estimate corresponding speeds, which take into account the dynamic properties of all axes in the respective configuration.
- If necessary contact SCANLAB for a suggestion of appropriate speeds both for the 3D calibration and for the intended application.

### 4.6.2 Setting Delays

| Relevant Process Parameters |
|---|
| • Tracking Error (Dynamic Focusing Unit), Page 31 |


- Case: varioSCAN or varioSCAN FLEX and SCANahead System, Page 51
- Case: varioSCAN or varioSCAN FLEX and Tracking Error System, Page 52
- Case: excelliSHIFT and SCANahead System, Page 53
- Case: excelliSHIFT and Tracking Error System, Page 54

### Case: vario*SCAN* or vario*SCAN* FLEX and SCANahead System

- A SCANahead System is, for example, an excelli*SCAN*

**(1)** In your marking software, switch on the Tracking Error between vario*SCAN* and xy Scan System. If you program the RTC6 board yourself, use the RTC6 command **set_timelag_compensation** to specify the Tracking Error t_tracking_z for vario*SCAN*. See also Table 5, Page 51.

**(2)** Set the following parameters for the xy Scan System to 100%:
- End Scale
- Corner Scale
- Acceleration Scale

Table 5 Product-specific notes on step 1

| SCANLAB Product | Typical[a] Tracking Error value t_tracking_z |
|---|---|
| fiberSYS | 0.84 ms |
| vario*SCAN* 20 | 0.9 ms |
| vario*SCAN* 40 | 1.4 ms |
| vario*SCAN* 40 FLEX | 1.4 ms |
| vario*SCAN* 40i FLEX | 0.7 ms |
| vario*SCAN* 60 FLEX | 0.7 ms |
| vario*SCAN* $_{de}$ 20i | 0.55 ms |
| vario*SCAN* $_{de}$ 40i | 0.7 ms |
| vario*SCAN* II 20i | 0.55 ms |
| vario*SCAN* II 40i | 0.7 ms |
| vario*SCAN* II 60i | 0.7 ms |

(a) Just for overview. Important: use the value from the corresponding manual!

### Case: vario*SCAN* or vario*SCAN* FLEX and Tracking Error System

- A Tracking Error System is, for example, an intelli*SCAN* or *SCAN*cube

| Relevant Process Parameters |
|---|
| • Tracking Error (xy Scan System), Page 31 |
| • Tracking Error (Dynamic Focusing Unit), Page 31 |

**(1)** If you use an RTC6 board for control, switch on Tracking Error compensation between vario*SCAN* and xy Scan System in the marking software. If you program the RTC6 board yourself, use the RTC6 command **set_timelag_compensation** to specify the Tracking Error t_tracking_z for the vario*SCAN* and the Tracking Error t_tracking_xy for the xy Scan System used. See also Table 5, Page 51.

**(2)** In your marking software, set:

| | |
|---|---|
| Jump delay | • If t_tracking_z > t_tracking_xy: 2.0 × t_tracking_z<br>• Otherwise: 2 × t_tracking_xy |
| Mark delay | 1.0 × t_tracking_xy |
| Polygon delay | 0.5 × t_tracking_xy |
| LASERON delay | 0.6 × t_tracking_xy |
| LASEROFF delay | 1.2 × t_tracking_xy |

### Case: excelli*SHIFT* and SCANahead System

- A SCANahead System is, for example, an excelliSCAN

| **Relevant Process Parameters** |
|---|
| • Focal Length (F-Theta Objective), Page 24 |

**(1)** Start Dynamics Matching Tool, Page 120.

**(2)** Enter the objective focal length in the field "**focal length [mm]**".
The maximum z speed for this focal length with the current Tracking Error value (for excelli*SHIFT*) is shown automatically. Note that you must change this value, if you change the objective.

**(3)** When delivered, the excelli*SHIFT* has a Tracking Error of 95 µs, which is also shown in the Dynamics Matching Tool. SCANLAB recommends this value for the calibration steps. If excelli*SHIFT* has been set differently in the meantime: in Dynamics Matching Tool, reduce z speed until it shows 95 µs Tracking Error.

**(4)** Click **Change + Save** to write the Tracking Error 95 µs to excelli*SHIFT* memory.(1)

**(5)** Make a note of the 2 dynamic values (maximum speed and Tracking Error) for later use in the marking software.

**(6)** In your marking software, switch on Tracking Error compensation between excelli*SHIFT* and xy Scan System. If you program the RTC6 board yourself, use the RTC6 command **set_timelag_compensation** to specify the Tracking Error for the excelli*SHIFT* from step 5 (current Tracking Error). You can also read this value out again in Dynamics Matching Tool.

**(7)** Set the following parameters for the xy Scan System to 100%:
- End Scale
- Corner Scale
- Acceleration Scale

(1) It may be necessary to optimize this value later for the actual laser application, see Chapter 6.4 "Dynamic Control".

### Case: excelli*SHIFT* and Tracking Error System

- A Tracking Error System is, for example, an intelliSCAN or SCANcube

| **Relevant Process Parameters** |
| --- |
| • Focal Length (F-Theta Objective), Page 24 |
| • Tracking Error (xy Scan System), Page 31 |

**(1)** Start Dynamics Matching Tool, Page 120.

**(2)** Enter the objective focal length in the field "**focal length [mm]**". Note that you must change this value, if you change the objective.

**(3)** Only with intelli*SCAN* as xy Scan System:
- Click **Measure intelliscan's timelag** button. The xy Scan System Tracking Error is shown in field "New timelag Z" and the Tracking Error for the excelli*SHIFT* is calculated based on this value. Alternatively, you can enter the xy Scan System Tracking Error manually in this field. The maximum z speed is shown automatically in the "Max. z-speed" field.

**(4)** Only with *SCAN*cube as xy Scan System:
- In the field "New timelag Z", enter the Tracking Error of the xy Scan System. The maximum z speed is shown automatically in the "Max. z-speed" field.

**(5)** Click **Change + Save**.

The values are written permanently to excelli*SHIFT* memory. If necessary, the Tracking Error and speed are recalculated when clicked for the purpose of appropriate rounding.

**(6)** In your marking software, set:

| | |
| --- | --- |
| Jump delay | 2.0 × t_tracking_z |
| Mark delay | 1.0 × t_tracking_xy |
| Polygon delay | 0.5 × t_tracking_xy |
| LASERON delay | 0.6 × t_tracking_xy |
| LASEROFF delay | 1.2 × t_tracking_xy |

**(7)** For t_tracking_z = t_tracking_xy, use the value shown in the field "New timelag Z" in Dynamics Matching Tool.

# 5 Optimizing Correction Files (“Calibration Steps”)

**Notice!**

Control values and measured values must always be within the SCANLAB Reference Coordinate System for Step 1: Initially Adjusting the Dynamic Focusing Unit, Page 59…(Optional) Step 6: Focus Plane Correction, Page 81!

The calibration steps, see Figure 8, Page 56, aim to optimize control of a 3-Axis Laser Scan System in such a way that static errors in the 2D Working Field or 3D Working Volume are largely compensated for by software (= optimized Correction File).

For this purpose, Correction File files are generated in some steps, see Figure 8, Page 56.

High positioning accuracy is only achieved if you subsequently use these optimized Correction Files for control.

In general, SCANLAB recommends performing Step 1: Initially Adjusting the Dynamic Focusing Unit, Page 59 to (Optional) Step 7: Determining the Maximum Control Values for Clipping (Value Range OK?), Page 82 at least 1× in order to achieve an optimal result.
*You must adhere to the specified sequence!*

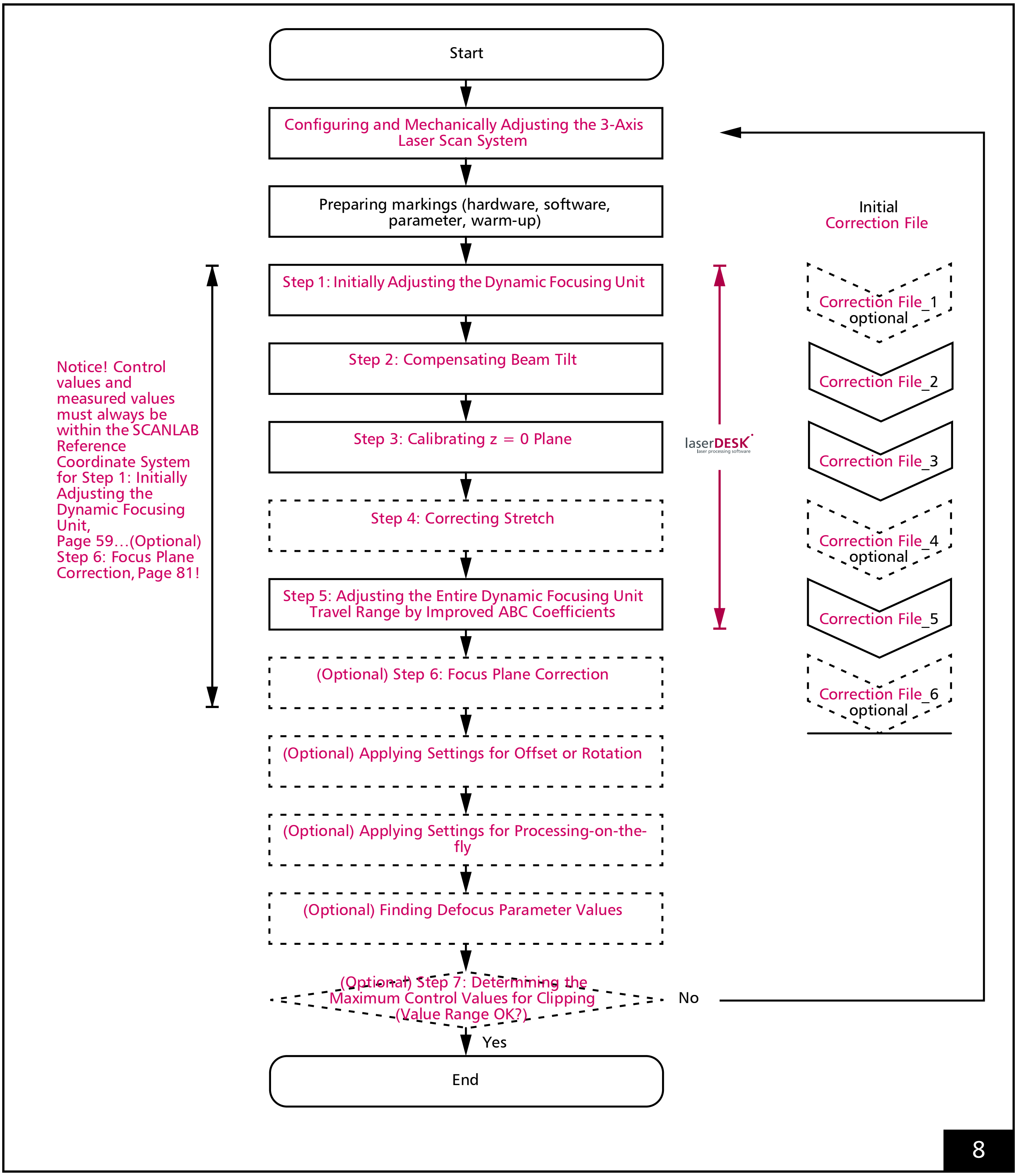
Depending on the exact configuration of the 3-Axis Laser Scan System, the calibration procedures may differ slightly, see case distinctions.

Depending on the respective starting status, and the respective goals, you may have to perform some sub-steps of the procedure several times or, conversely, can omit individual sub-steps in certain circumstances, that is:

- Whether you are establishing and setting up a complete system from scratch
- Whether you are replacing or changing a system component
- Whether you wish to better tune an already running system
- The precision you wish to achieve in the respective laser application
- The errors you actually have to eliminate or compensate

**Notes for laserDESK Users**

- Observe:
  – Figure 8, Page 56
  – Chapter 13.1 ”laserDESK 3D Calibration Wizard”, Page 114




3D Calibration Process: flow chart.

#### Notes on marking test patterns

> **Warning!**
>
> Before executing a test program, make sure that all applicable regulations on laser safety are met. Also observe the safety instructions in Chapter 3 "Safety".

- In the calibration procedures, test patterns must be marked on marking substrates using the 3-Axis Laser Scan System and Correction File. For this, you will need marking substrates and test programs.
- Suitable marking substrates are flat substrates, for example, of anodized aluminum or sheet steel. The evenness of the marking substrates is important if an accurate result is to be achieved.
- In the test programs, the test patterns must be defined as described in the following chapters.
  - Observe the SCANLAB Reference Coordinate System convention, see Page 36.
  - It must be possible to measure certain test patterns relative to the SCANLAB Reference Coordinate System after marking (at least in relation to the sign). In these test patterns, always integrate axis markings for identification of the x and y direction of the SCANLAB Reference Coordinate System.
  - Set any set coordinate transformations (for example, offset or rotation) to zero before the calibration procedure in order to avoid errors in the calibration procedure. After calibration, the previously defined values may no longer be valid.
  - Use the marking parameters developed in Chapter 4.6 "Make Settings for Test Pattern Marking", Page 49 so that easily measurable test patterns are produced on the marking substrates.
- In Step 1: Initially Adjusting the Dynamic Focusing Unit, use the Correction File provided by SCANLAB.
- Before executing a test program, make sure that you always load and assign the latest (optimized) Correction File.
  - In an RTC user program using the RTC command **load_correction_file** and **select_cor_table**.
  - In laserDESK, by the laserDESK hardware configuration.
  - If possible, mark test patterns under similar thermal conditions to the actual laser application. The 3-Axis Laser Scan System should be warmed up for at least 30 minutes before the calibration process in order to achieve maximum precision (system with excelli*SHIFT*: 2 hours). SCANLAB recommends monitoring the temperature of the galvanometer scanners and servo boards(1) and, if accessible, the xy Scan System housing and holder. The laser and the rest of the system must also be thermally stable (but not necessarily stabilized). (If available) switch on water cooling and/or air cooling before calibration procedure.
  - When using a vario*SCAN* FLEX, its stepper motor must be initialized and referenced before the calibration procedure (for example, by RTC6 command **stepper_init**).

(1) With intelli*SCAN* systems, temperature information can be read out digitally as status information, see intelli*SCAN* and RTC Manual.

#### Notes on Analyzing Test Pattern Marking Results and Gererating the Correction File

- You have to measure the test pattern marking results. For this, you need suitable measuring tools such as a coordinate measuring machine or digital reflected-light microscope.
- Unless otherwise specified, the measured values must always correspond to the absolute positions in the SCANLAB Reference Coordinate System. Note the SCANLAB Reference Coordinate System convention, see Page 36 or the corresponding axis markings in the marking result, see above note on marking test patterns.
- With the help of the measurement data, in general, you must then generate a new Correction File, see Figure 8, Page 56. For this, you need SCANLAB software tools, see Chapter 13 "Appendix G: About SCANLAB Software Tools", Page 113.

  Sometimes a new Correction File cannot be generated straight away. In this case, you must analyze the error message issued and the associated user documentation and fix the error.
- Always assign a unique file name for each created Correction File. An option (like in laserDESK) is to write the respective correction method into the file name of the Correction File created with it (for example, `D3_XXXX_Stretch.ct5`).
  After a complete 3D calibration the newly generated Correction File could be named as follows:

  `D3_1234_SNxxxxxx_BeamTilt_xy-Plane_Stretch_ABC.ct5`
- For the calibration steps, SCANLAB software tools create log files (`*.txt` or `*.log`) with the respective measurement data and/or calculation options. It is advisable to save these files for diagnostic purposes. If you need support, you should also send these files to SCANLAB.

## 5.1 Step 1: Initially Adjusting the Dynamic Focusing Unit

### Goal

- When the xy Scan System and Dynamic Focusing Unit are controlled, the laser beam moves to its correct focus position (otherwise, you have to readjust). This is:
  - With commanded Reference Point Coordinates
    - the Reference Point in 2D Working Field or 3D Working Volume, see Figure 37, Page 112
  - With commanded position (0, 0, 0)
    - exactly position (0, 0, 0)
- Step 1: Initially Adjusting the Dynamic Focusing Unit must be carried out first as the basis for all further steps
- The concrete steps depend on the system components:

| | |
|---|---|
| vario*SCAN*<br>vario*SCAN* FLEX<br>power*SCAN* II 50i<br>power*SCAN* II 70i | Chapter 5.1.1 "Procedure with varioSCAN or varioSCAN FLEX", Page 61 |
| excelli*SHIFT* with F-Theta objective | Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65 |
| fiberSYS without F-Theta objective | Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65 |

| **Relevant Process Parameters** |
|---|
| • Calibration Factor Kz, Page 22 |
| • Rayleigh Length, Page 27 |
| • Reference Point Coordinates, Page 28 |
| • Maximum Focus Shift in z Direction (±), Page 25 |
| • Stepper Motor Value (Dynamic Focusing Unit), Page 29 |

### Notes

- To determine the focus position, you must position a marking substrate at the Reference Point or in position (0, 0, 0) and mark a test pattern on it. With a positive z coordinate value(1) of the Reference Point, the marking substrate must be correspondingly closer to the xy Scan System than in Working Distance A. You must analyze the marking results with measurement tools. Depending on the result, you must then (if necessary iteratively) readjust the focus position and mark and analyze further test patterns.
- In system configurations with F-Theta objective, in general, after Reference Point Coordinates have been commanded:
  - xy Scan System is in neutral position
  - Dynamic Focusing Unit is in neutral position(2)
- In system configurations without F-Theta objective, after Reference Point Coordinates have been commanded:
  - xy Scan System is *not* in neutral position
  - Dynamic Focusing Unit is in neutral position(2)
- In system configurations with Dynamic Focusing Unit the following applies:
  - Do not change the SCANLAB-specified values for Calibration Factor Kz and Calibration Factor $K_{xy}$. Otherwise, inaccuracies may result.

(1) See also Reference Point Coordinates, Page 28.

(2) The neutral position is the center travel position of the Dynamic Focusing Unit which it moves to after z output value $z_{out}$ = 0 has been commanded by the control.

### Requirements on the Test Pattern

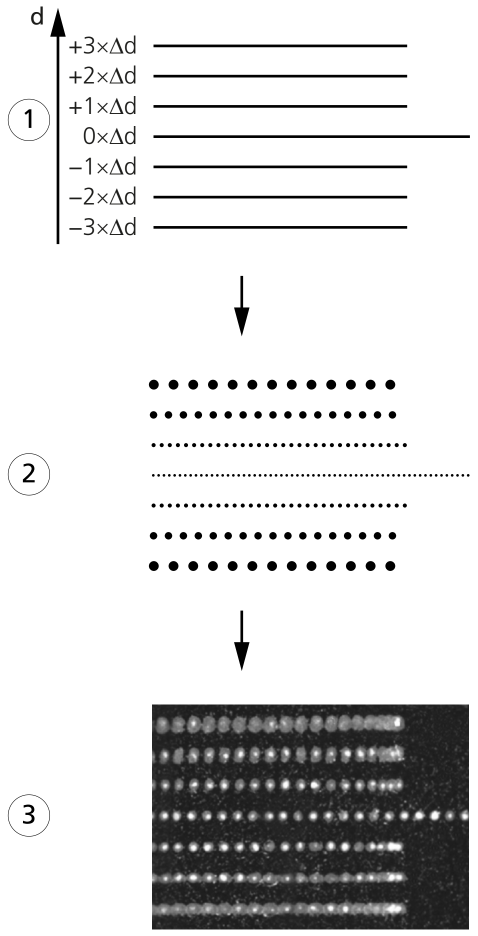
- 7 parallel lines (for different defocus values), see (1) in Figure 9, Page 60
- The central line is slightly longer on one side (for later identification of the individual lines)
- Recommended line spacing:
  4× minimal spot diameter
  – The line pattern should be
    - As small as possible so that it represents a specific position in the 3D Working Volume
    - Large enough that the individual lines can still be analyzed

### Requirements on the Marking Software

- The marking software assign a different defocus value d to each line by RTC command **set_defocus** (symmetrically to the central line):
  – Central line defocus value d = 0 mm
  – Starting from the central line, the defocus values from line to line should increase in one direction in equal or increasing increments (and decrease symmetrically in the other direction)
  – Defocus values for adjacent lines should differ by at least half a Rayleigh Length(1)
    - In Figure 9, Page 60 with 7 lines, this means $d = -3\times\Delta d\ldots+3\times\Delta d$ with $\Delta d \geq$ Rayleigh Length $z_R$ / 2 (2)
  – Calling RTC command **set_defocus**( `Shift` ) with `Shift` = Calibration Factor Kz (Dynamic Focusing Unit × d

### Requirements on the Marking Result

- See (2) in Figure 9, Page 60:
  (1) Line with smallest spots is the central line
  (2) Laser spot quality decreases symmetrically in + and –




**Legend**

1. Test pattern defined in the marking software with defocus values to be set.
2. To-be-expected marking result when focus setting is correct:
   – Line with smallest spots is the central line
   – Laser spot quality decreases symmetrically in + and –
3. Real marking result when focus setting is correct (microscopic image).

9

Test pattern for checking the focus positions.

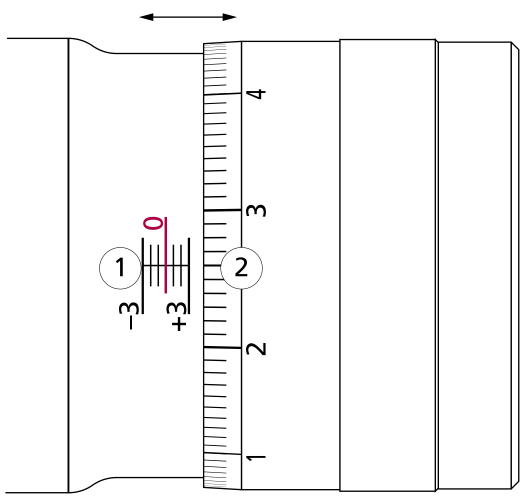
(1) The difference should not be too significant. Otherwise, you cannot see any marking at all. Within a Rayleigh Length, the spot radius increases by factor $\sqrt{2}$ .

(2) For rough setting, it can be advisable to select a non-linear sequence of steps for the defocus values from line to line, for example, d = –9×Δd, –4×Δd, –1×Δd, 0×Δd, +1×Δd, +4×Δd, +9×Δd. This increases the differences between the marked lines.

#### 5.1.1 Procedure with vario*SCAN* or vario*SCAN* FLEX

vario*SCAN* and vario*SCAN* FLEX are equipped with a mechanical adjustment option for fine adjustment of the beam divergence and thus for adjusting the focus.

- With the vario*SCAN*, the focusing ring can be rotated, see Figure 10, Page 61.
- vario*SCAN* FLEX has a built-in stepper motor. This must be brought to the position corresponding to the respective Correction File as specified in the manual. See also Product-specific notes on step 5, Page 63.




**Legend**

1. Scale on housing (graduations: 1 mm)
2. Scale on focusing ring

10

vario*SCAN* focusing ring. Schematic illustration.
A full focusing ring rotation changes the distance to 0 (red, (1)) by approx. 1 mm (and thus vario*SCAN* total length).

**Procedure**

**(1)** In your marking software, define the test pattern (1) according to Figure 9, Page 60.

**(2)** Position the test pattern in your marking software such that the center of the test pattern is at the Reference Point (see Chapter 12 "Appendix F: About the Reference Point", Page 112).

**(3)** Position the marking substrate surface as accurately as possible on the Reference Point.

**(4)** Then – with loaded and assigned Correction File – mark the test pattern on the marking substrate.

**(5)** Check the marking result with your measurement tools whether it meets *all* Requirements on the Marking Result, see also (2) in Figure 9, Page 60:
- – Line with smallest spots is the central line
- – Laser spot quality decreases symmetrically in + and –

Otherwise, you must readjust the focus in step 6.

Example: In Figure 11, Page 62 (1), focus position is $+2 \times \Delta d$. In this case, the focus is to be shifted to negative z direction.

**(6)** If step 5 has not been successfully, readjust the focus:
- – Observe Product-specific notes on step 5, Page 63
- – With a vario*SCAN*, turn the focusing ring clockwise (in laser beam direction or, from the vario*SCAN* beam entrance looking towards the vario*SCAN* beam exit)
- – With a vario*SCAN* FLEX, move the stepper motor to smaller control values (towards the bottom limit switch)

**(7)** Repeat step 3…step 5 until *all* Requirements on the Marking Result are met:
- – Line with smallest spots is the central line
- – Laser spot quality decreases symmetrically in + and –

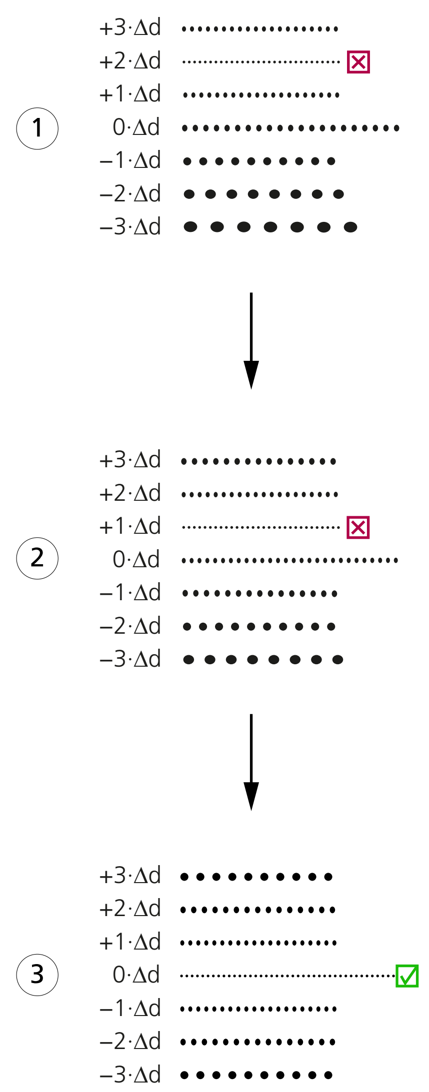
**(8)** Do not make further changes to the position of the focusing ring or stepper motor in the later calibration process if fine adjustment has been carried out.
*Important: This focusing ring position is only valid for the currently adjusted scan system and the associated Correction File.*

**(9)** With vario*SCAN* 20 and vario*SCAN* 40:
secure the focusing ring by the counter-ring[(1) (2)]

**(10)** With vario*SCAN* FLEX:
make a note of the determinated stepper motor position in step 7 (laserDESK shows it in "Motor control" dialog).
*Important: This stepper motor position is closely connected with the Correction File. Another Correction File requires a different stepper motor position. The stepper motor must be initialized and repositioned with every restart of the system.*

(1) vario*SCAN* II has no counter-ring. The focusing ring seats always securely enough.

(2) If this causes the focus position to change slightly, this is compensated for in Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients, Page 79.




**Legend**
1. Marking result 1
2. Marking result 2
3. Marking result 3
   – Line with smallest spots is the central line
   – Laser spot quality decreases symmetrically in + and –

11

Step 7: improving marking results of vario*SCAN* step-by-step by fine adjusting the focus.

Table 6 Product-specific notes on step 5

| SCANLAB Product | Notes |
|---|---|
| vario*SCAN* 40 in FLEX housing | • You must open FLEX housing to access the focusing ring, see associated manual. |
| vario*SCAN* 40 FLEX | • Before the first marking: carry out a stepper motor initialization run with the laser *switched off* (for example, by RTC command **stepper_init**). Then set the Position of the focusing optics, Seite 29 which is specified in the manual for this configuration. Move the stepper motor iteratively (for example, by RTC command) in the range from ±200 bit or ±2.6 mm around the specified Position of the focusing optics, Seite 29, see section on system-specific characteristics in vario*SCAN* 40 FLEX manual. For positioning stepper motors, $K_{xy}$ and Kz of the Correction File do not apply, but other calibration factors instead, see specifications in the respective manual. |
| vario*SCAN* FLEX in [power*SCAN* II 50i \| power*SCAN* II 70i] | • Before the first marking: carry out a stepper motor initialization run with the laser switched off (for example, by RTC command stepper_init). Then set the Position of the focusing optics, Seite 29 which is specified in the manual for this configuration. Move the stepper motor iteratively (for example, by RTC command) in the range from ±200 bit or ±2.6 mm around the specified Position of the focusing optics, Seite 29, see section on system-specific characteristics in varioSCAN 40 FLEX manual. For positioning stepper motors, $K_{xy}$ and Kz of the Correction File do not apply, but other calibration factors instead, see specifications in the respective manual.<br>• Move the stepper motor iteratively (for example, by RTC command) in the range from ±400 bit or ±2.6 mm around the specified Position of the focusing optics, Seite 29, see section on system-specific characteristics in [power*SCAN* II 50i manual \| power*SCAN* II 70i manual]. For positioning stepper motors, $K_{xy}$ and Kz of the Correction File do not apply, but other calibration factors instead, see specifications in the respective manual. |
| vario*SCAN* 20 | • If the focusing ring is not accessible, Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65 can be carried out for fine adjustment. However, this may reduce the accessible 3D Working Volume (in contrast to adjusting by focusing ring). |
| vario*SCAN* 40 | • If the focusing ring is not accessible, Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65 can be carried out for fine adjustment. However, this may reduce the accessible 3D Working Volume (in contrast to adjusting by focusing ring). |

Table 6 Product-specific notes on step 5 (cont'd.)

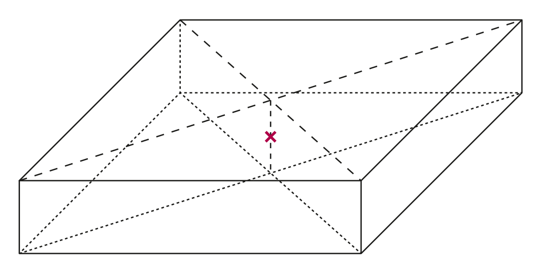
| SCANLAB Product | Notes |
|---|---|
| vario*SCAN* II 20 | • If the focusing ring is not accessible, Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65 can be carried out for fine adjustment. However, this may reduce the accessible 3D Working Volume (in contrast to adjusting by focusing ring). |
| vario*SCAN* II 40 | • If the focusing ring is not accessible, Chapter 5.1.2 "Procedure for excelliSHIFT with F-Theta Objective or fiberSYS Without F-Theta Objective", Page 65 can be carried out for fine adjustment. However, this may reduce the accessible 3D Working Volume (in contrast to adjusting by focusing ring). |

### 5.1.2 Procedure for excelli*SHIFT* with F-Theta Objective or fiberSYS Without F-Theta Objective

For system configurations with excelli*SHIFT*, the focus position can *only* be adjusted by adapting the ABC Coefficients. [1]

The initial adjustment of the Dynamic Focusing Unit focus position in position(0,0,0) is done by adapting *only* the *A Coefficient*.

Only later in Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients – when the focus position is adjusted in the entire travel range – also B Coefficient and C Coefficient are optimized.



12

Test position on the z coordinate in the 3D Working Volume.

**Procedure**

**(1)** For test position (0, 0, 0) carry out:

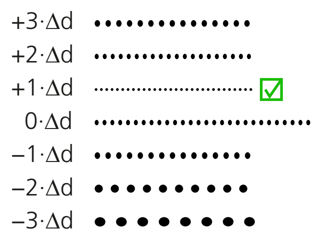
(a) Define the test pattern in your marking software as described in Figure 9, Page 60. In your marking software, position the test pattern so that the center of the test pattern is at the respective test position (0, 0, $z_{test}$).

(b) Position the surface of a suitable marking substrate as accurately as possible at the respective test position (0, 0, $z_{test}$) in the 3D Working Volume.

(c) With the Correction File loaded, mark the test pattern on the marking substrate.

(d) Check the marking result with your measurement tools (criteria: Line with smallest spots is the central line, Laser spot quality decreases symmetrically in + and –) and determine as a result, the corresponding defocus value d (in Figure 13, Page 65: d = +1×Δd).

(e) Determine for this line the according value $z_{out}$ as described in Chapter 9 "Appendix C: Determining Output Values", Page 104. Do this using the calculated defocus value d. Also note its sign.
This value $z_{out}$ is the new (optimized) value for the A Coefficient.




13

Step 1d: best focal quality line.

(1) If you use a device to adapt the beam divergence, only use it to collimate the incoming laser beam, not for focus adjustment with other divergence settings. With the excelli*SHIFT*, it is important that the incoming laser beam is collimated as accurately as possible.

**(2)** Generate a new Correction File containing the correct coefficients with CalibrationLibrary:

(a) Read the ABC coefficients from the supplied Correction File by **slcl_get_current_abc_coeffs**.

(b) Pass the following values to **slcl_set_abc_manually**:

- A Coefficient: value $z_{out}$ from step 1e. If you have determined a 16-bit value for $z_{out}$, multiply it by 16 before passing. (Note: A new ReadMe File containing the optimized value of the A coefficient is created for the new Correction File.)
- B Coefficient – from step 2a
- C Coefficient – from step 2a

**(3)** Use the newly calculated Correction File and once again mark test patterns in test position (0, 0, 0). Check the marking result:

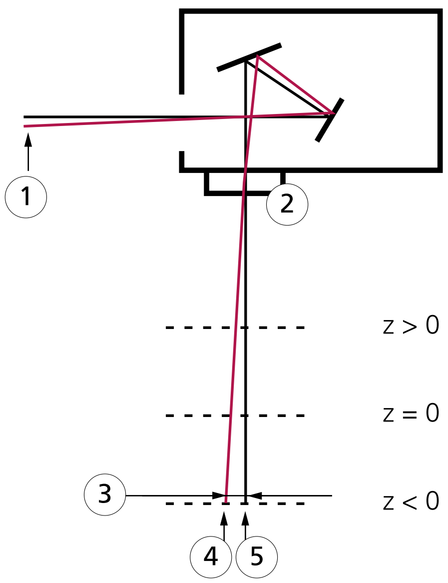
– Line with smallest spots is the central line

– Laser spot quality decreases symmetrically in + and –

If this is not the case, check whether you have used the correct sign for the defocus value when determining $z_{out}$ in step 1e.
Even with correct procedure, sometimes another iteration (with finer defocus step $\Delta$d) is necessary until the appropriate value for the A coefficient is found.
If this does not help either, contact SCANLAB.

**(4)** Check whether, together with the new Correction File (with the new A Coefficient), clipping to boundary values occurs and whether the output values at the Dynamic Focusing Unit are still within the permissible range. For this, proceed as described in Chapter 5.7 "(Optional) Step 7: Determining the Maximum Control Values for Clipping (Value Range OK?)", Page 82.

## 5.2 Step 2: Compensating Beam Tilt



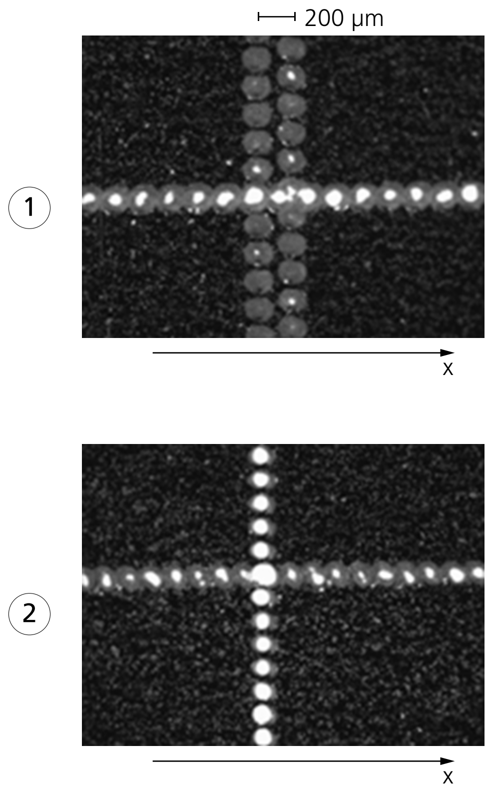

**Legend**
1. Angular Error
2. Non-Telecentric Objective
3. Offset
4. Beam Tilt
5. Ideal Position

14

Beam Tilt: the laser beam enters xy Scan System with a small Angular Error. As a result, the exiting laser beam is tilted.

**Goal**

- Errors that are caused by Beam Tilt, see Figure 14, Page 67 are compensated for by software (= optimized Correction File), see Figure 15, Page 67.




**Legend**
1. Unwanted marking result with offset.
2. Wanted marking result without offset.

15

Marking result before and after Step 2: Compensating Beam Tilt.

**Notes**

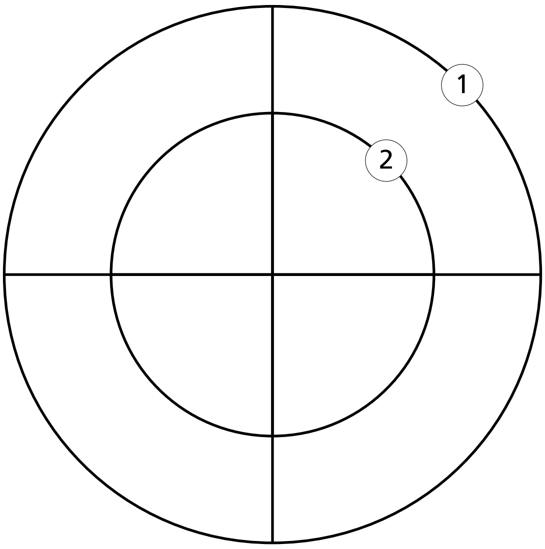
- Errors as a result of a Beam Tilt can be:
  - An offset of the 2D Working Field relative to its mechanically defined position, see Figure 14, Page 67, and consequently perhaps even clipping of the marking at the boundary.
  - In systems with 3D Working Volume (not: systems with telecentric objective), the effect that the offset changes continuously from the highest working plane to the lowest. This tilts the 3D Working Volume. This can have a negative influence on workpiece processing and must therefore, be compensated for.
  - With systems without an objective, the Beam Tilt not only has a negative impact on the shape of the 3D Working Volume, but also causes significant spot variations in the 2D Working Field.
- In principle, the following applies to 2D Configurations and 3D Configurations: a significant Beam Tilt causes vignetting in the xy Scan System. In some cases, it is not possible to compensate for this with software. In this case, you have to readjust the beam position at the beam input.
- For causes that trigger errors similar to a Beam Tilt, see Page 128.
- With a *telecentric objective*, the offset resulting from the tilt remains constant throughout the entire 3D Working Volume.

  This offset can, but does not necessarily have to be compensated for. Here, the Procedure described in the following does not necessarily reduce the offset.

  Instead, it rather identifies effects due to a tilted marking substrate or tilting of the travel axis of the elevation stage but without compensating them, see previous note. Often no optimized Correction File can be generated and an error message is outputted.

**Procedure**

In 2 consecutive steps, 2 concentric circles of different sizes (see Figure 16, Page 69) in 2 test planes are marked on the same marking substrate. In the marking result, the relative shift of the 2D Working Field in the 2 test planes are determined and written down (= $\Delta x$ and $\Delta y$ in Step 4). Using these values, an offset value must each be calculated. This offset value is then used to generate an optimized Correction File (= with offset compensation).




**Requirements**

1. Marking pattern for $z_{top}$ only
   Larger circle with cross-hairs and circle center point in 2D Working Field center
2. Marking pattern for $z_{bottom}$ only
   Like 1 but smaller circle

16

Test pattern for step 3.

**(1)** Define the 2 test planes $z_{top}$ and $z_{bottom}$ for the markings:

- Case A: 3D Configurations
- Case B: 2D Configurations
- Case C: System set-up does not permit marking substrate surfaces to be brought into the recommended planes

(a) Case A: 3D Configurations
SCANLAB recommends using the boundary planes of the 3D Working Volume as the test planes:

$$z_{top} = z_{max}$$
$$z_{bottom} = z_{min}$$

(b) Case B: 2D Configurations
(= no 3D Working Volume)
SCANLAB recommends the 2 planes resulting from the following calculation[(1)]:

(1) Calculate 4 Focus Length Values by the following formula and observe the 4 possible sign combinations:

$$l = \frac{-B \pm \sqrt{(B^2 - 4C(A \pm 31100))}}{2C}$$

For ABC Coefficients use the values saved in the current Correction File.
Enter A, B, C, l uniformly either as 16-bit values or as 20-bit values.

(2) Choose the 2 Focus Length Value $l_1$ and $l_2$ from one of these ranges:
16-bit values: [–32,768…+32,767]
20-bit values: [–524.288…+524.287]
Use uniformly either 16-bit values or 20-bit values.

(3) Calculate $z_{top}$ and $z_{bottom}$ using the following formula:

$$z_{top} = -l_2 / Kz$$
$$z_{bottom} = -l_1 / Kz$$

(1) Actually, for 2D Configurations, the 2D Correction File is only calculated for marking in a single plane. Nevertheless, in step 3, test patterns with sufficient focus quality can be marked at and between the 2 planes calculated in step 1 – in each case in the area of the 2D Working Field center (x = y = 0).

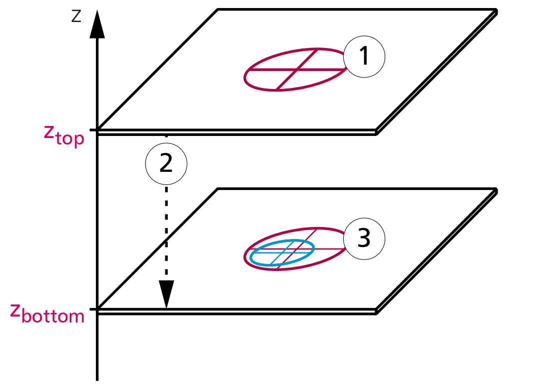
(c) Case C: System set-up does not permit marking substrate surfaces to be brought into the recommended planes
   - Select 2 test planes between the 2 planes recommended above.
     These should be as far apart from each other as possible (the larger the distance between the test planes, the more accurate the correction). They do not necessarily have to be on either side of the z = 0. plane.

**(2)** In your marking software, define the test pattern see Figure 16, Page 69.

**(3)** Mark[1] the test pattern from step 2 on a marking substrate, see Figure 17, Page 70:

(a) Position the marking substrate at (0, 0, $z_{top}$) using a lifting table[1] and mark the larger circle there.

(b) With a lifting table[1], move the marking substrate downwards (0, 0, $z_{bottom}$) and mark the smaller circle there.
When moving the marking substrate along the z direction, make sure that the marking substrate is not shifted in xy direction.



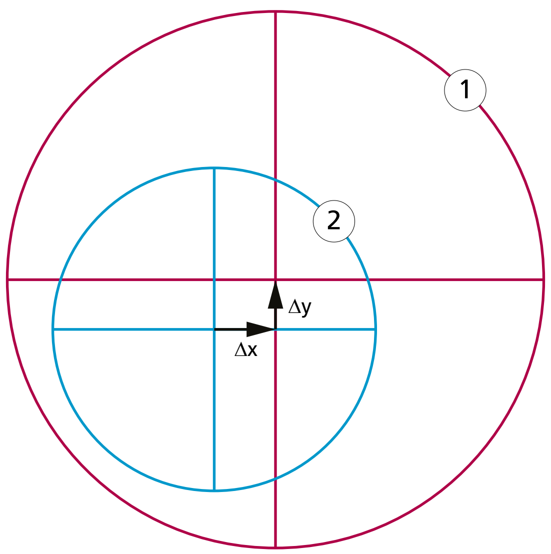

**Legend**
1. Marking at (0, 0, $z_{top}$)
2. Shifting the marking substrate down
3. Marking at (0, 0, $z_{bottom}$)

17

Step 3: marking on 2 test planes.

(1) If no lifting table is available, you can bring the marking substrate into different z positions for example, by underlaying plates and ensure a fixed xy position with an angular stop.

(4) To evaluate the shift of the 2D Working Field, use measurement tools to determine the offset (Δx, Δy) of the larger circle relative to the smaller circle. Take the center and cross-hairs of the smaller circle as reference. Observe the SCANLAB Reference Coordinate System convention (when measuring/analyzing the test pattern, make sure that the marking substrate is correctly aligned in xy direction).
Example in Figure 18, Page 71: the large (red) circle is offset to the upwards and to the right relative to the smaller (blue) circle. Here, the values for Δx and Δy are positive.




**Legend**
1. Marking result from $z_{top}$ (red)
2. Marking result from $z_{bottom}$ (blue)

18

Step 4: in marking result from step 3, determine offset (Δx, Δy) of the two circles.

(5) With CalibrationLibrary function **slcl_do_beam_tilt_calibration_measurement_data**:
Generate a new Correction File with Δx from Step 4 (= `DeltaXMM`) and Δy (= `DeltaYMM`) from Step 4.
Recommendation: ReadMe File and Correction File should be in the same directory. Then the calculation result is more accurate.

(6) Load the new Correction File into the memory of the RTC Board using the RTC command **load_correction_file** and assign it with the RTC command **select_cor_table**.

(7) Repeat step 3. Check the marking result. Ideally, both cross-hairs of the circles are now centered.(1)(2)

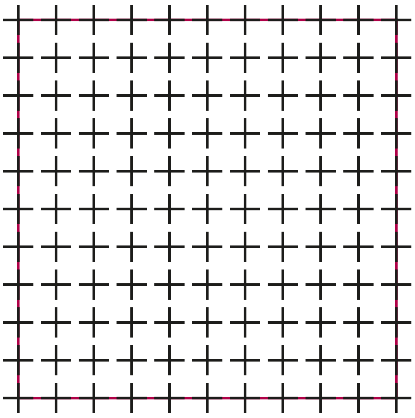
(8) Note that due to the compensating offset in the Correction File, the 3D Working Volume shifts overall in comparison with the starting position. If necessary, this shift can be compensated for at the end of the calibration process by **set_offset**, see Chapter 6.1 "(Optional) Applying Settings for Offset or Rotation", Page 84.(3)

(1) Exception: For systems with telecentric objective, an offset usually remains.
(2) If you can now see an offset twice as high as with the old Correction File, you have probably selected the wrong sign when for Δx and Δy.
(3) Correcting with **set_offset** leaves the tilt offset compensation by Correction File unchanged.

## 5.3 Step 3: Calibrating z = 0 Plane

### Goal

- To improve the xy positioning in the $z = 0$ plane[1] (= “nominal plane”)
- To reduce residual deviations (see Notes) in the xy position, which are not yet compensated for by the Correction File used until then.



**Requirements**

- $11 \times 11$ raster points (at least)
- These span an imaginary square over the entire 2D Working Field
- Square center point is in the center of the 2D Working Field
- Choose the symbol type of the raster points (+, ×, filled circle) so that it can be measured as accurately as possible with your measurement device

19

Test pattern for step 1.

### Notes

- Possible causes for residual deviations include:
  - Mechanical tolerances
  - Offset Error
  - Gain Error
  - Skew Error
  - Non-Linearity
  - Objective tolerances
- correXion pro and CalibrationLibrary use the same algorithms to generate Correction Files. However, as described below, data acquisition for calculation differs.
- Synonyms for Step 3: Calibrating $z = 0$ Plane are:
  - “xy calibration”
  - “field calibration”
  - “flat field correction”
  - “2D Working Field Calibration”
- In the test pattern, even a raster point distribution is allowed other than in Figure 19, Page 72. For example, you can also mark the raster points on just one part of the 2D Working Field in order to only calibrate this sub-area of the 2D Working Field. The raster points may also be distributed unevenly or may form a rectangular grid instead of a square. In the correXion pro Manual and CalibrationLibrary Manual, you find additional information on this and on other options. If your calibration situation requires a special solution, contact SCANLAB.

(1) “To minimize xy positioning errors in $z = 0$ plane”

**Procedure**

**(1)** In your marking software, define a test pattern that meet the 11 × 11 raster points (at least) in Figure 19, Page 72.

**(2)** On a marking substrate, mark the test pattern from step 1 at z = 0.

**(3)** Use your measurement tools to determine the actual positions of each raster point in the marking result. To prevent an undesired offset in the Correction File, you should use the raster point marked at x = 0 and y = 0 as the origin of the measurement coordinate system. In addition, axis direction of the measurement coordinate system should meet the SCANLAB Reference Coordinate System convention.(1)

**(4)** Generate a new Correction File. Leave(2) the calibration factor (bit/mm) at the original value of the standard Correction File.

- Case A: With correXion pro
- Case B: With CalibrationLibrary and slcl_xy_calibration_mm_targets
- Case C: With CalibrationLibrary and slcl_xy_calibration_bit_targets

(a) Case A: With **correXion pro**

(1) Create an input file for correXion pro, which contains the measured values and adjustment positions. Refer to correXion pro Manual.

(2) Use correXion pro to generate a new Correction File. Do *not* select the check box ‘Restricted correction file’ (unless absolutely necessary).

– Case B: With **CalibrationLibrary** and **slcl_xy_calibration_mm_targets**

(1) Write down in mm and use as parameter values:

- x-set positions (= `XTargetsMM`)
- y-set positions (= `YTargetsMM`)
- x-actual positions (= `XMeasurementsMM`)
- y-actual positions (= `YMeasurementsMM`)

(2) With CalibrationLibrary function **slcl_xy_calibration_mm_targets**: Generate the new Correction File.

– Case C: With **CalibrationLibrary** and **slcl_xy_calibration_bit_targets**

(1) Write down in bit (= positions in mm × relevant calibration factor K in bit/mm) and use as parameter values:

- x-set positions (= `XTargetsBit`)
- y-set positions (= `YTargetsBit`)

(2) Write down in mm and use as parameter values:

- x-actual positions (= `XMeasurementsMM`)
- y-actual positions (= `YMeasurementsMM`)

(3) With CalibrationLibrary function **slcl_xy_calibration_bit_targets**: Generate the new Correction File.

**(5)** Load the new Correction File into the memory of the RTC Board using the RTC command **load_correction_file** and assign it with the RTC command **select_cor_table**.

(1) The origin is defined by the symbol at the center of the pattern. This symbol is marked with (0, 0) values for the xy Scan System and corresponds to the origin of the scan system coordinate system. If your measurement tools find values not equal to zero for the origin, these values will produce an offset for all positions. You must then subtract this offset from all measured positions before they are used for generating the new Correction File.

(2) Applies to calibrating 3-Axis Laser Scan Systems. With calibrating 2-Axis Laser Scan Systems – due to content-related reasons (see correXion pro Manual) – a changed calibration factor could be applied in this step.

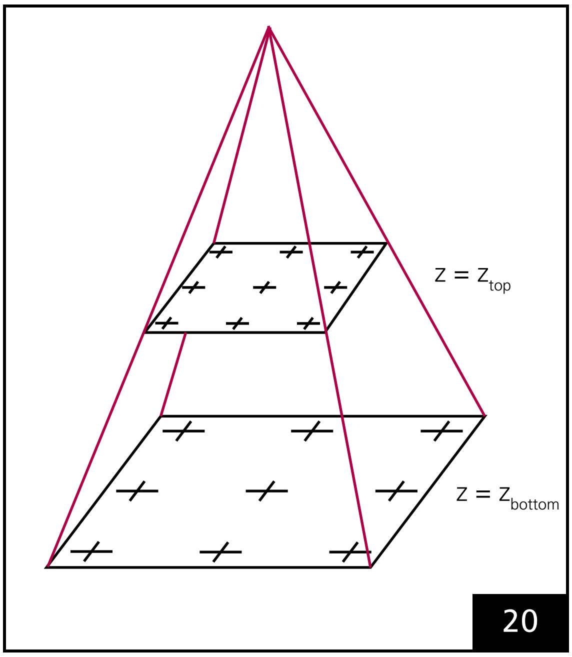
## 5.4 Step 4: Correcting Stretch

### Prerequisites

- A system configuration with 3D Working Volume

### Goal

- To reduce z-dependent 2D Working Field scalings in 3D Working Volume.

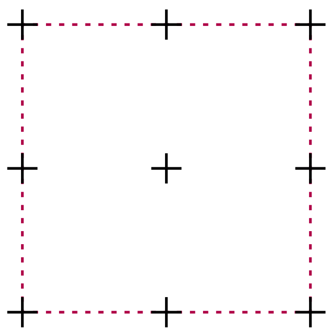



Stretch effect (no stretch correction).

### Notes

- SCANLAB `D3_xxxx.*`-Correction Files contain one value each for Stretch Factor (x Direction) Sx and Stretch Factor (y Direction) $S_y$. They are used to compensate for pyramidal 2D Working Field changes (or linear z-dependent scaling effects outside the z = 0 plane), see also Figure 20, Page 74.
- The stretch correction usually only has a very minor effect on the Beam Tilt correction from Step 2: Compensating Beam Tilt, Page 67. Therefore, as a general rule, Step 2: Compensating Beam Tilt, Page 67 (in which stretch factors are used for calculation) does not have to be repeated again after Step 4: Correcting Stretch, Page 74.

## 5.4.1 Checking the Stretch



**Requirements**

- 3 × 3 raster points
- These span an imaginary square over the entire 2D Working Field
- Square center point is in the center of the 2D Working Field
- Choose the symbol type of the raster points (+, ×, filled circle) so that it can be measured as accurately as possible with your measurement device

21

Test pattern for step 1.

**(1)** Define a test pattern that meet the Requirements in Figure 21, Page 75.

**(2)** Mark the test pattern from step 1in 2 test planes $z_{bottom}$ and $z_{top}$, in each case on a separate marking substrate. SCANLAB recommends using the boundary planes of the 3D Working Volume as test planes ($z_{bottom} = z_{min}$ and $z_{top} = z_{max}$). If your system set-up does not allow this, then select 2 test planes in between this. These test planes should be as far apart from each other as possible (the larger the distance between the test planes, the more accurate the correction). For this sub-process, it is advisable to select the planes on both sides of the z = 0 plane ($z_{bottom} < 0$ and $z_{top} > 0$).

**(3)** Use your measurement tools to determine the size of the imaginary square and the actual position of each raster point relative to the center raster point for the 2 test pattern marking results.

**(4)** Compare the size of the imaginary square from the $z_{top}$ plane with the variables from the $z_{bottom}$ plane:

- If the sizes differ from each other, for a rough optimization, continue with Chapter 5.4.2 "Carrying out Basic Stretch Correction", Page 76
- If the sizes do not differ from each other, for a "fine correction", continue with Chapter 5.4.3 "Carrying out Advanced Stretch Correction"[1]

(1) If your measurement tool finds values not equal to zero for the origin, these values will produce an offset for all positions in this plane. You must then subtract this offset from all measured positions before they are used for generating the new Correction File.

### 5.4.2 Carrying out Basic Stretch Correction

**(1)** Generate a new Correction File by CalibrationLibrary function **slcl_do_stretch_calibration**. Pass the measurement data of the $3 \times 3$ test pattern from step 3 as parameter. Refer to CalibrationLibrary Manual.

**(2)** Load the new Correction File into the memory of the RTC Board using the RTC command **load_correction_file** and assign it with the RTC command **select_cor_table**.

**(3)** Continue with step Chapter 5.4.3 “Carrying out Advanced Stretch Correction”.

### 5.4.3 Carrying out Advanced Stretch Correction

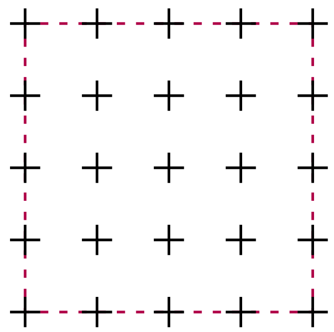
**Notes**

- In this step Chapter 5.4.3 "Carrying out Advanced Stretch Correction" no new Correction File is created (in contrast to Chapter 5.4.2 "Carrying out Basic Stretch Correction").
- In addition to loading the Correction File, you must therefore, call the RTC command **load_stretch_table** in every user program to load the [StretchTable<No>] (see RTC Manual).
- This step Chapter 5.4.3 "Carrying out Advanced Stretch Correction" ist *not* supported by:
  – laserDESK 3D Calibration Wizard
  – CalibrationLibrary

For the majority of F-Theta objectives Chapter 5.4.2 "Carrying out Basic Stretch Correction", with both stretch factors Sx and $S_y$, is sufficient to achieve good results in 3D Working Volume.

However, there are also systems that also require a location-dependent correction. In this case, you can increase precision through an advanced stretch correction in the form of a table with measurement data/support points gained through experimentation.(1)

To find out whether your configuration requires advanced stretch correction:



**Requirements**

- 5 × 5 raster points
- These span an imaginary square over the entire 2D Working Field
- Square center point is in the center of the 2D Working Field
- Choose the symbol type of the raster points (+, ×, filled circle) so that it can be measured as accurately as possible with your measurement device
- The distance from raster point to raster point is now half as big as in the test pattern in Figure 21, Page 75

22

Test pattern for step 1.

**(1)** Define a test pattern that meet the Requirements in Figure 22, Page 77.

**(2)** Mark the test pattern from step 1 in the 2 test planes as described in Chapter 5.4.1 "Checking the Stretch" and measure the 2 test pattern marking results.

(1) This can at least compensate for 2D Working Field distortion, which changes linearly through z.

(3) Here too, compare the size of the imaginary square from the $z_{top}$ plane with the size from the $z_{bottom}$ plane. If these differ too much from each other and therefore, do not achieve the required accuracy, an advanced stretch correction is required. Proceed as follows:

(4) Create a `*.dat` file ([StretchTable<No>] (see RTC Manual) with the measured test pattern values of the test pattern from step 1. For more information on the content of the file, see Chapter an "Advanced 3D correction" in RTC5 Manual/RTC6 Manual.

(5) Load the a `*.dat` file from step 4 by RTC command **load_stretch_table**.

(6) Mark a 9 × 9 test pattern in the 2 test planes as described in Chapter 5.4.1 "Checking the Stretch". The distance from raster point to raster point is now half as big as in the previous step.

(7) Measure the 2 test pattern marking results.

(8) Continue with increasingly smaller intervals or increasingly more raster points, until the size differences are minimized in accordance with your requirements.

**Notes**

- Note that, in contrast to the basic stretch factor correction, no new Correction File is created with the advanced stretch factor correction.

## 5.5 Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients

### Goal

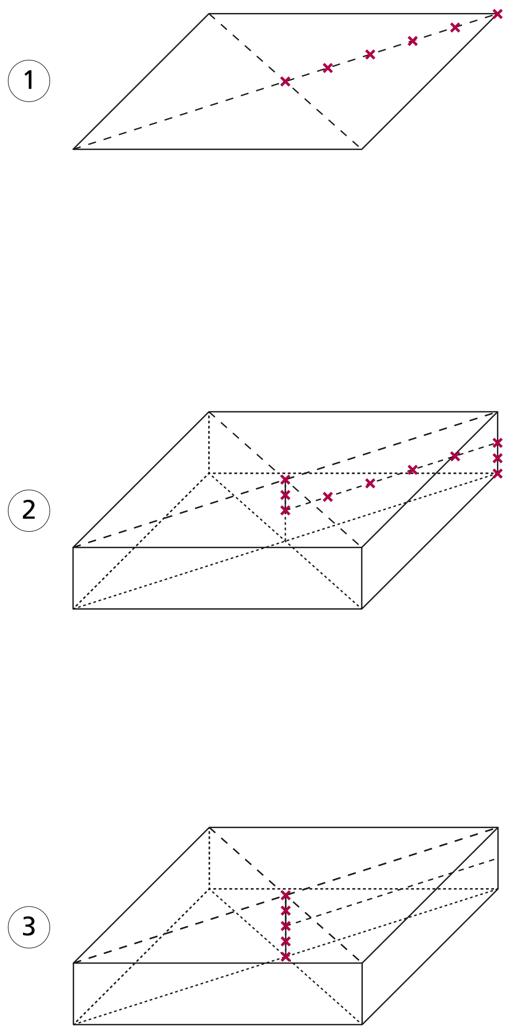
- New Correction File containing improved ABC Coefficients values
- Spot variations in the entire 2D Working Field or 3D Working Volume are minimized

### Procedure

In this step, the focus position is adjusted by adapting ABC Coefficients and thus in the entire travel range of the Dynamic Focusing Unit. Finally, a new Correction File is generated, which contains the new ABC Coefficients ("ABC correction").

**(1)** Define test positions ($x_{test}$, $y_{test}$, $z_{test}$), see Figure 23, Page 79:

- For 3D Configurations, the maximum possible 3D Working Volume specified in the Dynamic Focusing Unit Manual should be covered
- The minimum number of test positions is dependent on the system configuration




**Legend**
1. 2D Configuration: at least 5 test positions
2. 3D Configuration without F-Theta objective: at least 10 test positions
3. 3D Configuration with F-Theta objective: at least 6 test positions

23

Step 1: Typical location of the test positions and their number.

**(2)** For each test position, perform the following:

(a) In your marking software, define the test pattern (1) in Figure 9, Page 60, see Chapter 5.1 "Step 1: Initially Adjusting the Dynamic Focusing Unit".
In your marking software, position the test pattern so that the center of the test pattern is at the respective test position ($x_{test}$, $y_{test}$, $z_{test}$).

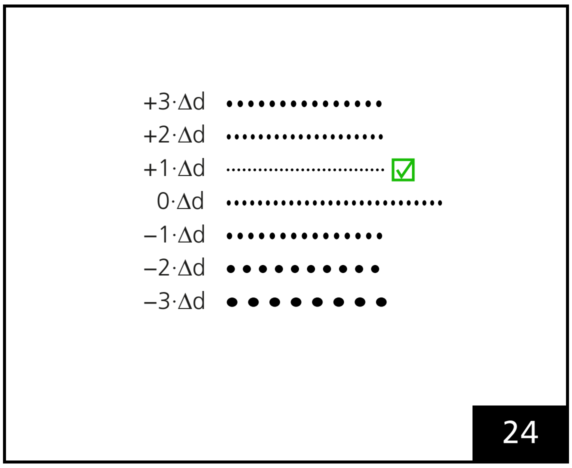
(b) Position a suitable marking substrate at the respective test position ($x_{test}$, $y_{test}$, $z_{test}$) in the 3D Working Volume. The surface of the marking substrate must be at $z_{test}$.

(c) Load the Correction File and mark the test pattern on the marking substrate.

(d) Check the marked substrate with your measurement tools: Determine the line with the best focal quality and, as a result, the corresponding defocus value d (in the example Figure 24, Page 80: d = $+1 \times \Delta d$).

(e) Determine for this line a value pair from the associated Focus Length Value l and the z output value $z_{out}$.

- Determine l by RTC command **get_z_distance** ($x_{test}$, $y_{test}$, $z_{test}$), see Chapter 8 "Appendix B: Determining Focus Length Values", Page 103
- Determine $z_{out}$ as described in Chapter 9 "Appendix C: Determining Output Values", Page 104. Do this using the defocus value d from step 2d (observe its sign).




Step 2d: best focal quality line.

**(3)** Using the value pairs determined for all test positions (l and $z_{out}$), create a new Correction File with optimized ABC Coefficients.

(a) To CalibrationLibrary-Funktion **slcl_do_abc_calibration**, pass the values l and $z_{out}$ as 20-bit values in an array (if 16-bit values have been determined, multiply these by 16 first).

(b) Read out the newly calculated ABC Coefficients from the new Correction File, see ABC Coefficients, Page 16.
Make a note of them.
In addition to the Correction File, a new ReadMe File is created that contains the optimized values for the ABC Coefficients.

**(4)** Apply the newly generated Correction File from step 3 and mark the test pattern again at all test positions ($x_{test}$, $y_{test}$, $z_{test}$). Inspect the focus position at these test positions. For all test patterns, the respective central line should now be marked with the smallest spot size. If this is not the case, check whether you have used the correct sign for the defocus values in the formula from step 2d. A further iteration with more detailed defocus steps may be advisable though. If this does not help either, contact SCANLAB.

**(5)** Check whether, together with the new Correction File (with the new ABC Coefficients), from step 3 clipping to boundary values occurs and, if relevant determine the maximum $z_{min}$ and $z_{max}$ control values with which the output values on the Dynamic Focusing Unit are still in the allowed range. To do this, proceed as described in Chapter 5.7 "(Optional) Step 7: Determining the Maximum Control Values for Clipping (Value Range OK?)", Page 82 and Chapter 9 "Appendix C: Determining Output Values", Page 104.

## 5.6 (Optional) Step 6: Focus Plane Correction

### Goal

- Local focal deviations in the z = 0 plane should be compensated for by an optimized Correction File.

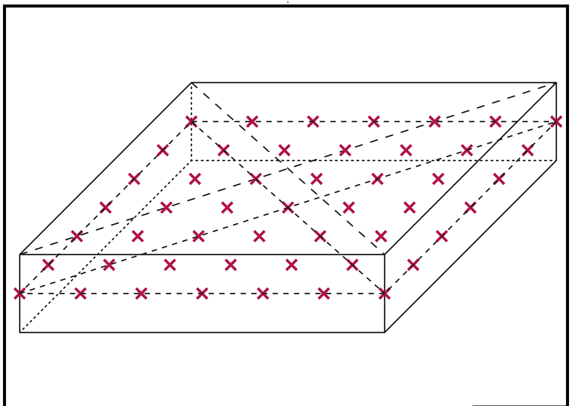
### Notes

- This step can be carried out for all system configurations. With this step, it is possible to compensate for local or non-rotation-symmetric focal deviations in the z = 0 plane.

### Procedure

**(1)** In your marking software, define the test pattern described in Chapter 5.1 "Step 1: Initially Adjusting the Dynamic Focusing Unit", see Figure 9, Page 60.

**(2)** Position this test pattern at different test positions ($x_{test}$, $y_{test}$, 0) in the z = 0 2D Working Field:
- In a grid that covers the entire 2D Working Field.
- At 7 × 7 test positions as shown in Figure 25, Page 81.
- The center of each individual test pattern must be at the respective test position ($x_{test}$, $y_{test}$, 0)



25

(Optional) Step 6: Focus Plane Correction: test positions in z = 0 plane.

**(3)** Mark the 7 × 7 test patterns on a marking substrate in the z = 0 plane. Only use marking substrates that are very even and ensure correct z positioning of the marking substrates.

**(4)** Check the marked substrate with your measurement tools and analyze each individual test pattern as follows:
- (a) Determine the line with the best focal quality and, as a result, the corresponding defocus value d.
- (b) For the line with the best focus quality, determine the associated value $z_{out}$ as described in Chapter 9 "Appendix C: Determining Output Values", Page 104. Do this using the calculated defocus value d. Also note its sign.
- (c) Make a note of the three values that belong together $x_{test}$ [mm], $y_{test}$ [mm] and $z_{out}$ [as 20-bit value]. If a 16-bit value has been determined for $z_{out}$, multiply this by 16 first.

**(5)** With CalibrationLibrary function **slcl_do_focus_calibration:**
Generate a new Correction File from the 7 × 7 triple values with
$x_{test}$ (= `XMeasurementBit`),
$y_{test}$ (= `YMeasurementBit`),
$z_{out}$ (= `ZControlBit`).

**(6)** Apply the newly calculated Correction File and mark the test pattern again. Check whether the calibration step was successful.

**(7)** If necessary, repeat (Optional) Step 6: Focus Plane Correction, Page 81 with a finer grid (for example, with 11 × 11 test positions in the z = 0 plane) and/or with more detailed defocus steps.

## 5.7 (Optional) Step 7: Determining the Maximum Control Values for Clipping (Value Range OK?)

**Goal**

- To determine a maximum control value range that is used with a newly calculated Correction File.

An RTC Board clips x, y, z Output Values that exceed the respective allowed range to the boundary values of these ranges[1]:

| RTC Board | Axis | Range |
|---|---|---|
| RTC4 board | x axis | [–32,767…+32,767] |
| | y axis | [–32,767…+32,767] |
| | z axis | [–32,767…+32,767] |
| RTC5 board | x axis | [–524,288…+524,287] |
| | y axis | [–524,288…+524,287] |
| | z axis | [–32,767…+32,767] |
| RTC6 board | x axis | [–524,288…+524,287] |
| | y axis | [–524,288…+524,287] |
| | z axis | [–524,288…+524,287] |

In addition, the excelli*SHIFT* firmware further restricts the z output values to the following range to prevent vignetting in the system:

- [-8066, +8066] (converted to 16-bit)

The standard Correction File practically excludes clipping in the specified 2D Working Field or 3D Working Volume.

After 3D calibration to compensate for static errors, a shift in the output values can occur, which results in clipping in extreme cases. The initially specified working range is then no longer reached or reduces even if this is not immediately visible from the quality of the test pattern. In particular, the compensation of significant focal length tolerances of the F-Theta objective used could result in a significant shift in the z output values, for example after a change of ABC Coefficients values. Even with the 3D calibration of the excelli*SHIFT*, this kind of shift is to be expected, as excelli*SHIFT* does not have a mechanical adjustment option (for example, focusing ring).

For this reason, SCANLAB recommends at least inspecting the z output values for possible clipping after 3D calibration. The check can be carried out immediately after Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients, Page 79 (see notes in the individual calibration steps) or at the end of the overall calibration, when the final Correction File is ready.

clipping can also occur due to offset settings and rotation settings[2].

The associated coordinate transformations also make clipping of the x and y output values more likely and require a separate check for clipping.

(1) Clipping must not be confused with cutting, which is brought about by the 'restricted' option.

(2) With these settings, the scan system is often aligned to the machine coordinate system, see Chapter 6.1 "(Optional) Applying Settings for Offset or Rotation", Page 84.

#### Recommended: inspecting z output values

**(1)** For the boundary points specified below for the specified working area, calculate the z output value as described in Chapter 9 "Appendix C: Determining Output Values", Page 104. If using an RTC5 board, divide the 20-bit z output values by 16 to convert them into 16-bit values. Boundary points of the working area with regard to z[(1)]:

- for a 2D Configuration: the center point (0, 0, 0) and one corner point of the 2D Working Field, for example, ($x_{max}$ ,$y_{max}$, 0).
- for a 3D Configuration without F-Theta objective: top center point (0, 0, $z_{max}$) and bottom corner point ($x_{max}$, $y_{max}$, $z_{min}$) of the 3D Working Volume.
- for a 3D Configuration with F-Theta objective: top and bottom center point (0, 0, $z_{max}$) and (0, 0, $z_{min}$) of the 3D Working Volume.

**(2)** If the z output values at these boundary points are identical to the allowed boundary values, you should iteratively determine the currently available working area (without clipping). If this does not adequately cover your application, inspect the mechanical alignment and beam adjustment, repeat the calibration, if necessary, or contact SCANLAB.

#### Optional: inspecting x, y, z Output Values after applied coordinate transformations

After making the offset and rotation settings, determine the x, y, z Output Values:

- with regard to z at the boundary points of the working area as specified in the previous section
- for x and y, at the following points:
  - for a 2D Configuration: at the four corner points of the 2D Working Field ($x_{min}$, $y_{min}$, 0), ($x_{max}$, $y_{min}$, 0), ($x_{min}$, $y_{max}$, 0), ($x_{max}$, $y_{max}$, 0)
  - for a 3D Configuration with and without F-Theta objective: at the four corner points of the top working plane ($x_{min}$, $y_{min}$, $z_{max}$), ($x_{max}$, $y_{min}$, $z_{max}$), ($x_{min}$, $y_{max}$, $z_{max}$), ($x_{max}$, $y_{max}$, $z_{max}$)
- If the z output values at these boundary points are identical to the allowed boundary values, you should iteratively determine the currently available working area (without clipping).

#### Notes

- It cannot be ruled out that, after a 3D calibration, limiting effects that impair the specified working area will occur even without clipping, such as vignetting at the Mirrors or at the objective. A computational evaluation of such effects can be done only with great difficulty.
- If offset settings or rotation settings shift the x, y, z Output Values into areas that were not intended during 3D calibration, this can impair the position precision.

(1) See external test positions in Figure 23, Page 79.

# 6 (Optional) Carrying out Further Measures

In this Chapter:



## 6.1 (Optional) Applying Settings for Offset or Rotation

After the calibration procedures to adapt Correction Files, you can apply coordinate transformations such as offset or rotation. For this, also read the corresponding notes in the RTC Manual or in laserDESK Help.

Such coordinate transformations are required if the system includes several axes and their coordinate systems have to be coordinated with each other.


- (Optional) Compensating an Angle Between xy Scan System and Positioning Stage, Page 85
- (Optional) Calibrating a Multi-Head System, Page 86
- Estimating the Defocus Value and Checking the Beam Diameter, Page 91

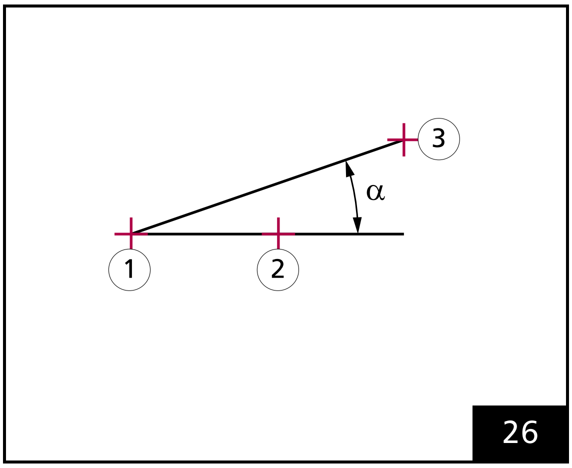
### 6.1.1 (Optional) Compensating an Angle Between xy Scan System and Positioning Stage

**Notes**

- Angle correction of `D3_xxxx.*`-Correction Files is not currently possible.

**Goal**

- An angle between the x axis of a positioning stage coordinate system and the xy Scan System coordinate system should be compensated for by software.




Measurement schema for angle compensation.

**Procedure**

**(1)** Place a suitable marking substrate on the positioning stage.

**(2)** Mark a test pattern with 2 crosses along the x axis of the xy Scan System without moving the positioning stage, see cross (1) and (2) in Figure 26, Page 85.

**(3)** Move the positioning stage along the x axis of the positioning stage.

**(4)** Mark a cross again, see cross (3) in Figure 26, Page 85.

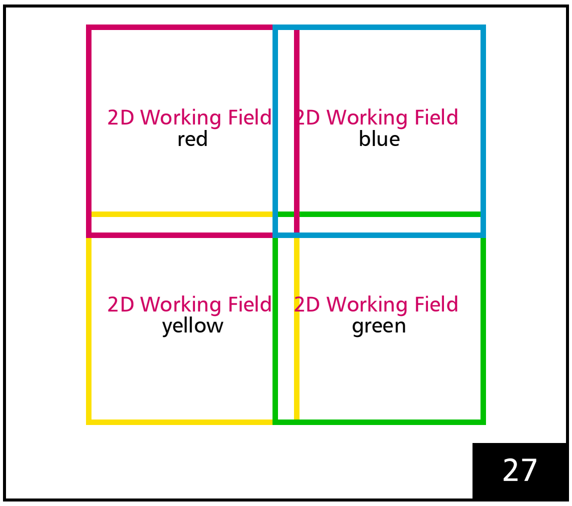
**(5)** Using your measurement tools, determine the angle α as illustrated in Figure 26, Page 85.

**(6)** Use the RTC command **set_angle** or **set_matrix** command or the laserDESK hardware configuration to rotate the xy Scan System coordinate system around the angle α.

## 6.1.2 (Optional) Calibrating a Multi-Head System

### Goal

- In a multi-head system, 2D Working Fields of the individual xy Scan Systems, see Figure 27, Page 86, are to be aligned relative to each other.




Multi-head system: 2D Working Fields.

### Notes

- The Procedure, Page 87 is just one of many possibilities for aligning the coordinate systems of several xy Scan Systems with each other. Alternatively, you can determine the relative position and orientation of the xy Scan System coordinate systems as follows:
  (a) With all xy Scan Systems, mark spot grids on one or more marking substrates.
  (a) Use a measuring machine to determine the xy Scan System coordinate systems.
- On step 1(a)1: Instead of lines, you can even mark 2 circles for each xy Scan System. These also define a line and are more easily measured by a measuring machine.
  (a) Using a measuring machine, from the centers of one pair or circles, define an origin and an axis for the coordinate system of the master xy Scan System.
  (b) Measure the other 2 circles in the reference coordinate system.
  (c) The rotation angle can be calculated from the coordinates using the tan function.

**Procedure**

All xy Scan Systems are calibrated individually to correct the local errors.

**(1)** Determine one xy Scan System as the master xy Scan System (which then serves as the reference system, here: red). Then, align an adjacent xy Scan System (here: blue) relative to this master xy Scan System.

(a) To compensate for a relative rotation of the 2 2D Working Fields:

(1) Using the 2 xy Scan Systems, mark lines in the overlap area of the 2 2D Working Fields (in each case along the respective x axis and y axis), see Figure 28, Page 88.

(2) Measure the angle between these lines, see Figure 29, Page 88.

(3) Rotate the coordinate system of the adjacent xy Scan System (blue) to align its 2D Working Field parallel to the master xy Scan System 2D Working Field (red):

- Apply RTC command **set_angle** to adjacent xy Scan System (blue)
- With laserDESK: set a rotation in laserDESK hardware configuration

(b) To compensate the offset of the 2 2D Working Fields:

(1) Repeat the marking from step 1(a)1, Page 87. For the marking result, see Figure 30, Page 88).

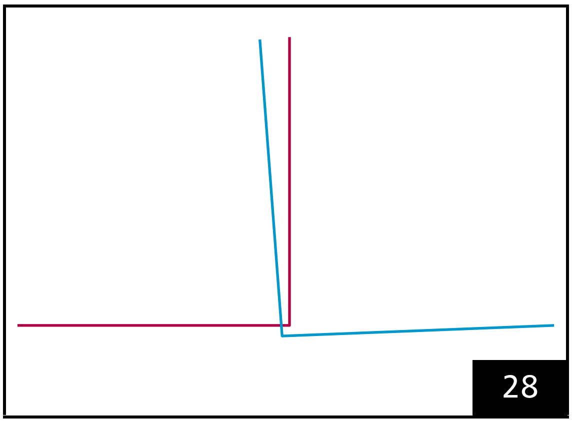
(2) Determine offset $\Delta x$ and $\Delta y$, see Figure 31, Page 88.

(3) If relevant, offset the coordinate system of the adjacent xy Scan System (blue):

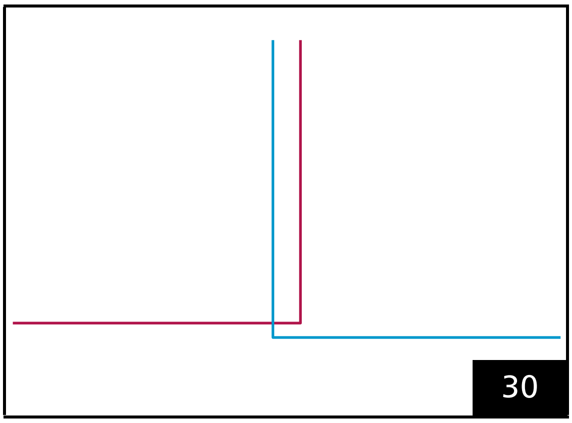
- Apply RTC command **set_offset** to adjacent xy Scan System (blue)
- With laserDESK: set an offset in laserDESK hardware configuration

**(2)** Repeat step 1 with xy Scan System (yellow) to align its 2D Working Field with the already aligned 2D Working Fields.

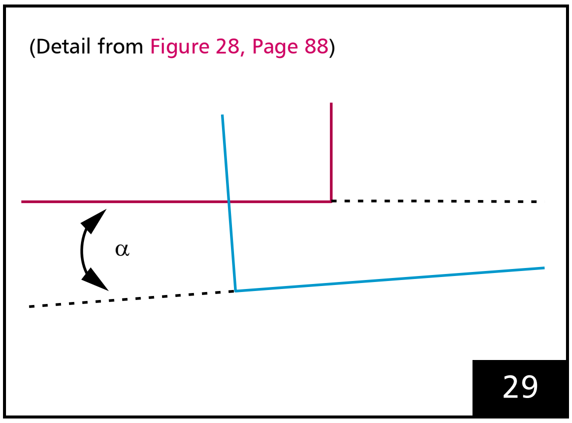
**(3)** Repeat step 1 with xy Scan System (green) to align its 2D Working Field with the already aligned 2D Working Fields.



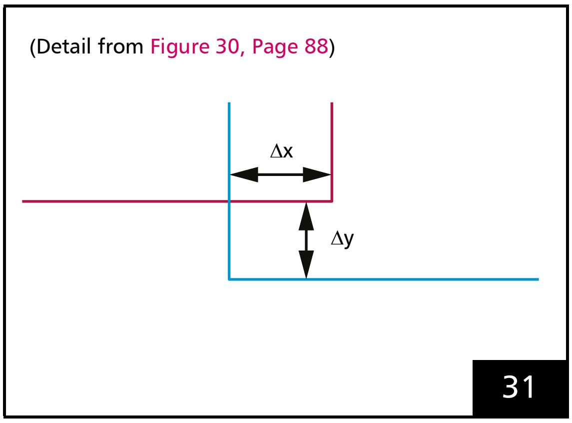
Step 1(a)1: marking result (detail).



Step 1(b)1: marking result (detail).




Step 1(a)2: determining the angle.




Step 1(b)2: determining the offset.

## 6.2 (Optional) Applying Settings for Processing-on-the-fly

**Prerequisites**

- You are performing Processing-on-the-fly applications
- All preceding calibration steps are completed, see Figure 8, Page 56

**Procedure**

- Set the associated scaling factors (for example, by RTC command **set_fly_x**).

## 6.3 (Optional) Finding Defocus Parameter Values

### Goal

- The focus of the laser beam should be set lower or higher than the working plane corresponding to the z control value (usually lower than the surface of the workpiece, to prevent an intermediate focus). This kind of work with defocus is required for certain applications and materials, in order to process the workpiece with larger spot diameters. Sometimes, a workpiece even passes through several processing phases, which are carried out both with a focused beam and with a defocused beam.

Upon customer request, SCANLAB can calculate the Correction Files already during system design in such a way that it is possible to work both without defocus and with specific defocus values in the complete specified 2D Working Field (depending on requirements and possibility with one-sided defocus – beneath or above the working plane – or with two-sided).

Upon customer request, SCANLAB can assist with any back reflections that may occur.

As a rule, however, the actual spot diameter still has to be determined on the respective material and with the respective processing parameters. This kind of determination should only be carried out at the end of a 3D calibration, after all adaptations – also with regard to the vario*SCAN* – have been incorporated in the new Correction File.

Note that, even with purely 2D applications with a defocused beam, full 3D calibration is required. A defocus should only be set after the focus position has been correctly adjusted without defocus.

### Procedure

| Relevant Process Parameters |
|---|
| • Calibration Factor Kz, Page 22 |
| • Defocus Value d according to Chapter 6.3.1 "Estimating the Defocus Value and Checking the Beam Diameter", Page 91 |

- Set a defocus by RTC command **set_defocus**`( Shift )`.
  Where: `Shift` = Calibration Factor Kz × desired Defocus Value d
  - Desired Defocus Value d: positive value or negative value. In mm.
    A positive value increases the focus length of the Dynamic Focusing Unit and shifts the focus position for example, for
    the control value (0|0|0) by approx.
    d = Shift / K to the plane z = –d [mm]. This focus shift runs against the z-coordinate axis.

  For further information on **set_defocus** refer to the RTC Manual.

### 6.3.1 Estimating the Defocus Value and Checking the Beam Diameter

**Procedure**

| **Relevant Process Parameters** |
|---|
| • Beam Diameter (Focal Plane), Page 19 |
| • Rayleigh Length, Page 27 |
| • ABC Coefficients, Page 16 |
| • Calibration Factor Kz, Page 22 |

**(1)** Estimate the defocus value d, which is required to achieve a beam diameter $D_{defocus}$ (regardless of the Correction File used) by:

$$|d| = \sqrt{\left(\left(\frac{D_{defocus}}{D_{focus}}\right)^2 - 1\right) \times z_R^2}$$

With:

- $D_{focus}$ = Beam Diameter (Focal Plane)
- $z_R$ = Rayleigh Length

**(2)** Check whether this theoretically estimated defocus value d can also be applied in the overall 2D Working Field together with the currently used Correction File.

(a) Check whether the z output values $z_{out}$ for the Dynamic Focusing Unit with defocus are in the allowed range:
16-bit values: [–32.768…+32.767]
20-bit values: [–524.288…+524.287]

(b) For a system configuration without 3D Working Volume – at the 2D Working Field center and at a 2D Working Field corner point – calculate the associated Focus Length Values l by RTC command **get_z_distance** (x, y, 0), with the Correction File used.

- Example for a 2D Working Field of 200 mm without 3D Working Volume:
  - l = **get_z_distance** (100, 100, 0)
    This 2D Working Field position corresponds to the largest positive z output value for work without defocus.
  - l = **get_z_distance** (0, 0, 0)
    This 2D Working Field position corresponds to the largest negative z output value for work without defocus.

(c) For both Focus Length Values l from step 2b, use the following formulas to calculate the 2 following z output values in each case.

- negative defocus

$$-z_{out} = A + B \times [l - Kz \times |d|] + C \times [l - Kz \times |d|]^2$$

- positive defocus

$$z_{out} = A + B \times [l + Kz \times |d|] + C \times [l + Kz \times |d|]^2$$

Use the ABC Coefficients of the Correction File used.[1]
Enter A, B, C, l, Kz, d consistently either as 16-bit values or as 20-bit values.

(1) Alternatively, you can determine the z output values $z_{out}$ as described in Chapter 9 "Appendix C: Determining Output Values", Page 104.

(d) If 1 of the 4 z output values $z_{out}$ calculated in step 2c exceeds the allowed range, then the selected defocus with the Dynamic Focusing Unit is not available in the entire volume that was used for the calculation.

(e) You can also verify this with a measurement of the actual beam diameter in the 2D Working Field, if necessary (for example, by measuring the beam diameter at the 2D Working Field center point, at the Reference Point and at an 2D Working Field corner with various defocus values).

(f) If you do not achieve the desired beam diameter in the entire 2D Working Field, try the following measures:
- Reduce the defocus
- Reduce the 2D Working Field used
- Increase the beam diameter in front of the vario*SCAN* in order to reach the largest diameter with less focus shift
- If two-sided defocus has been selected, omit the critical side

(g) If these measures do not help, contact SCANLAB. SCANLAB can then check the design of your 3D Working Volume and suggest an adapted design or further measures.

**Notes**

- Depending on the beam profile in the defocus, the actual diameter may differ from the diameter estimated above.

## 6.4 Dynamic Control

As a rule, you must perform your 3D laser applications with different dynamic settings than for marking test patterns in Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55 (= different settings than described in Chapter 4.6 "Make Settings for Test Pattern Marking", Page 49). Set appropriate delay values and speed values in your software.

**Procedure**

**(1)** Leave activated any previously activated Tracking Error compensation between Dynamic Focusing Unit and xy Scan System, see Chapter 4.6.2 "Setting Delays", Page 50.

**(2)** If necessary, ask SCANLAB for suitable jump speed and marking speed values.

**(3)** If you are using an excelli*SHIFT* together with an xy Scan System with *SCAN*ahead control (for example, excelli*SCAN*), then use the Dynamics Matching Tool again to adapt the excelli*SHIFT* dynamically to the xy Scan System.

**(4)** As a rule, you muse adapt the delay values again.[1]

**(5)** Activate the `DirectMove3D` option of the RTC Board (parameter of RTC command **set_delay_mode**).

**(6)** Note that with excessive power draw by the Dynamic Focusing Unit, deactivation can occur, see also the respective manual. A high power draw is often an indicator for inadequately set parameters such as speed or delays.

## 6.5 (Optional) Adjusting the Pilot Laser Correction File

If you use a pilot laser Correction File (laser wavelength 633 nm) during commissioning, during tests or generally in your application, adjust this pilot laser Correction File to increase the precision.

**Procedure**

**(1)** Make a copy of the Correction File optimized for the processing laser wavelength as a basis for the new pilot laser Correction File.

**(2)** Get the ABC coefficients from the supplied pilot laser Correction File by CalibrationLibrary function **slcl_get_current_abc_coeffs**.

**(3)** With CalibrationLibrary function **slcl_set_abc_manually**: Generate a new pilot laser Correction File with
`Handle` = Correction File from step 1 and
`NewCoeffs` = ABC Coefficients from step 2.

**(4)** Load the new pilot laser Correction File from step 3 and assign it accordingly.

**(5)** Scan a rectangle with the pilot laser and check its dimensions: To do this, you can first mark the rectangle with the working laser Correction File and then scan it again with the pilot laser Correction File.

**(6)** If the dimensions are not correct: contact SCANLAB to obtain instructions on further adjustments to the pilot laser Correction File.

(1) Not for xy Scan Systems with *SCAN*ahead control.

## 6.6 About Repeating Steps

The steps described in Chapter 5 ”Optimizing Correction Files (“Calibration Steps”)”, Page 55 and Chapter 6 ”(Optional) Carrying out Further Measures”, Page 84 must be carried out again, if the system is changed:

- If the xy Scan System is replaced
- If the Dynamic Focusing Unit is replaced
- If the objective is replaced
- As a rule, also if these components are replaced 1:1 with other components of the same type
- Possibly even if one of the components for example, for cleaning is removed (and installed again)

Even without one of the above-mentioned system changes, the accuracy can be affected by changes in the application, ambient conditions and over the operating time of the system.

Depending on the accuracy requirements, you may then have to repeat the entire calibration or possibly only individual steps.

# 7 Appendix A: About Correction Files

SCANLAB Correction Files are binary files and either part of the RTC delivery or can be ordered from SCANLAB.

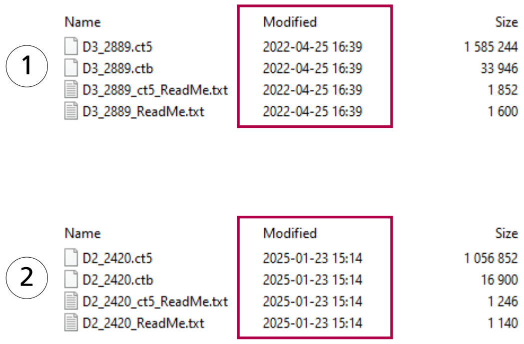
SCANLAB supplies Correction Files together with ReadMe Files, see Figure 32, Page 95.

Typical file names are (“xxxx” are consecutive numbers):

- `D3_xxxx.*`
  for 3-Axis Laser Scan Systems
- `D2_xxxx.*`
  for 2-Axis Laser Scan Systems

File name extensions:

- `ctb`
  (binary file format for RTC4 boards)
- `ct5`
  (binary file format for RTC5 boards and RTC6 boards)




**Legend**

1. `D3_xxxx.*`, with “xxxx” = 2889.
   Note: same timestamps with
   `*.ct5`, `*.ctb`, `*_ct5_ReadMe.txt`, `*_ReadMe.txt`.
2. `D2_xxxx.*`, with “xxxx” = 2420.
   Note: same timestamps with
   `*.ct5`, `*.ctb`, `*_ct5_ReadMe.txt`, `*_ReadMe.txt`.

32

SCANLAB Correction Files and SCANLAB ReadMe Files.

To control a 3-Axis Laser Scan System with an RTC Board from SCANLAB, a Correction File appropriate for the system should always be used. For initialization of the RTC Board, the user program must load 3D correction data from the Correction File into the memory of an RTC Board using the RTC command and assign them to the xy Scan System connections of the RTC Board to be used. For each individual micro-step, the RTC Board then automatically calculates the output values for the three axes of the 3-Axis Laser Scan System from the 3D coordinate values specified by the user program and outputs them at the xy Scan System connections.(1) Part of this calculation is a 3D Working Volume correction algorithm: The RTC Board automatically transforms the coordinate values according to the data from the Correction File.(2)

Each Correction File from SCANLAB contains the following data for this 3D Working Volume correction algorithm:

- Data for control of the Dynamic Focusing Unit to set the focus position in a plane or in a 3D Working Volume
- Data for conversion of set positions (set focus positions in the 2D Working Field or in the 3D Working Volume) to Focus Length Values
  - Correction Files for systems without F-Theta objective include further Correction Tables for corresponding conversion. The Focus Length Value l belonging to a set position (according to currently assigned Correction File) can be read out using the RTC command **get_z_distance**.
- ABC Coefficients for conversion of Focus Length Values l into z output values $z_{out}$ for the Dynamic Focusing Unit in accordance with the Parabolic Function, Page 16.

ABC Coefficients loaded from a Correction File onto an RTC Board can be changed subsequently by the following RTC commands:

| Bit resolution | **RTC command** |
|---|---|
| 16-bit values | **load_z_table**<br>RTC6 command **load_z_table_no** |
| 20-bit values | RTC6 command **load_z_table_20b**<br>RTC6 command **load_z_table_no_20b** |

(1) The RTC Board does not output any z signals without a xy Scan System connection having been assigned 3D correction data.

(2) This transformation includes, amongst other things, an interpolation according to the grid points of Correction Tables from the Correction File.

- Correction Tables and stretch factors for correction of the x and y control of the xy Scan Systems
  – Correction Tables for compensation of a pillow-shaped distortion of the 2D Working Field (due to the arrangement of the mirrors in the xy Scan System) and, if relevant, also for compensation of an overlapping barrel-shaped distortion of the 2D Working Field (due to an F-Theta objective).
  – Stretch factors for compensation of the dependency of the 2D Working Field size on the z coordinates (for position corrections in x and y for different z planes in 3D applications).(1)

With the help of these kinds of Correction Files and the 3D Working Volume correction algorithm of the RTC Board, the movement of the axes in the 3-Axis Laser Scan System can be adjusted specifically, in order to optimize the precision of the laser focus positioning.

For a 3-Axis Laser Scan System, available from SCANLAB are:

- "Standard" D3-Correction Files, Page 97
- D3 Serial-Number-Specific Correction Files, Page 98

- "Standard" D3-Correction Files
  SCANLAB calculates them individually for a very specific theoretical system configuration (including Dynamic Focusing Unit). Only *general* system data is taken into account:
  – xy Scan Systems – Mirror geometry data and angle calibration of the
  – Dynamic Focusing Unit – Optics data and calibration of the s
  – objective (if relevant) – optics data
  – Standard laser parameters

  A specific "Standard" D3-Correction Files is in principle suitable for all scan systems with the theoretical system configuration for which it was calculated. Although the calculation does not include any information on deviations in the respective individual system from the theoretical system configuration, "Standard" D3-Correction Filess can be used to achieve adequately accurate results in many laser applications (for example, for markings).

(1) In addition, by RTC command **load_stretch_table**, a table for extended, coordinate-dependent stretch correction can also be loaded onto the RTC Board.

- D3 Serial-Number-Specific Correction Files
  Like "Standard" D3-Correction Filess, but in addition, SCANLAB takes actual measurement data of the respective, individual xy Scan System into account. These measured data come from measurements on SCANLAB-internal test benches.

  Unlike with "Standard" D3-Correction Filess, specific inaccuracies of the xy Scan System (such as Gain Error, Offset Error, Non-Linearity) whose size can vary serial number specifically without compensation, are automatically compensated for when using D3 Serial-Number-Specific Correction Filess. As a rule, more accurate results can therefore, be achieved with a D3 Serial-Number-Specific Correction Files than with a "Standard" D3-Correction Files.

  The maximum precision, however, is generally only achieved with optimized Correction Files, which are generated during a calibration procedure.[1][2]

With SCANLAB software, see Chapter 13 "Appendix G: About SCANLAB Software Tools", Page 113, and measured user data[3], you can generate own Correction Files based on SCANLAB-supplied Correction Files.

By using such optimized Correction Files, static errors in the 2D Working Field or 3D Working Volume can be reduced, which are caused for example, by:

- Mechanical tolerances
- Tolerances of the optical components (for example, radial lens distortions
- System misalignment

However, this requires a calibration procedure, as described in Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55.

(1) See Figure 8, Page 56.

(2) During the calibration procedure, the use of a D3 Serial-Number-Specific Correction Files as a starting point has no advantage compared to "Standard" D3-Correction Files.

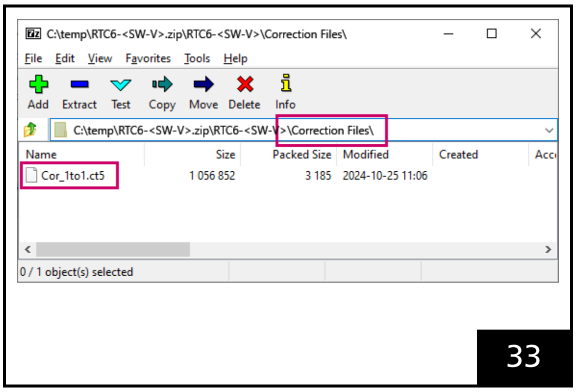
(3) Must be determined by marking and analyzing certain test patterns, see Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55.

## 7.1 About 1to1-Correction Files

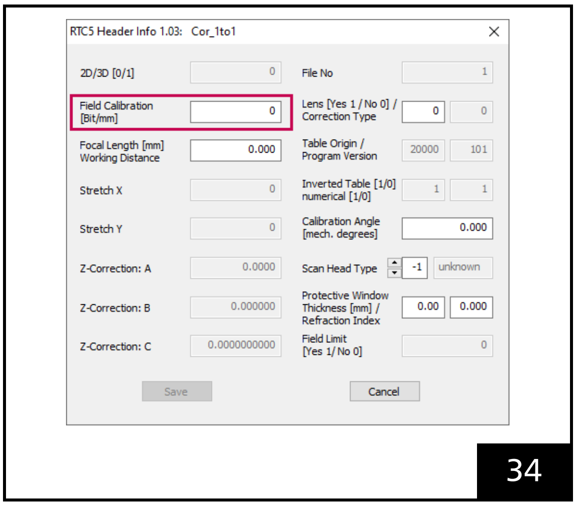
Table 7 SCANLAB 1to1-Correction Files

| 1to1-Correction File | Where to get? |
|---|---|
| `Cor_1to1.ct5` | RTC6 Software Package[a] |
| | RTC5 Software Package |
| `Cor_1to1.ctb` | RTC4 Software Package |

(a) See Figure 33, Page 99




Example: RTC6 Software Package \Correction Files\`Cor_1to1.ct5`




`Cor_1to1.ct5` in CorrectionFileConverter.
1to1-Correction File file header is still “empty”: that is, most fields are populated with zero values (in particular the field for the calibration factor = red rectangle).

**Notes**

- With a 1to1-Correction File, see Table 7, Page 99, an RTC Board does not apply 2D Working Field correction (that is, there is no compensation of distortions, for example).
  - Therefore, SCANLAB advises against controlling 3-Axis Laser Scan Systems with 1to1-Correction Files.
  - 1to1-Correction Files are, however, suitable for testing the basic functionality of x axis and y axis[1].
  - A 1to1-Correction File is needed for Chapter 17.1 ”Special Case: No ”Standard” D2-Correction File `D2_xxxx.*` Available”, Page 142
  - 1to1-Correction Files are also useful for “simulation tests“ in which actual positions are read back from the scan system and compared with the set positions. This kind of comparison is most easily done *without* 2D Working Field correction, that is, with 1to1-Correction File.
- `Cor_1to1.ct5` and `Cor_1to1.ctb` only include 2D correction data.
  - However, `Cor_1to1.ct5` can be loaded to an RTC5 board | RTC6 board by **load_correction_file** ( `Dim` = 3 ) for 1:1 3D correction.
- 3D 1to1-Correction Files for RTC4 boards are available from SCANLAB on request.
- When using a 1to1-Correction File, you must experimentally determine the calibration factors for $K_{xy}$ and Kz (in [bit/mm]) for the respective system.
  - With CorrectionFileConverter you can write the calibration factor to 1to1-Correction File header, if K = K_xy = K_z (important: as a 20-bit value!), see Figure 34, Page 99.

(1) `Hpgl.exe` from the RTC6 Software Package | RTC5 Software Package, for example, is suitable for this.

## 7.2 About ReadMe Files

- Text file supplied by SCANLAB together with the Correction File, see Figure 32, Page 95
  - Exactly the same name as the Correction File
    - For `ctb`-Correction Files "`_ReadMe`" is appended
    - For `ct5`-Correction Files "`_ct5_ReadMe`" is appended
  - File extension is `*.txt`
  - Example(s)
    - `D3_2889.ctb` => `D3_2889_ReadMe.txt`, see Figure 35, Page 101
    - `D3_2889.ct5` => `D3_2889_ct5_ReadMe.txt`, see Figure 36, Page 102
- Contains information about the respective, associated system configuration as well as calculated data, such as the calibration factor (in [bit/mm]). The calibration factor can be used by the user program to convert set positions in mm (in the 2D Working Field or 3D Working Volume) into set positions in bits (as input value for the RTC commands). Some of this information is also included in the file header of `ct5`-Correction Files and can be read out by an RTC command.

```
SCANLAB RTC 3D Correction File
==============================

This ctb correction file is calculated for a SCANLAB 3-axis scan system
for 3D image field correction. For further information please refer
to the RTC manual.


3D Correction File Parameters
-----------------------------

Filename:                     D3_2889.ctb
Program Version:              4.0.3
Date:                         25.04.2022
Description:                  3D Correction File Without F-Theta-Lens
varioSCAN Article Number:
Scanning Lens:                -
Working Distance:             525.0 mm

Evaluation Wavelength:        1070 nm

Scan Head Type:               n30
Scan Angle Calibration:       +/- 11.7 degrees mech.
XY-Swap:                      No


Scan Field Calibration K:     137 bit/mm

Max. Field Size (z=0):        478.365 mm
Max. Z-Range:                 +/- 0.0 mm
Max. Field Size (z=max):      478.365 mm
Max. X-/Y-Coordinate Value:   32768 bit



Reference Point:                     (145.635,145.635,0) mm
(focus shifter in neutral position)

dl (max. z Control Value +32767):    101.136 mm
dl (min. z Control Value -32767):    -81.933 mm
Max. Scan Angle Mirror 1:            11.424 degrees mech.
Max. Scan Angle Mirror 2:            12.121 degrees mech.


Polynomial Coefficients for Focus Shift Control:
Focus Shift = ds (directed from z=0 opposite to z)
Control Value = A + B*ds*K + C*(ds*K)^2
A = -14157.2
B = 2.89589
C = -2.20993e-05



Protective Window:
Thickness:                    4.0 mm
Refractive Index:             1.45
```

35

Example: D3_2889_ReadMe.txt.

```
SCANLAB RTC 3D Correction File
==============================

This ct5 correction file is calculated for a SCANLAB 3-axis scan system
for 3D image field correction. The ct5 format succeeds the ctb correction
file format, which is used with the RTC2 to RTC4. For further information
please refer to the RTC manual.


3D Correction File Parameters
-----------------------------

Filename:                     D3_2889.ct5
Program Version:              4.0.3
Date:                         25.04.2022
Description:                  3D Correction File Without F-Theta-Lens
varioSCAN Article Number:
Scanning Lens:                -

Working Distance:             525.0 mm

Evaluation Wavelength:        1070 nm


Scan Head Type:               n30
Scan Angle Calibration:       +/- 11.7 degrees mech.
XY-Swap:                      No

Scan Field Calibration K_xy:  2192 bit/mm
Scan Field Calibration K_z:   16-bit: 137 bit/mm | 20-bit: 2192 bit/mm
Max. Field Size (z=0):        478.365 mm
Max. Z-Range:                 +/- 0.0 mm
Max. Field Size (z=max):      478.365 mm
Max. X-/Y-Coordinate Value:   524288 bit



Reference Point:                     (145.635,145.635,0) mm
(focus shifter in neutral position)

dl (max. z Control Value +32767):    101.136 mm
dl (min. z Control Value -32767):    -81.933 mm
Max. Scan Angle Mirror 1:            11.424 degrees mech.
Max. Scan Angle Mirror 2:            12.121 degrees mech.

Polynomial Coefficients for Focus Shift Control:
Focus Shift = ds (directed from z=0 opposite to z)
Control Value = A + B*ds*K_z + C*(ds*K_z)^2
16-bit:
A = -14157.2
B = 2.89589
C = -2.20993e-05
20-bit:
A = -2.26515e+05
B = 2.89589
C = -1.38121e-06


Protective Window:
Thickness:                    4.0 mm
```

36

Example: D3_2889_ct5_ReadMe.txt.

# 8 Appendix B: Determining Focus Length Values

A Focus Length Value, Page 16 is determined either as 16-bit value or 20-bit value.

Conversion:

- Determined 16-bit value × 16 = 20-bit value
- Determined 20-bit value × 1/16 = 16-bit value

The Focus Length Value l for a specific control value (x, y, z) can be determined:

- By RTC command get_z_distance( x, y, z )
- By CalibrationLibrary function slcl_get_z_distance
- Mathematically – only for Systems with F-Theta objective

**By RTC command get_z_distance( x, y, z )**

**(1)** Load the respective Correction File and assign it.

**(2)** Specify x, y, z in bit.

- **get_z_distance** delivers
  - a 20-bit value for the RTC6 board (mode-independent)
  - a 16-bit value for the RTC5 board (mode-independent)
  - a 16-bit value for RTC4 board

**By CalibrationLibrary function slcl_get_z_distance**

- **slcl_get_z_distance** delivers
  - a 20-bit value for `ct5`-Correction Files
  - a 16-bit value for `ctb`-Correction Files

**Mathematically – only for Systems with F-Theta objective**

Table 8 Systems with F-Theta objective: calculating a Focus Length Value

| $l = -Kz \times z$ | |
|---|---|
| l | Focus Length Value |
| Kz | Calibration Factor Kz (Dynamic Focusing Unit) |
| z | In mm. Observe its sign! |
| Important: *Consistently* use either 16-bit values or 20-bit values in the formula! | |

# 9 Appendix C: Determining Output Values

Output values are determined either as 16-bit values or 20-bit values.

Conversion:

- Determined 16-bit value × 16 = 20-bit value
- Determined 20-bit value × 1/16 = 16-bit value

The z output value $z_{out}$ for the Dynamic Focusing Unit for a specific control value (x, y, z) can be determined:

- By RTC command get_value
- By RTC command get_galvo_controls
- By CalibrationLibrary function slcl_transform_points_3d_io
- By CalibrationLibrary function slcl_transform_points_3d
- Mathematically

**By RTC command get_value**

**(1)** Load and assign the respective Correction File and bring the Dynamic Focusing Unit and xy Scan System into the respective control position:
   - If relevant, **set_defocus**( d )
   - If relevant, RTC commands for coordinate transformation (**set_scale**, etc.)
   - **goto_xyz**( x, y, z )

**(2)** By **get_value**, determine the output value $z_{out}$ to the Dynamic Focusing Unit and the output value to the xy Scan System. The channel used depends on which connection the Dynamic Focusing Unit is connected to, refer to RTC Manual.
   **get_value** delivers
   - a 20-bit value for the RTC6 board and RTC5 board (mode-independent)
   - a 16-bit value for RTC4 board

**By RTC command get_galvo_controls**

Prerequisite: RTC6 board and RTC5 board, not RTC4 board.

**(1)** Load and assign the respective Correction File.

**(2)** If relevant, execute the RTC commands for coordinate transformation (**set_scale**, etc.).

**(3)** Using **get_galvo_controls**, determine output values for control values (x, y, z, defocus).
   **get_galvo_controls** delivers 20-bit values for the x, y, z Output Values, regardless of the mode.

**By CalibrationLibrary function slcl_transform_points_3d_io**

- **slcl_transform_points_3d_io** delivers
  - a 20-bit value for `ct5`-Correction Files
  - a 16-bit value for `ctb`-Correction Files

**By CalibrationLibrary function slcl_transform_points_3d**

- **slcl_transform_points_3d** delivers
  - a 20-bit value for `ct5`-Correction Files
  - a 16-bit value for `ctb`-Correction Files

**Mathematically**

Table 9 Calculating z output value for the Dynamic Focusing Unit

| $z_{out} = A + B \times (l - Kz \times d) + C \times (l - Kz \times d)^2$ | |
|---|---|
| l | Focus Length Value |
| d | Defocus value. In mm. Observe its sign! |
| Kz | Calibration Factor Kz (Dynamic Focusing Unit) |
| A | A Coefficient, Page 16 from the currently used Correction File |
| B | B Coefficient, Page 16 from the currently used Correction File |
| C | C Coefficient, Page 16 from the currently used Correction File |
| $z_{out}$ | z output value. The result depends on the values used in the formula:<br>• If 16-bit values are used for l, Kz and the ABC Coefficients, $z_{out}$ corresponds to a 16-bit value.<br>• If 20-bit values are used for l, Kz and the ABC Coefficients, $z_{out}$ corresponds to a 20-bit value. |
| Important: *Consistently* use either 16-bit values or 20-bit values in the formula!<br>The possible bit resolution of l, Kz, ABC Coefficients and $z_{out}$ depends on the RTC Board:<br>• RTC4 board consistently 16-bit values<br>• RTC5 board consistently 16-bit values<br>• RTC6 board ≤ SW-V.1.11.0 consistently 16-bit values<br>• RTC6 board SW-V ≥ 1.12.0 consistently 16-bit values or consistently 20-bit values | |
| See also Table 2 Parabolic Function, Page 16. | |

# 10 Appendix D: Notes on Relevant RTC Commands

The following table lists RTC commands that play a role in

- Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55
- Chapter 6 "(Optional) Carrying out Further Measures", Page 84

| RTC command | Functionality (extract, see RTC Manual for complete functionality) | Available with |
|---|---|---|
| get_galvo_controls | • Delivers the output values corresponding to the input values (20-bit values, mode-independent). | • RTC6 command<br>• RTC5 command |
| get_head_para | • Reads out the currently assigned ABC Coefficients, amongst other things. | • RTC6 command<br>• RTC5 command |
| get_table_para | • Reads, amongst other things, the ABC Coefficients from the currently loaded 3D Correction Table. | • RTC6 command<br>• RTC5 command |
| get_value | • Delivers a signal value, depending on selection, for example, the current output value for the x axis, y axis or z axis.<br>– Delivers a 20-bit value for the RTC6 board and RTC5 board (mode-independent).<br>– Delivers a 16-bit value for RTC4 board. | • RTC6 command<br>• RTC5 command<br>• RTC4 command |
| get_z_distance | • For a set position, delivers the associated Focus Length Value l (as per the currently assigned Correction File).<br>– Delivers a 20-bit value for the RTC6 board (mode-independent).<br>– Delivers a 16-bit value for the RTC5 board (mode-independent).<br>– Delivers a 16-bit value for RTC4 board. | • RTC6 command<br>• RTC5 command<br>• RTC4 command |
| goto_xyz | • Moves the output point for the laser focus from the current position to the specified position in the 3D Working Volume. | • RTC6 command<br>• RTC5 command<br>• RTC4 command |

| RTC command (cont'd.) | Functionality (extract, see RTC Manual for complete functionality)(cont'd.) | Available with (cont'd.) |
|---|---|---|
| **load_correction_file** | • Loads correction data from a Correction File into the memory of the RTC Board; Also sets the ABC Coefficients to the values preset in the loaded Correction Table. | • RTC6 command<br>• RTC5 command<br>• RTC4 command |
| **load_stretch_table** | • Loads a [StretchTable<No>] (see RTC Manual) for an extended, coordinate-dependent stretch factor correction into the memory of the RTC Board. | • RTC6 command<br>• RTC5 command |
| **load_z_table** | • Loads the ABC Coefficients into the currently assigned 3D Correction Table (values loaded with **load_z_table** are overwritten by a subsequent **load_correction_file** call). | • RTC6 command<br>• RTC5 command<br>• RTC4 command |
| **load_z_table_20b** | • Loads coefficients *A*, *B* and *C* into the currently assigned 3D Correction Table. For a Focus Length Value l in the RTC6 board 20-bit range [–524.288…+524.287]. | • RTC6 command ≥ SW-V.1.12.0 |
| **load_z_table_no** | • See **load_z_table**. | • RTC6 command |
| **load_z_table_no_20b** | • Loads coefficients *A*, *B* and *C* and then assigns them to the 3D Correction Table `No`. For a Focus Length Value l in the RTC6 board 20-bit range [–524.288…+524.287]. | • RTC6 command ≥ SW-V.1.12.0 |
| **move_to** | • Only for vario*SCAN* FLEX: moves the stepper motor (by RTC Step Motor Extension). | • RTC6 command<br>• RTC5 command<br>• RTC4 command |

| RTC command (cont'd.) | Functionality (extract, see RTC Manual for complete functionality)(cont'd.) | Available with (cont'd.) |
|---|---|---|
| **read_abc_from_file** | • Reads values of the ABC Coefficients from a Correction File.<br>For a Focus Length Value l in the 16-bit range [–32,768…+32,767]. | • RTC6 command<br>• RTC5 command |
| **read_abc_from_file_20b** | • Reads values of the ABC Coefficients from a Correction File.<br>For a Focus Length Value l in the RTC6 board 20-bit range [–524.288…+524.287]. | • RTC6 command ≥ SW-V.1.12.0 |
| **select_cor_table** | • Assigns previously loaded correction data to the desired xy Scan System connectors of the RTC Board. | • RTC6 command<br>• RTC5 command<br>• RTC4 command |
| **set_offset**<br>**set_matrix** | • Define settings for coordinate transformations. | • RTC6 command<br>• RTC5 command<br>• RTC4 command |
| **set_defocus** | • Defines a defocus for all 3D vector outputs. This focus shift causes a defocusing of the laser focus relative to the working plane. | • RTC6 command<br>• RTC5 command<br>• RTC4 command |
| [*]**stepper**[*] | • Only for vario*SCAN* FLEX:<br>Moves the stepper motor (by RTC5/6 vario*SCAN* FLEX Extension board). | • RTC6 command<br>• RTC5 command |
| **write_abc_to_file** | • Writes values of the ABC Coefficients into a Correction File. | • RTC6 command<br>• RTC5 command |
| **write_abc_to_file_20b** | • Writes the ABC values directly into a specified Correction File on the PC.<br>For a Focus Length Value l in the RTC6 board 20-bit range [–524.288…+524.287]. | • RTC6 command ≥ SW-V.1.12.0 |

# 11 Appendix E: About Calibration Factors

Whether a calibration factor specification is to be interpreted as a 16-bit value or a 20-bit value depends on the ReadMe File from which it is taken, see Table 10, Page 109.

In principle, only use the calibration factor specifications that SCANLAB has been specified for the corresponding Correction File.

**Notes**

- The calibration factor is stored as a 20-bit value in the file header of a `ct5`-Correction File (a `ctb`-Correction File does not have a file header).

Table 10 Specifications of calibration factors (16-bit value or 20-bit value) in various ReadMe Files

| ReadMe File | Correction File | $K_{xy}$ specified? | Kz specified? | K specified?[a] |
|---|---|---|---|---|
| `D3_xxxx_ct5_ReadMe.txt` | `D3_xxxx.ct5` | Yes[b]<br>• The specification is to be interpreted as 20-bit value | Yes[c]<br>• The specification is to be interpreted as 16-bit value<br>• Newer Correction Files explicitly list both 16-bit value and 20-bit value | No |
| `D3_xxxx_ReadMe.txt` | `D3_xxxx.ctb` | No | No | Yes[d]<br>• The specification is to be interpreted as 16-bit value |
| `D2_xxxx_ct5_ReadMe.txt` | `D2_xxxx.ct5` | No | No | Yes[d]<br>• The specification is to be interpreted as 20-bit value |
| `D2_xxxx_ReadMe.txt` | `D2_xxxx.ctb` | No | No | Yes [d]<br>• The specification is to be interpreted as 16-bit value |

(a) K = K_xy = K_z

(b) In the line beginning with "`Scan Field Calibration K_xy:`"

(c) In the line beginning with "`Scan Field Calibration K_z:`"

(d) In the line beginning with "`Scan Field Calibration K:`"

In RTC user programs, calibration factors (in bit/mm) are used to convert target positions (in mm) to command parameter values (in bit). Command parameter values are to be specified either as 16-bit values or 20-bit values, see Table 11, Page 110.

Table 11 Specification of RTC command parameter values with RTC boards

| RTC board | | Correction File | Parameter values for xy positions | Parameter values for z positions |
|---|---|---|---|---|
| RTC6 board | • in RTC6 Standard Mode | • *.ct5 | • 20-bit | • 20-bit ($Kz = K_{xy}$) (the specified 16-bit value calibration factor Kz must be increased by a factor of 16) |
| | • in RTC5 Compatibility Mode | • *.ct5 | • 20-bit | • 16-bit ($Kz = K_{xy}/16$) |
| | • in RTC4 Compatibility Mode | • *.ct5 | • 16-bit (the specified 20-bit value calibration factor $K_{xy}$ must be reduced by a factor of 1/16) | • 16-bit ($Kz = K_{xy}$) |
| RTC5 board | • in RTC5 Standard Mode | • *.ct5 | • 20-bit | • 16-bit ($Kz = K_{xy}/16$) |
| | • in RTC4 Compatibility Mode | • *.ct5 | • 16-bit (the specified 20-bit value calibration factor $K_{xy}$ must be reduced by a factor of 1/16) | • 16-bit ($Kz = K_{xy}$) |
| RTC4 board | • in RTC4 Standard Mode | • *.ctb | • 16-bit | • 16-bit ($Kz = K_{xy}$) |

**Notes**

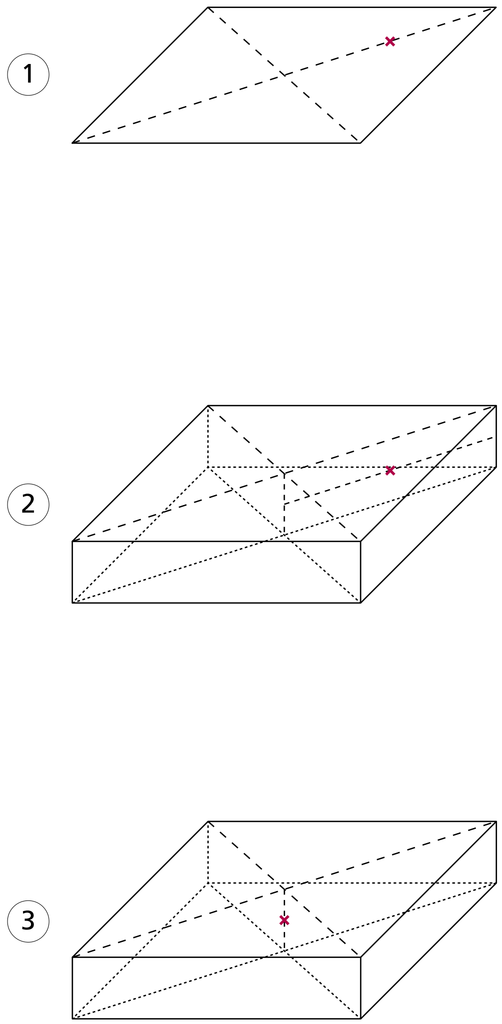
- Product-specific notes see Table 12, Page 111.

Table 12  Product-specific notes

| **SCANLAB-Product** | **Notes** |
|---|---|
| • vario*SCAN* FLEX | • For positioning stepper motors, $K_{xy}$ and Kz of the Correction File do *not* apply, but other calibration factors instead, see specifications in the respective manual. |
| • power*SCAN* II 50i | • For positioning stepper motors, $K_{xy}$ and Kz of the Correction File do not apply, but other calibration factors instead, see specifications in the respective manual. |
| • power*SCAN* II 70i | • For positioning stepper motors, $K_{xy}$ and Kz of the Correction File do not apply, but other calibration factors instead, see specifications in the respective manual. |

# 12 Appendix F: About the Reference Point

- For a system configuration without F-Theta objective, the Reference Point is typically between the center and the top right corner of the 2D Working Field in position ($x_{max}$, $y_{max}$, 0), see (1) and (2) in Figure 37, Page 112.
- For a system configuration with F-Theta objective, the Reference Point is typically in position (0, 0, 0), that is, in the center of the 3D Working Volume, see (3) in Figure 37, Page 112.
- Sometimes, the Reference Point is at a different position than shown in Figure 37, Page 112. For customer-specific systems without F-Theta objective, the Reference Point may also be outside the typical 2D Working Field in rare cases. In this case, still attempt marking in the Reference Point nonetheless, if possible. If not possible – for example, because not provided for in the machine system – find a point within the typical 2D Working Field (on the diagonal), that is as close as possible to the Reference Point.
- If, for a multi-head system, the specified Reference Point for one of the xy Scan Systems is not in the shared (or not in the used) 2D Working Field, it is possible to use the xy coordinates of the Reference Point with the opposite sign. In this case, leave the z coordinate of the Reference Point unchanged.




**Legend**
1. 2D Configuration
2. 3D Configuration without F-Theta objective
3. 3D Configuration with F-Theta objective

37

Typical position of the Reference Point in different system configurations.

# 13 Appendix G: About SCANLAB Software Tools

SCANLAB offers several software tools that can be used to generate customized Correction Files.

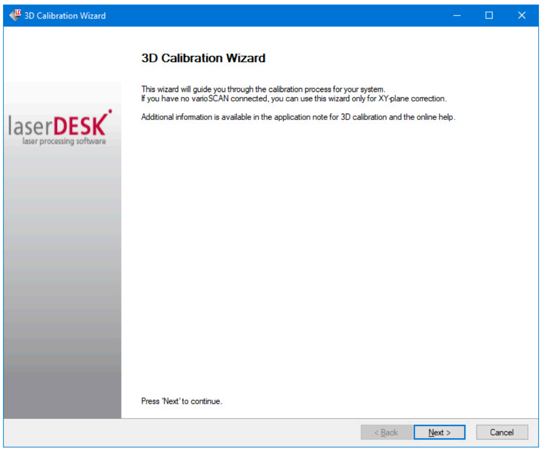
In this Chapter:

## 13.1 laserDESK 3D Calibration Wizard

laserDESK 3D Calibration Wizard, see Figure 38, Page 114, is part of laserDESK. It is started from laserDESK-GUI and then guides the user through the individual calibration steps.
See also Prerequisites, Page 115.

Functionalities:

- Loading Correction Files
- Marking the required test patterns
- Entering measured data
- Calculation of optimized Correction Files from user's measured data




38

laserDESK 3D Calibration Wizard: start page.

**Notes**

- laserDESK 3D Calibration Wizard supports the following steps from Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55:
  - Step 1: Initially Adjusting the Dynamic Focusing Unit, Page 59
  - Step 2: Compensating Beam Tilt, Page 67
  - Step 3: Calibrating z = 0 Plane, Page 72
  - Step 4: Correcting Stretch, Page 74
  - Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients, Page 79
- laserDESK 3D Calibration Wizard
  - Does not offer any functionality for measuring of marking results
  - Provides information on which measured data must be determined and entered
  - Can be run in full function mode or in demo mode
    - In full function mode a valid laserDESK USB dongle must be connected to the production PC and an RTC5 board or RTC6 board is properly installed in the production PC
    - In demo version, neither a dongle nor an RTC Board is required. Then laserDESK cannot control the laser scan system. Therefore, all test patterns required must be created and marked externally
- When using a vario*SCAN* FLEX, you should open the "Motor Control" dialog window (**Motor Control**) and leave it open to see the position information of the vario*SCAN* FLEX.
- Prerequisites
  - Installed laserDESK software V1.6 for full function mode or demo mode
  - Full function mode only: laserDESK USB dongle and RTC5 board or RTC6 board
  - `ct5`-Correction File (2D or 3D) (not: 1to1-Correction File, not: `ctb`-Correction File)
  - Dynamic Focusing Unit
  - laserDESK 3D Calibration Wizard does not open unless the correct hardware configuration has been set (CTRL + H).
- For every optical configuration, an appropriate laserDESK XML configuration file can be ordered from SCANLAB (in addition to an appropriate Correction File). The specific optical configuration is saved in this. This laserDESK XML configuration file can be imported. The marking parameters and test pattern parameters are then automatically adapted to the optical configuration of the respective 3-Axis Laser Scan System used.
- For more information, refer to laserDESK Help.

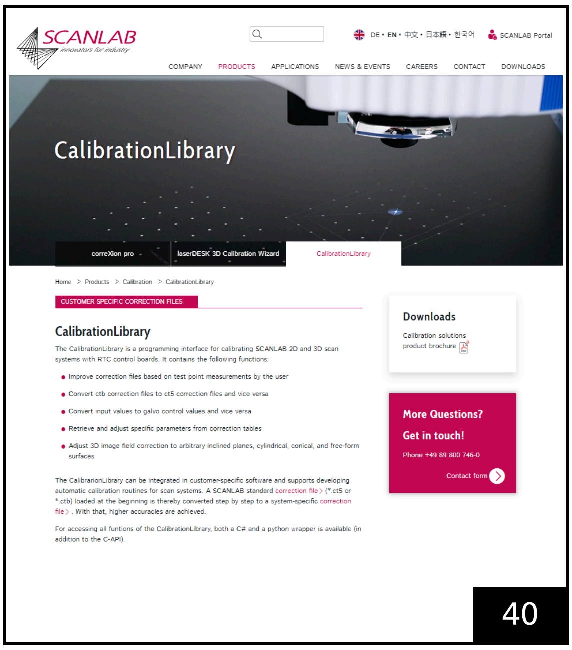
```xml
<?xml version="1.0" encoding="UTF-8"?>
<data_file
            filename="Snnnnnn_Vnnnnnn_D3_2889_VER1"
            datetime="10.06.2022 13:36:19"
            file_structure_version="1"
            generator_version="4"
            data_version="1"
            head_id="nnnnnn"
            head_name="fiberSYS; 1060-1085nm+Vision"
            varioSCAN_id="nnnnnn"
            varioSCAN_name="BG-Z-Achse-2; fiberSYS"
            ftheta=""
            correction_dimension="D3"
            correction_nr="2889"
            xsd_version="1.0">
<reference_point unit="x, y in [mm]">
      <value>145.635378031197, 145.635378031197, 0</value></reference_point>
<working_distance_a unit="[mm], A-Distance">
      <value>525.0</value></working_distance_a>
<focus_distance unit="[mm]">
      <value></value></focus_distance>
<coefficient_f2 unit="[mm]">
      <value></value></coefficient_f2>
<coefficient_f3 unit="[mm]">
      <value></value></coefficient_f3>
<coefficient_f4 unit="[mm]">
      <value></value></coefficient_f4>
<tracking_error_xy unit="[ms]">
      <value>0.4</value></tracking_error_xy>
<tracking_error_z unit="[ms]">
      <value>0.84</value></tracking_error_z>
<scan_field unit="[mm], quadratic">
      <value>450.0</value></scan_field>
<z_range unit="maximum z-Range [mm] from - to +">
      <value>0.0</value></z_range>
<mark_speed unit="[m/s]">
      <value>1.0</value></mark_speed>
<jump_speed unit="[m/s]">
      <value>6.3861357856</value></jump_speed>
<rayleigh_length unit="[mm]">
      <value>1.797</value></rayleigh_length>
<a_value unit="only for information">
      <value>-14157.191507723</value></a_value>
<b_value unit="only for information">
      <value>2.8958864648</value></b_value>
<c_value unit="only for information">
      <value>-0.0000220993</value></c_value>
<distance_b unit="[mm], only for information">
      <value></value></distance_b>
</data_file>
```


39

laserDESK XML configuration file. Hypothetical example: Snnnnnn_Vnnnnnn_D3_2889_VER1.xml.

## 13.2 CalibrationLibrary

- CalibrationLibrary software package
  - Can be ordered from SCANLAB, see Figure 40, Page 117
  - Contains the CalibrationLibrary DLL
    - With this, software developers can implement Step 1: Initially Adjusting the Dynamic Focusing Unit…(Optional) Step 6: Focus Plane Correction from Figure 8, Page 56 (not: excelli*SHIFT*) into the workflow of a machine software (and into its GUI)
- The CalibrationLibrary Manual contains a description of CalibrationLibrary DLL API
- CalibrationLibrary DLL
  - Does not require an RTC Board
  - Offers the following functionalities
    - Loading, editing, modifying and creating `ct5`-Correction Files and `ctb`-Correction Files
    - Offline transformation of bit coordinates using Correction Files
    - Simple access function for setting and retrieving specific parameters from Correction Tables
    - Calculation and generation of Correction Files based on measured user data

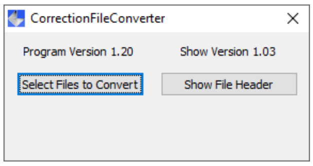



40

CalibrationLibrary Homepage under `https://www.scanlab.de/en/products/calibration/calibrationlibrary`.

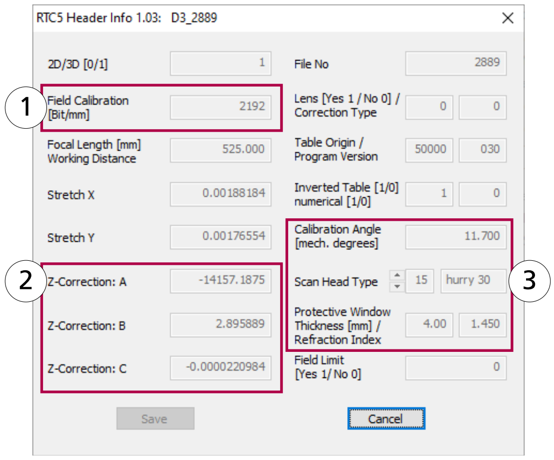
## 13.3 CorrectionFileConverter

- Is included in the RTC Software Package
- See Figure 41, Page 118
- Converts (**Select Files to Convert**):
  - `ctb`-Correction File to `ct5`-Correction Files
  - `ct5`-Correction Files to `ctb`-Correction Files
- Reads out parameter values from the `ct5`-Correction File header(1) (**Show File Header**) and shows them, see Figure 42, Page 118
- GUI mode yes
- Silent mode no
- For further information, refer to CorrectionFileConverter Manual




41

CorrectionFileConverter (`CorrectionFileConverter.exe`).




**Legend**

1. Calibration factor. The value shown here is always to be interpreted as a 20-bit value.
2. ABC Coefficients. Always as 16-bit values.
3. Only for `ct5`-Correction Files converted from `ctb`-Correction Files: changeable parameter values.

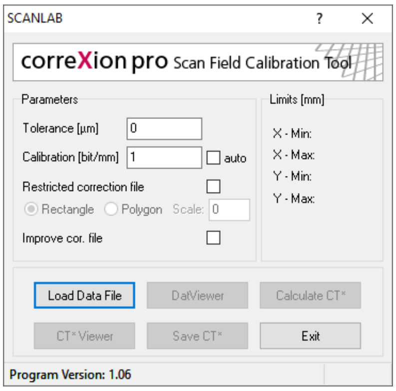
42

CorrectionFileConverter (`CorrectionFileConverter.exe`): after **Show File Header** > `D3_2889.ct5`.

(1) A `ctb`-Correction File does not have a file header.

## 13.4 correXion pro

- correXion pro software package
  - Can be ordered from SCANLAB
  - Contains `correXionPro.exe`, see Figure 43, Page 119
- Supported file formats:
  - `ct5`-Correction Files
  - `ctb`-Correction Files
- Calculates an optimized xy table for raster points in a 2D Working Field
  - Only for the (z = 0) plane
  - With 3D Correction File, the 3D portion is *not* changed
- Provides support for Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72
- GUI mode yes
- Silent mode yes
- For further information, refer to correXion pro Manual

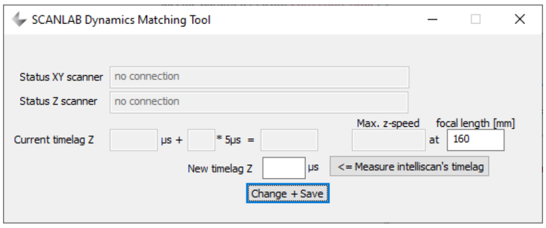



43

correXion pro (`correXionPro.exe`).

## 13.5 Dynamics Matching Tool

- Dynamics Matching Tool is supplied along with excelli*SHIFT*.
- Dynamics Matching Tool serves for Tracking Error matching, see Figure 44, Page 120.
- Used in:
  - Section "Case: excelliSHIFT and SCANahead System", Page 53
  - Section "Case: excelliSHIFT and Tracking Error System", Page 54




44

Dynamics Matching Tool
(`Dynamics_Matching_Tool.exe`;
file date 2017-12-05).

# 14 Appendix H: Work Sheet Work Sheet Process Parameters

- See also Chapter 2.1 "Calibration-Relevant Parameters (Alphabetical)", Page 14
- See also Work Sheet Process Steps, Page 123
- See also Figure 8, Page 56
- Complete this worksheet separately for each Correction File!

Table 13 Work Sheet Process Parameters

| Process Parameter | Value |
|---|---|
| 2D Working Field Size (Typical), Page 15 | |
| ABC Coefficients, Page 16<br>• A Coefficient, Page 16<br>• B Coefficient, Page 16<br>• C Coefficient, Page 16 | |
| Allowed Laser Power (Dynamic Focusing Unit), Page 17 | |
| Allowed Laser Power (xy Scan System), Page 17 | |
| Allowed Output Density (xy Scan System), Page 17 | |
| Aperture (Dynamic Focusing Unit), Page 18 | |
| Aperture (xy Scan System), Page 18 | |
| Average Back Focal Length (Dynamic Focusing Unit), Page 18 | [mm] |
| Beam Diameter (Focal Plane), Page 19 $D_{focus}$, Page 19 | |
| Calibration Factor $K_{xy}$, Page 21 | |
| Calibration Factor Kz, Page 22 | |
| Damage Threshold (xy Scan System), Page 23 | |
| Defocus Value d, Page 23 | |
| Distance B, Page 23 | [mm] |
| Focal Length (F-Theta Objective), Page 24 | [mm] |

Table 13 Work Sheet Process Parameters(cont'd.)

| **Process Parameter** | **Value** |
|---|---|
| Internal Beam Expansion Factor (Dynamic Focusing Unit), Page 24 | |
| Laser Frequency (Repetition Rate), Page 24 | |
| Maximum Focus Shift in z Direction (±), Page 25 | |
| Maximum Jump Speed for Marking Test Patterns, Page 26 | |
| Maximum Marking Speed for Marking Test Patterns, Page 26 | |
| Rayleigh Length, Page 27 | |
| Reference Point Coordinates, Page 28 | |
| Stepper Motor Value (Dynamic Focusing Unit), Page 29 | |
| Stretch Factor (x Direction), Page 30 | |
| Stretch Factor (y Direction), Page 30 | |
| Tracking Error (Dynamic Focusing Unit), Page 31 | |
| Tracking Error (xy Scan System), Page 31 | |
| Working Distance A, Page 32 | [mm] |
| Working Distance A', Page 32 | [mm] |

# 15 Appendix I: Work Sheet Work Sheet Process Steps

- See also Work Sheet Process Parameters, Page 121

Table 14 Work Sheet Process Steps

| Step | New Correction File? | Completed / Notes |
|---|---|---|
| Chapter 4 "Configuring and Mechanically Adjusting the 3-Axis Laser Scan System", Page 35 | no<br>Initial Correction File | |
| Chapter 5.1 "Step 1: Initially Adjusting the Dynamic Focusing Unit", Page 59 | yes or no<br>Correction File_1 optional | |
| Chapter 5.2 "Step 2: Compensating Beam Tilt", Page 67 | yes<br>Correction File_2 | |
| Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72 | yes<br>Correction File_3 | |
| Chapter 5.4 "Step 4: Correcting Stretch", Page 74 | yes or no<br>Correction File_4 optional | |
| Chapter 5.5 "Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients", Page 79 | yes<br>Correction File_5 | |
| Chapter 5.6 "(Optional) Step 6: Focus Plane Correction", Page 81 | yes or no<br>Correction File_6 optional | |
| Chapter 6.1 "(Optional) Applying Settings for Offset or Rotation", Page 84 | no | |
| Chapter 6.2 "(Optional) Applying Settings for Processing-on-the-fly", Page 89 | no | |
| Chapter 6.3 "(Optional) Finding Defocus Parameter Values", Page 90 | no | |
| Chapter 5.7 "(Optional) Step 7: Determining the Maximum Control Values for Clipping (Value Range OK?)", Page 82 | no | |

# 16 Appendix J: Troubleshooting Static Errors in Laser Applications

This chapter describes:

- Static errors in laser applications
- Their possible causes
- Possible measures to reduce or eliminate them

There are many causes for positioning inaccuracies or errors in laser applications with a 3-Axis Laser Scan System:

- (Specified) inaccuracies of the individual system components
- Operating the system with
  – Unsuitable Correction File
  – Inadequate adjustment
  – Inadequate calibration
- Other causes

There are often several causes at the same time, and the resulting errors overlap.

This overlapping can make it difficult to determine the respective individual errors and causes. The errors can overlap additively, but they can also overlap in a compensating manner.

A compensating overlapping, individual elimination of a cause can even temporarily result in a reduction in the positioning accuracy.
Therefore, as a rule, it is recommended:

**(1)** Perform the steps from Chapter 4 "Configuring and Mechanically Adjusting the 3-Axis Laser Scan System", Page 35 and Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55 in the specified order

**(2)** Only then (and also only if required) reduce further any remaining errors in laser applications, as per the following tables

The following tables only describe static errors.

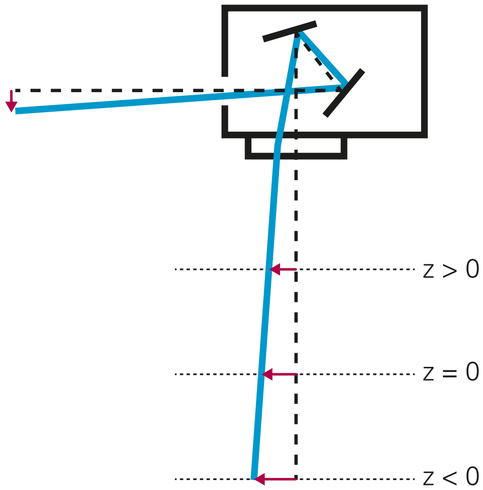
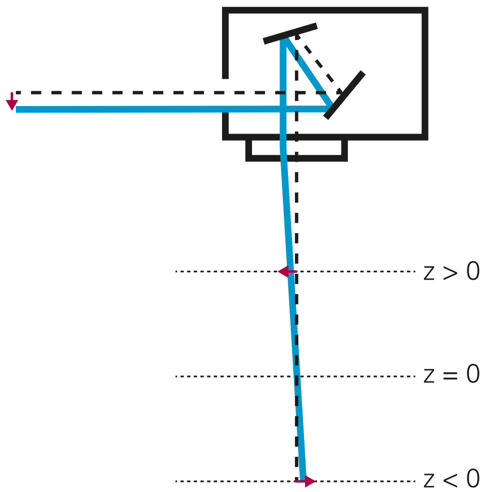
Other errors (such as drift or vibrations) can occur due to thermal influences or the use of unfavorable dynamic control parameters.

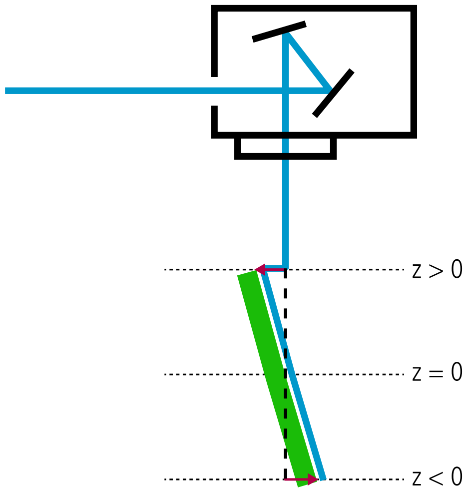
**Correctable static error in laser application**

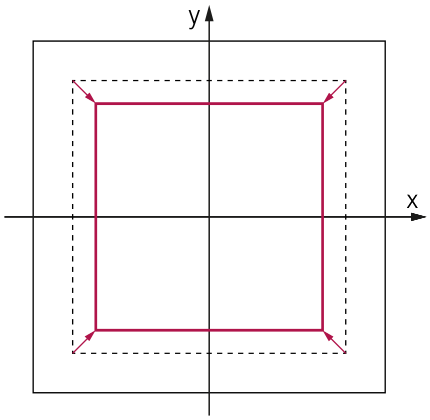

- Mirroring | Rotation, Page 126
- Offset, Page 126
- z-Dependent Offset (1-2), Page 127
- z-Dependent Offset (2-2), Page 128
- Scaling (1-3), Page 129
- Scaling (2-3), Page 130
- Scaling (3-3), Page 130
- z-Dependent Scaling, Page 131
- Rotation | Skew of Marking Result, Page 132
- Incompleteness of Marking Result, Page 133
- 2D Working Field Distortion is Asymmetric, Page 134
- 2D Working Field Distortion (1-2), Page 135
- 2D Working Field Distortion (2-2), Page 136
- Variation of Spot Quality (or Spot Size) Across 2D Working Field | Generally Reduced Spot Quality (1-3), Page 137
- Variation of Spot Quality (or Spot Size) Across 2D Working Field | Generally Reduced Spot Quality (2-3), Page 138
- Variation of Spot Quality (or Spot Size) Across 2D Working Field | Generally Reduced Spot Quality (3-3), Page 138
- Focus Position Does Not Change Accurately Enough with z Control Value, Page 139

| | |
|---|---|
| Correctable static error in laser application | **Mirroring \| Rotation**<br>• Marking result is mirrored or rotated |
| **Possible causes** | • Axes are controlled interchanged<br>• The swap xy option is activated in the Correction File = ReadMe File shows the line "swap xy: Yes"<br>• Wrong cabling<br>• The user program does not relates to SCANLAB Reference Coordinate System<br>• A coordinate transformation is set in the user program by mistake |
| **Possible measures to reduce or eliminate the error** | • To check the wiring, see manuals<br>• To check the user program for SCANLAB Reference Coordinate System, see Figure 5, Page 36 |

| | |
|---|---|
| Correctable static error in laser application | **Offset**<br>• Marking result has an offset to the side in the z = 0 plane (the 2D Working Field zero position is offset relative to the position that would be expected according to the design – with ideal, tolerance-free mechanical installation and ideal neutral position of the axes) |
| Possible causes | • Specified offset error of the xy Scan System (typ. < 5 mrad optical, to be multiplied by the focal length of the F-Theta objective for calculation of the offset in mm)<br>• Mechanical tolerances of the xy Scan System and the customer-supplied machine set-up<br>• Tilted input beam at beam input of the xy Scan Systems (set: < 5 mrad; a slight tilt of the input beam may also be caused by the Dynamic Focusing Unit)<br>• In the Correction File used, an offset is set (deliberately or unintentionally) |
| Possible measures to reduce or eliminate the error | • To manually correct, if possible: readjust the machine setup and/or input beam, see<br>– Chapter 4.2 "Ensuring the Proper Mechanical Configuration of System Components", Page 36<br>– Chapter 4.4.2 "Aligning the Beam Position", Page 44<br>• To do a limited correction by software (= optimized Correction File):<br>– To set global offset in user program<br>• By RTC command **set_offset**<br>• With laserDESK under "Hardware-Settings"<br>– To check beam position and manually correct, if relevant. To compensate for beam tilting by software (= optimized Correction File), that is, to set an offset in the Correction File, see Chapter 5.2 "Step 2: Compensating Beam Tilt", Page 67 |

| Correctable static error in laser application | **z-Dependent Offset (1-2)**<br>• Marking result has different lateral offsets in different z planes |
|---|---|
| Possible causes | • Input beam is tilted<br>(angle error when coupling the laser beam in the xy Scan System)<br><br><br>• Systems with F-Theta objective:<br>input beam is off center<br><br> |
| Possible measures to reduce or eliminate the error | • To check the beam position and manually correct, if relevant, see Chapter 4.4.2 "Aligning the Beam Position", Page 44<br>• To compensate beam tilt by software (= optimized Correction File), see Chapter 5.2 "Step 2: Compensating Beam Tilt", Page 67 |

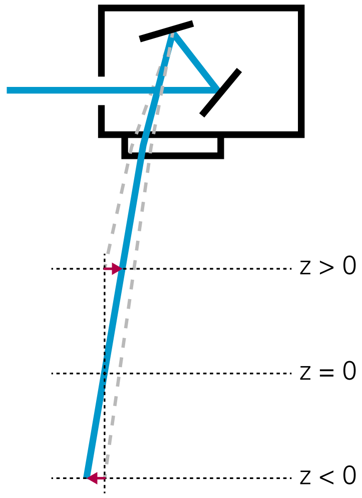
| | |
|---|---|
| **Correctable static error in laser application** | **z-Dependent Offset (2-2)**<br>• Marking result has different lateral offsets in different z planes<br>(Similar error pattern as caused by a Beam Tilt) |
| **Possible causes** | • Tilted surface to be processed<br>(= a tilted marking substrate)<br>• A tilt of the lifting table travel axis<br> |
| **Possible measures to reduce or eliminate the error** | • To check setup |

| | |
|---|---|
| **Correctable static error in laser application** | **Scaling (1-3)**<br>• Marking result is compressed or stretched in the z = 0 plane<br><br> |
| **Possible causes** | • Specified Gain Error of the xy Scan System (typ. < 5 mrad optical) |
| **Possible measures to reduce or eliminate the error** | • To perform Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72 to generate an optimized Correction File (thus potentially achieving the best error compensation)<br>• To use a Serial-Number-Specific Correction File<br>• To set global gain factors in user program<br>– By RTC command **set_hi**<br>– With laserDESK under "Hardware-Settings" |

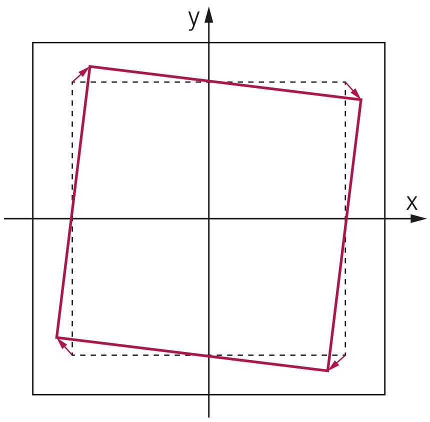
| | |
|---|---|
| **Correctable static error in laser application** | **Scaling (2-3)**<br>• Marking result is compressed or stretched in the z = 0 plane |
| **Possible causes** | • Errors in the user program (for example, scaling errors, different calibration factors than provided for in Correction File)<br>• Use of an unsuitable Correction File[a]<br>• Unsuitable downscaling has been set by mistake (for intelli*SCAN*) |
| **Possible measures to reduce or eliminate the error** | • To inspect the user program<br>• To check which Correction File is used<br>• To check the downscaling setting (for example, with `iscancfg.exe`) |

(a) “unsuitable”, for example, can mean: A. The Correction File used was not calculated for the optical configuration used (for example, not for the actual calibration of xy Scan System and/or Dynamic Focusing Unit). B. In laserDESK, neither a Correction File nor a calibration factor is explicitly specified (laserDESK then automatically uses a 1:1 correction with calibration factor K = 10000 bit/mm).

| | |
|---|---|
| **Correctable static error in laser application** | **Scaling (3-3)**<br>• Marking result is compressed or stretched in the z = 0 plane |
| **Possible causes** | • The 2D Working Field is not in the intended work plane<br>– for example, because the distance between the system and work plane has not been set mechanically to suit the working distance of the F-Theta objective<br>– for example, due to a specific beam divergence of the laser used |
| **Possible measures to reduce or eliminate the error** | • To manually correct, if possible: readjust the distance and/or beam divergence<br>• To do a limited correction by software (= optimized Correction File):<br>– To perform Chapter 5.3 ”Step 3: Calibrating z = 0 Plane”, Page 72 to generate an optimized Correction File<br>• To set global gain factors in user program<br>– By RTC command **set_hi**<br>– With laserDESK under “Hardware-Settings“ |

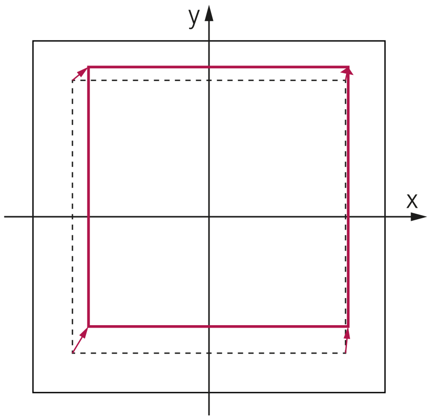
| Correctable static error in laser application | z-Dependent Scaling<br>• Marking result is laterally compressed or stretched differently in different z planes |
|---|---|
| Possible causes | • Objective errors (such errors may be associated with other errors, such as defocus or imaging errors)<br>• Use of a Correction File, which is not optimized for the system set-up with regard to stretch factors (for example, because a different objective or a different objective mounting kit is used)[a]<br><br> |
| Possible measures to reduce or eliminate the error | • To use of a SCANLAB Correction File which has been generated for the present configuration, see Chapter 7 "Appendix A: About Correction Files", Page 95<br>• To perform Chapter 5.4 "Step 4: Correcting Stretch", Page 74 |

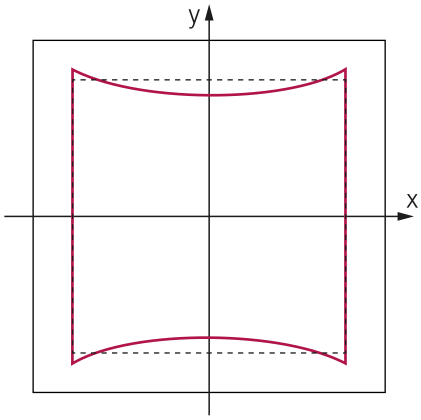
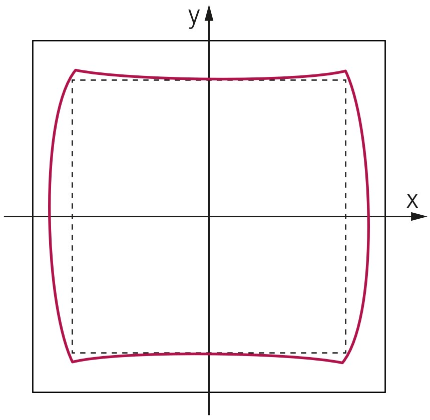
(a) "unsuitable", for example, can mean: A. The Correction File used was not calculated for the optical configuration used (for example, not for the actual calibration of xy Scan System and/or Dynamic Focusing Unit). B. In laserDESK, neither a Correction File nor a calibration factor is explicitly specified (laserDESK then automatically uses a 1:1 correction with calibration factor K = 10000 bit/mm).

| | |
|---|---|
| **Correctable static error in laser application** | **Rotation \| Skew of Marking Result**<br>• Marking result is rotated or skewed<br> |
| **Possible causes** | • Specified Skew Error of the xy Scan System (typ. < 5 mrad optical) |
| **Possible measures to reduce or eliminate the error** | • To perform Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72 to generate an optimized Correction File (thus potentially achieving the best error compensation)<br>• To use a Serial-Number-Specific Correction File |

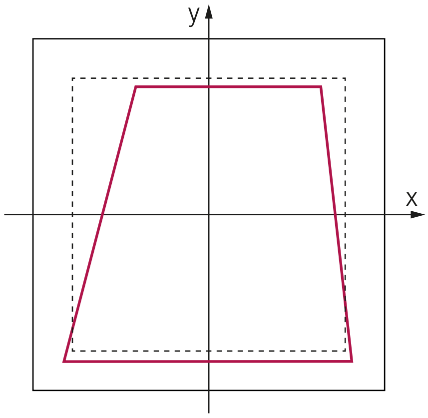
| | |
|---|---|
| **Correctable static error in laser application** | **Incompleteness of Marking Result**<br>• Marking result is cut off at the boundary = marking result is not complete |
| **Possible causes** | • Vignetting in the xy Scan System or at the objective<br>– Marking pattern too large<br>– Tilted input beam<br>– Use of an unsuitable Correction File[a]<br>– Offset set is to high (potentially also an offset in the Correction File)<br>• The Correction File has been generated with the "restricted" option with the result that the output values are clipped at a maximum value (Correction File entry "Field Size Limited by User Input") |
| **Possible measures to reduce or eliminate the error** | • To make sure marking pattern and control parameters do not result in an exceedance of the specified 2D Working Field (or specified maximum allowed scan angle)<br>• To check which Correction File is used<br>• To check the beam position and manually correct, if relevant, see Chapter 4.4.2 "Aligning the Beam Position", Page 44<br>• To compensate beam tilt by software (= optimized Correction File), see Chapter 5.2 "Step 2: Compensating Beam Tilt", Page 67 |

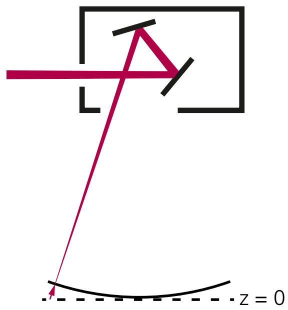
(a) "unsuitable", for example, can mean: A. The Correction File used was not calculated for the optical configuration used (for example, not for the actual calibration of xy Scan System and/or Dynamic Focusing Unit). B. In laserDESK, neither a Correction File nor a calibration factor is explicitly specified (laserDESK then automatically uses a 1:1 correction with calibration factor K = 10000 bit/mm).

| | |
|---|---|
| **Correctable static error in laser application** | **2D Working Field Distortion is Asymmetric**<br><br> |
| **Possible causes** | • Specified nonlinearity of the xy Scan System (for example, <0.5 mrad/44° optical; the course of the actual deflection angle shows a non-linear deviation from the set deflection angle over the entire available angle range, often with S-shaped type curve progression) |
| **Possible measures to reduce or eliminate the error** | • To perform Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72 to generate an optimized Correction File (thus potentially achieving the best error compensation)<br>• To use a Serial-Number-Specific Correction File |

| | |
|---|---|
| **Correctable static error in laser application** | **2D Working Field Distortion (1-2)**<br>• Marking result has pillow shape<br><br>• Marking result has barrel-pillow shape<br> |
| **Possible causes** | • Use of an unsuitable Correction File, so that distortions by mirror layout and the distortion of the objective are not adequately compensated for[a]<br>– The mirror layout (including scan angle dependency of the distance between the 2 Mirrors) causes a pillow-shaped distortion of the 2D Working Field<br>– When using an F-Theta objective the pillow-shaped distortion overlaps a barrel-shaped distortion of the 2D Working Field – resulting in a barrel-pillow distortion |
| **Possible measures to reduce or eliminate the error** | • To perform Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72 to generate an optimized Correction File (thus potentially achieving the best error compensation)<br>• To use a Serial-Number-Specific Correction File |

(a) "unsuitable", for example, can mean: A. The Correction File used was not calculated for the optical configuration used (for example, not for the actual calibration of xy Scan System and/or Dynamic Focusing Unit). B. In laserDESK, neither a Correction File nor a calibration factor is explicitly specified (laserDESK then automatically uses a 1:1 correction with calibration factor K = 10000 bit/mm).

| | |
|---|---|
| **Correctable static error in laser application** | **2D Working Field Distortion (2-2)**<br>• Marking result has a trapezoidal shape<br> |
| **Possible causes** | • System misalignment:<br>– Angle error in the processing plane<br>– Angle error when mounting the scan system |
| **Possible measures to reduce or eliminate the error** | • To manually correct, if possible<br>• To compensate by software (= optimized Correction File):<br>– To perform Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72 for compensation in xy<br>– To perform Chapter 5.6 "(Optional) Step 6: Focus Plane Correction", Page 81 for compensation in z |

| Correctable static error in laser application | **Variation of Spot Quality (or Spot Size) Across 2D Working Field \| Generally Reduced Spot Quality (1-3)** |
|---|---|
| Possible causes | • For systems without objective<br>– Unsuitable Correction File[a]<br>– Incorrect working plane (Dynamic Focusing Unit is incorrectly controlled: focus may therefore, be on a spherical surface rather than a flat surface)<br> |
| Possible measures to reduce or eliminate the error | • To use of a SCANLAB Correction File, which has been calculated for the configuration present (incl. Dynamic Focusing Unit), see Chapter 7 ”Appendix A: About Correction Files”, Page 95<br>• To perform Chapter 5.5 ”Step 5: Adjusting the Entire Dynamic Focusing Unit Travel Range by Improved ABC Coefficients”, Page 79 |

(a) “unsuitable”, for example, can mean: A. The Correction File used was not calculated for the optical configuration used (for example, not for the actual calibration of xy Scan System and/or Dynamic Focusing Unit). B. In laserDESK, neither a Correction File nor a calibration factor is explicitly specified (laserDESK then automatically uses a 1:1 correction with calibration factor K = 10000 bit/mm).

| Correctable static error in laser application | Variation of Spot Quality (or Spot Size) Across 2D Working Field \| Generally Reduced Spot Quality (2-3) |
|---|---|
| Possible causes | • For systems with objective<br>– Usual objective imaging error<br>– Mechanical tolerances of the F-Theta objective (lens error)<br>– Objective is not an F-Theta objective, for example, individual lens instead |
| Possible measures to reduce or eliminate the error | • To choose a suitable objective<br>• To perform Chapter 5.6 "(Optional) Step 6: Focus Plane Correction", Page 81 |

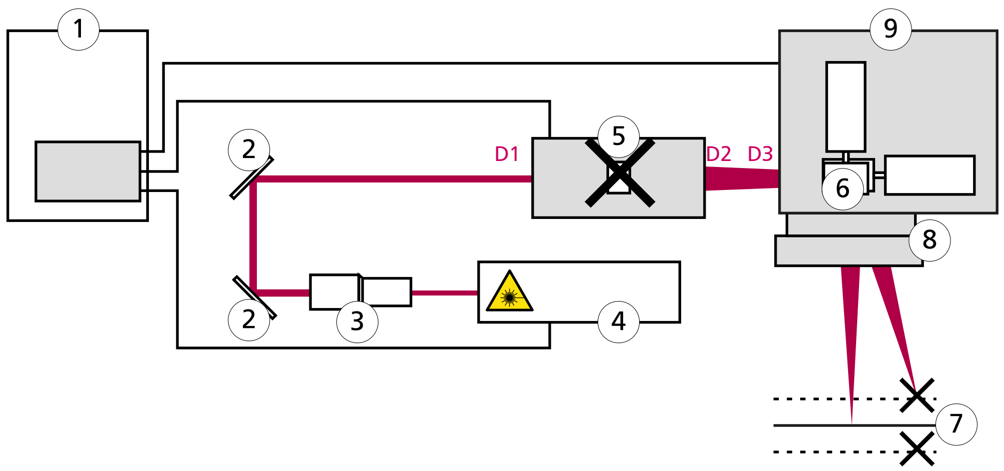
| Correctable static error in laser application | Variation of Spot Quality (or Spot Size) Across 2D Working Field \| Generally Reduced Spot Quality (3-3) |
|---|---|
| Possible causes | • Working plane and/or workpiece are<br>– Not flat<br>– Tilted by mistake |
| Possible measures to reduce or eliminate the error | • To check the working plane and workpiece |

| Correctable static error in laser application | Focus Position Does Not Change Accurately Enough with z Control Value |
|---|---|
| Possible causes | • Working Distance A does not match the Correction File<br>• Distance B does not match the Correction File<br>• Tolerances of the optical components<br>• Beam divergence of the laser used<br>• Unsuitable Correction File[a]<br>• Correction file used not yet optimized for the system set-up with regard to ABC Coefficients<br>• Incorrect calibration of the Dynamic Focusing Unit (for example, incorrect downscaling factor set) |
| Possible measures to reduce or eliminate the error | • To set Working Distance A and Distance B correctly or have suitable Correction File calculated<br>• To perform Chapter 5.6 "(Optional) Step 6: Focus Plane Correction", Page 81<br>• To have SCANLAB check the calibration of the Dynamic Focusing Unit |

# 17 Appendix K: Calibrating 2-Axis Laser Scan Systems

- 2-Axis Laser Scan Systems and 3-Axis Laser Scan Systems are essentially the same in terms of their components, see Figure 45, Page 140:
  - necessary files have a different name (1)
  - 2-Axis Laser Scan Systems have fewer components (5)
- Accordingly, 2-Axis Laser Scan Systems are basically calibrated in the same way as 3-Axis Laser Scan Systems, only steps are omitted, see Figure 46, Page 141. Apart from that, procedures described in this publication are to be applied *analogously*.(1)

(1) "transfer of learning"

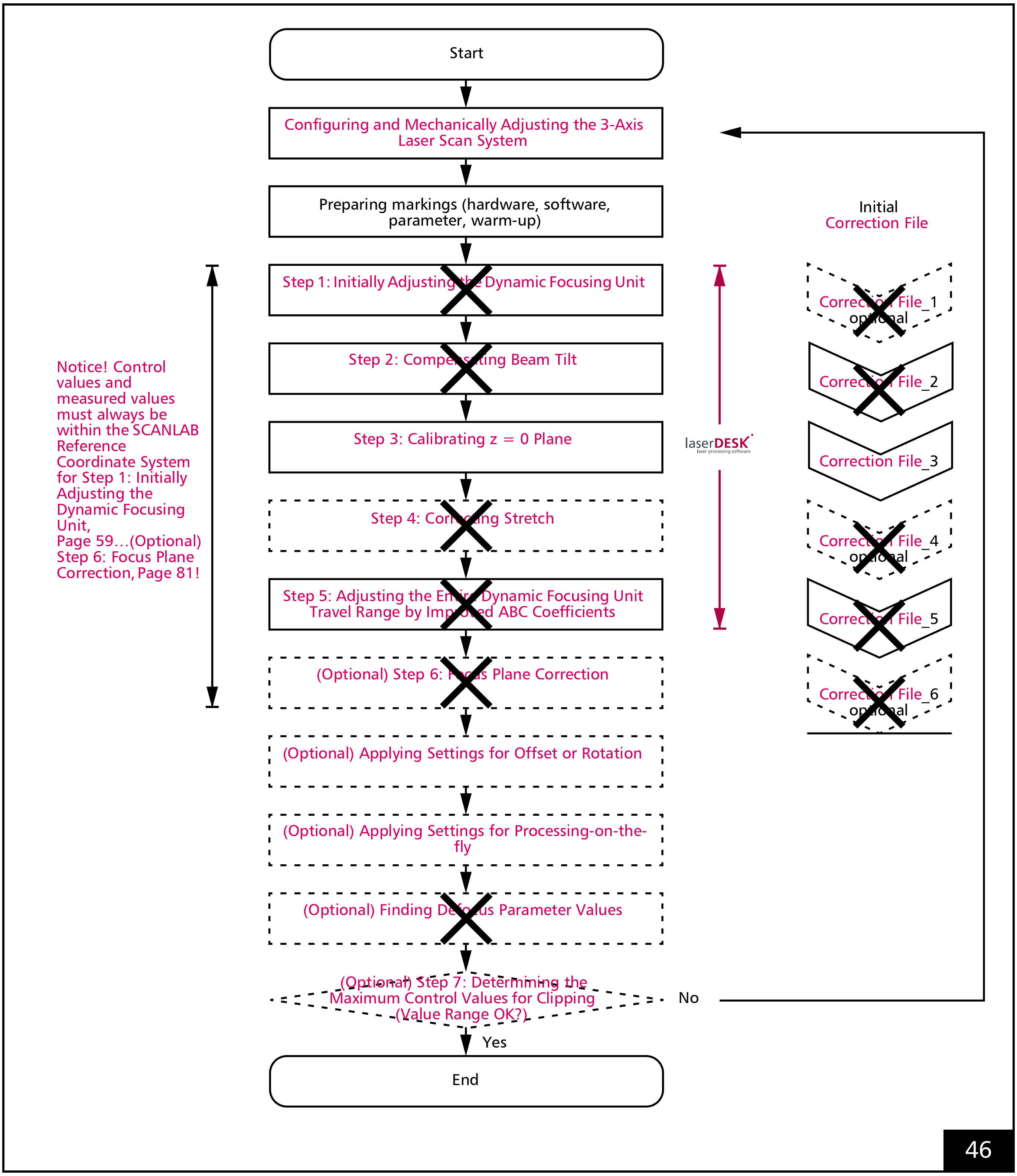



**Legend**

1. PC with User Program, RTC Board, `D2_xxxx.*`-Correction File (instead of: `D3_xxxx.*`-Correction File)
2. Adjustment Mirror
3. Beam Expander
4. Laser
5. Not present: Dynamic Focusing Unit = 1 axis
6. Mirror
7. Laser focus in 2D Working Field (instead of: working plane or 3D Working Volume)
8. F-Theta Objective
9. xy Scan System = 2 axes

45

2-Axis Laser Scan System. Compare to 3-Axis Laser Scan System, Figure 2, Page 12.




2D Calibration Process: flow chart.

## 17.1 Special Case: No "Standard" D2-Correction File D2_xxxx.* Available

In this Chapter:



- This chapter does not apply to most SCANLAB customers: Usually, enough(1) information about the F-Theta Objective used is shared with SCANLAB. In return, a "Standard" D2-Correction File D2_xxxx.* is then available that exactly matches the respective 2-Axis Laser Scan System.

If you do not provide SCANLAB with any information about the F-Theta Objective used, SCANLAB neither can calculate nor provide you with a "Standard" D2-Correction File D2_xxxx.*.

This means that you are initially missing essential values for the 2D calibration process, such as calibration factor and typical (usable) Image Field size.

Nevertheless, you can carry out the 2D calibration process for your 2-Axis Laser Scan System even without "Standard" D2-Correction File D2_xxxx.*.

A prerequisite for this (for example, for markings) is that you estimate a *reasonable* calibration factor by yourself:

- Chosen calibration factor is too small
  – corresponds – contrary to reality – to an oversized Image Field (that is, control values can be specified for a wide that is, border area that does not even exist)
- Chosen calibration factor is too big
  – corresponds to a restricted Image Field(2)
  – gives no flexibility to set an offset (as soon as this would become necessary)
  – Sky Writing cannot utilize the entire galvanometer scanner excursion range

(1) See also "Standard" D3-Correction Files.

(2) This is the consequence, if you use the original Cor_1to1.ct5 from the RTC Software Package in laserDESK 3D calibration wizard as initial Correction File. In this case, laserDESK automatically determines and sets a calibration factor that limits Image Field size to the size of the to-be-marked 11 × 11 grid.

**RTC5 board user | RTC6 board user – To determine a reasonable calibration factor for your 2-Axis Laser Scan System**

**(1)** Look up Calibration Angle (xy Scan System) in SCANLAB xy Scan-System Manual and note the value for step 3.

**(2)** Look up F-Theta Objective focal length, for example, in the manufacturer data sheet and note the value for step 3.

**(3)** Estimate the to-be-expected maximum Image Field size based on F-Theta condition:
2× Calibration Angle (xy Scan System) [rad])
from step 1.
×
F-Theta Objective focal length [mm]
from step 2

For the example ±0.408 rad and 160 mm the result is 2 × 0.408 rad × 160 mm ≈ 130 mm; that is, 130 mm × 130 mm.

**(4)** Define calibration factor K (as 20-bit value):
(a) Divide $2^{20}$ bit by the result from step 3.
Example: 1,048,576 bit / 130 mm
= 8,065 bit/mm
(b) Round the number down to a number divisible by 16. Here: 8,064 bit/mm

**(5)** Make a copy of `Cor_1to1.ct5` and give it a meaningful name.

**(6)** In CorrectionFileConverter, open the file from step 5.

**(7)** Complete the following fields
(a = mandatory; b, c, d = recommended):
(a) 'Field Calibration [Bit/mm]'
value from step 4b
(b) 'Focal Length [mm] Working Distance'
value from step 2
(c) 'Lens [Yes 1 / No 0] Correction Type'
value '1'.
(d) 'Calibration Angle [mech. degrees]'
value from step 1 [rad optical]
× 180° / 3.14 / 2 (see Page 20)

**(8)** Click **Save**.
This creates your initial Correction File which now contains meaningful data.

**(9)** Define the typical (usable) Image Field size(1). This is alway smaller than maximum Image Field size (= see step 3). Parameters that you need to take into account include Back Focal Length, distortion, vignetting, beam diameter, image quality.

**(10)** Work through the Checklist.

| **Checklist** |
|---|
| • Calibration Angle (xy Scan System) is known |
| • F-Theta Objective focus length is known |
| • Maximum Image Field size has been estimated |
| • K calibration factor (as 20-bit value) has been estimated |
| • Typical (usable) Image Field size has been estimated |
| • File from step 8 is available |

**(11)** Carry out 2D Calibration Process using the file from step 8, see Figure 46, Page 141.

(1) See also 2D Working Field Size (Typical), Page 15.

**RTC4 board user – To determine a reasonable calibration factor for your 2-Axis Laser Scan System**

**(1)** Look up Calibration Angle (xy Scan System) in SCANLAB xy Scan-System Manual and note the value for step 3.

**(2)** Look up F-Theta Objective focal length, for example, in the manufacturer data sheet and note the value for step 3.

**(3)** Estimate the to-be-expected maximum Image Field size based on F-Theta condition:
2 × Calibration Angle (xy Scan System) [rad])
from step 1.
×
F-Theta Objective focal length [mm]
from step 2

For the example ±0.408 rad and 160 mm the result is 2 × 0.408 rad × 160 mm ≈ 130 mm; that is, 130 mm × 130 mm.

**(4)** Define calibration factor K (as 16-bit value):
(a) Divide $2^{16}$ bit by the result from step 3.
Example: 65,536 bit / 130 mm = 504 bit/mm
(b) If applicable: round the number down to a number divisible by 2

**(5)** Define the typical (usable) Image Field size[(1)]. This is alway smaller than maximum Image Field size (= see step 3). Parameters that you need to take into account include Back Focal Length, distortion, vignetting, beam diameter, image quality.

**(6)** Work through the Checklist.

| Checklist |
|---|
| • Calibration Angle (xy Scan System) is known |
| • F-Theta Objective focus length is known |
| • Maximum Image Field size has been estimated |
| • K calibration factor (as 16-bit value) has been estimated |
| • Typical (usable) Image Field size has been estimated |
| • `Cor_1to1.ctb` is available |

**(7)** Carry out 2D Calibration Process, see Figure 46, Page 141. Use 1to1-Correction File `Cor_1to1.ctb` as initial Correction File.

(1) See also 2D Working Field Size (Typical), Page 15.

# 18 Appendix L: Change Index

The following are changes in this manual due to the technical evolution of the product as well as significant editorial changes.

In this Chapter:

**Changes to document revision 1.4.0 en-US from document revision 1.3.2 en-US**

| **Where** | **What** |
|---|---|
| Global | Document Revision<br>• 1.4.0 en-US |
| Global | Editorial change.<br>Manual restructured. |
| Global | Software change.<br>ABCcorreXion5 removed from excelli*SHIFT* software package. |
| Global | Software change.<br>CALsheet is discontinued. Last Shipment: 2023-06-30. |
| Global | Software change.<br>OffsetcorreXion5 removed from excelli*SHIFT* software package. |
| Global | Software change.<br>StretchCorreXion5 removed from excelli*SHIFT* software package. |
| Chapter 2.2 "About the SCANLAB Reference Coordinate System", Page 33 | Editorial enhancement.<br>SCANLAB Reference Coordinate System: Figure 4, Page 33. |
| Chapter 5 "Optimizing Correction Files ("Calibration Steps")", Page 55 | Editorial enhancement.<br>Flow chart: Figure 8, Page 56. |
| Chapter 5.2 "Step 2: Compensating Beam Tilt", Page 67 | Software change.<br>New CalibrationLibrary function in CalibrationLibrary V1.4:<br>**slcl_do_beam_tilt_calibration_measurement_data**, Page 71. |
| Appendix L: Change Index, Page 145 | |

**Changes to document revision 1.5.0 en-US from document revision 1.4.0 en-US**

| Where | What |
|---|---|
| Global | Document Revision<br>• 1.5.0 en-US |
| Related Documents, Page 6 | Editorial enhancement.<br>Data sheet "Characteristics of the 3-Axis Configuration". |
| Case: excelliSHIFT and Tracking Error System, Page 54 | Editorial change.<br>Procedure text improved. |
| Chapter 2.1 "Calibration-Relevant Parameters (Alphabetical)", Page 14 | Editorial enhancement.<br>Calibration Angle (xy Scan System), Page 20. – Only relevant for Special Case: No "Standard" D2-Correction File `D2_xxxx.*` Available –. |
| Chapter 2.1 "Calibration-Relevant Parameters (Alphabetical)", Page 14 | Software change. Rayleigh Length, Page 27.<br>SCANcalc can now calculate the Rayleigh Length for xy Scan Systems with apertures > 30 mm (previously: ≤ 30 mm). |
| Chapter 5.1.1 "Procedure with varioSCAN or varioSCAN FLEX", Page 61 | Editorial change. There is no as-delivered state of the focusing ring. Corresponding information to the contrary ("typically unscrewed from the stop as follows" as well as in Table 6) was incorrect and therefore, have been deleted. |
| Chapter 5.1.1 "Procedure with varioSCAN or varioSCAN FLEX", Page 61 | Editorial enhancement.<br>New Figure 10, Page 61. |
| Chapter 5.2 "Step 2: Compensating Beam Tilt", Page 67 | Editorial enhancement.<br>Step 5, Page 71. New recommendation for **slcl_do_beam_tilt_calibration_measurement_data**. |
| Chapter 5.2 "Step 2: Compensating Beam Tilt", Page 67 | Editorial change. Procedure simplified. Information on **slcl_do_beam_tilt_calibration** is no longer needed (because of **slcl_do_beam_tilt_calibration_measurement_data**) and therefore, has been moved to CalibrationLibrary Manual. |
| Chapter 5.3 "Step 3: Calibrating z = 0 Plane", Page 72 | Editorial enhancement.<br>Procedure separated. Case B: With CalibrationLibrary and slcl_xy_calibration_mm_targets and Case C: With CalibrationLibrary and slcl_xy_calibration_bit_targets. |
| Appendix L: Change Index, Page 145 | |

| Where (cont'd.) | What (cont'd.) |
|---|---|
| Chapter 6.5 "(Optional) Adjusting the Pilot Laser Correction File", Page 93 | Editorial enhancement.<br>Clarifications. |
| Chapter 7 "Appendix A: About Correction Files", Page 95 | Editorial enhancement.<br>New Figure 32, Page 95. |
| Section "About 1to1-Correction Files", Page 99 | Editorial enhancement.<br>Clarifications. New Figure 33, Page 99. New Figure 34, Page 99. |
| Chapter 11 "Appendix E: About Calibration Factors", Page 109 | Editorial change.<br>Clarifications. |
| Chapter 17 "Appendix K: Calibrating 2-Axis Laser Scan Systems", Page 140 | Editorial enhancement. |
| Appendix L: Change Index, Page 145 | |