XL *SCAN*

large-field scanning solution

XL *SCAN* Overview

XL *SCAN* Overview

- Joint development by
  - ACS Motion Control, Ltd.
  - SCANLAB GmbH

- Combining 30+ years’ expertise in each of
  - solution for motion control
  - solution for laser scanning with galvanometer motors

- Target applications
  - Large-field marking, cutting, engraving
  - Glass and foil processing
  - Micromachining
  - Via-hole drilling on PCBs
  - etc.

XL *SCAN* Overview

large-field scanning solution

excelli*SCAN* and XY stage in synchronized motion by

- **High-precision trajectory planning with sync*AXIS* control software**
- **Motion distribution between scan head and stage by low-pass filtering**

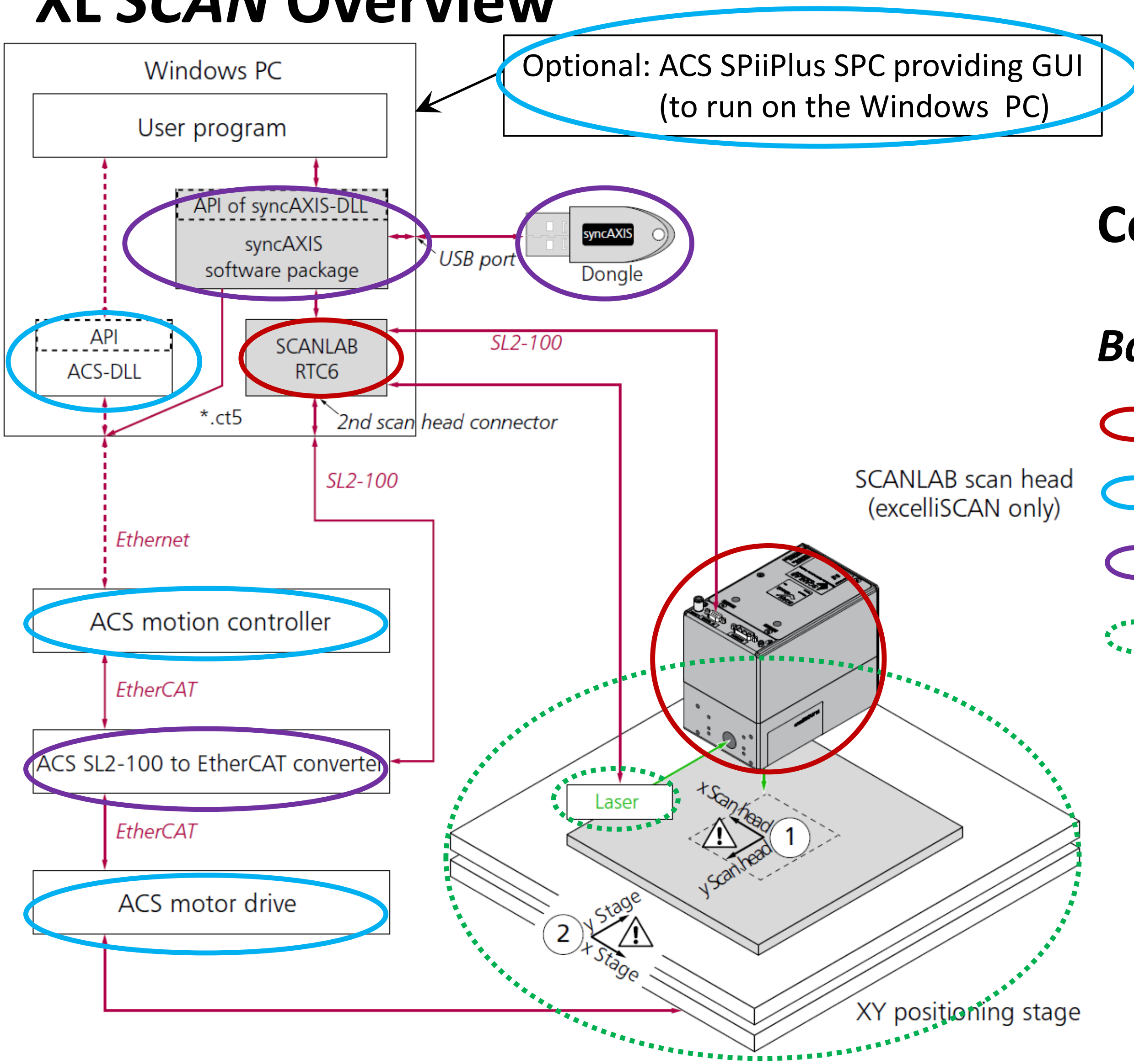
XL *SCAN* Overview

XL *SCAN* offers

- **Unlimited Field of View**
- **Unlimited Job Duration**
- **High Throughput**
- **High Accuracy**
  in particular, zero tracking error in sharp curves and no stitching errors
- **Highly Dynamic Processes without Stage Vibration**
- **Automatized Trajectory Planning and Laser Control**
  in particular, simultaneous control of spot distance & pulse energy (or pulse length

allowing users to exploit the full potential of machine setup.

XL *SCAN* Overview



Components of XL *SCAN*

Basic Setup

- SCANLAB component
- ACS component
- Common component
- External component left to the user's choice

XL *SCAN* Overview

sync*AXIS* control with syncAXIS.dll / APIs for C++/C#

sync*AXIS* API is an application programming interface (API) for developing user programs in the form of functions for simultaneous control of laser, excelli*SCAN* and XY stage.
It includes planning and status monitoring of jobs.

SCANLAB RTC6

The RTC6 board is used for real-time control of the scan head, the laser and the signal for xy-stage via SL2-100 transmission protocol.

SLEC

The SCANLAB-EtherCAT Converter (SLEC) translates the signals from the scanner's SL2-100 protocol to an EtherCAT protocol. This can be read by ACS motion drive.

ACS API / ACS DLL

ACS API / DLL is the software from ACS for controlling the motion drive. This is used for installation and configuration.
It can also be used in the user program.

ACS Controller

The ACS controller is the master of the EtherCAT protocol.
It computes corrections of the stage in real time for the suppression of inaccuracies due to vibrations, overdrives and so on.

ACS Drives

ACS Drives are the motion drives for physical axes.

Software tools for XL *SCAN* system setup

Software tools for XL *SCAN* system setup

A) **Ready-to-use installation project** (included in sync*AXIS* control SW package)
=> providing a command-line console tool for 1st-time test operation

B) **sync*AXIS* Configurator** (included in sync*AXIS* control SW package)
=> providing a GUI tool for parameter setting

C) **sync*AXIS* Viewer** (included in sync*AXIS* control SW package)
=> providing a GUI tool for simulation and offline parameter optimization

D) **sync*AXIS*.dll** (included in sync*AXIS* control SW package as its **core component**)
=> providing C++ and C# APIs for the development of user application programs

E) **Optional: ACS SPiiPlus SPC** (**NOT included** in sync*AXIS* control SW package)
=> providing a GUI for complete machine control

Software tools for XL *SCAN* system setup

A) Ready-to-use installation project providing a command-line console tool

with examples for demo & quick start of sync*AXIS*

C:\syncAXIS-1.3-win32\example\Installation_Project_Build\Installation_Project.exe

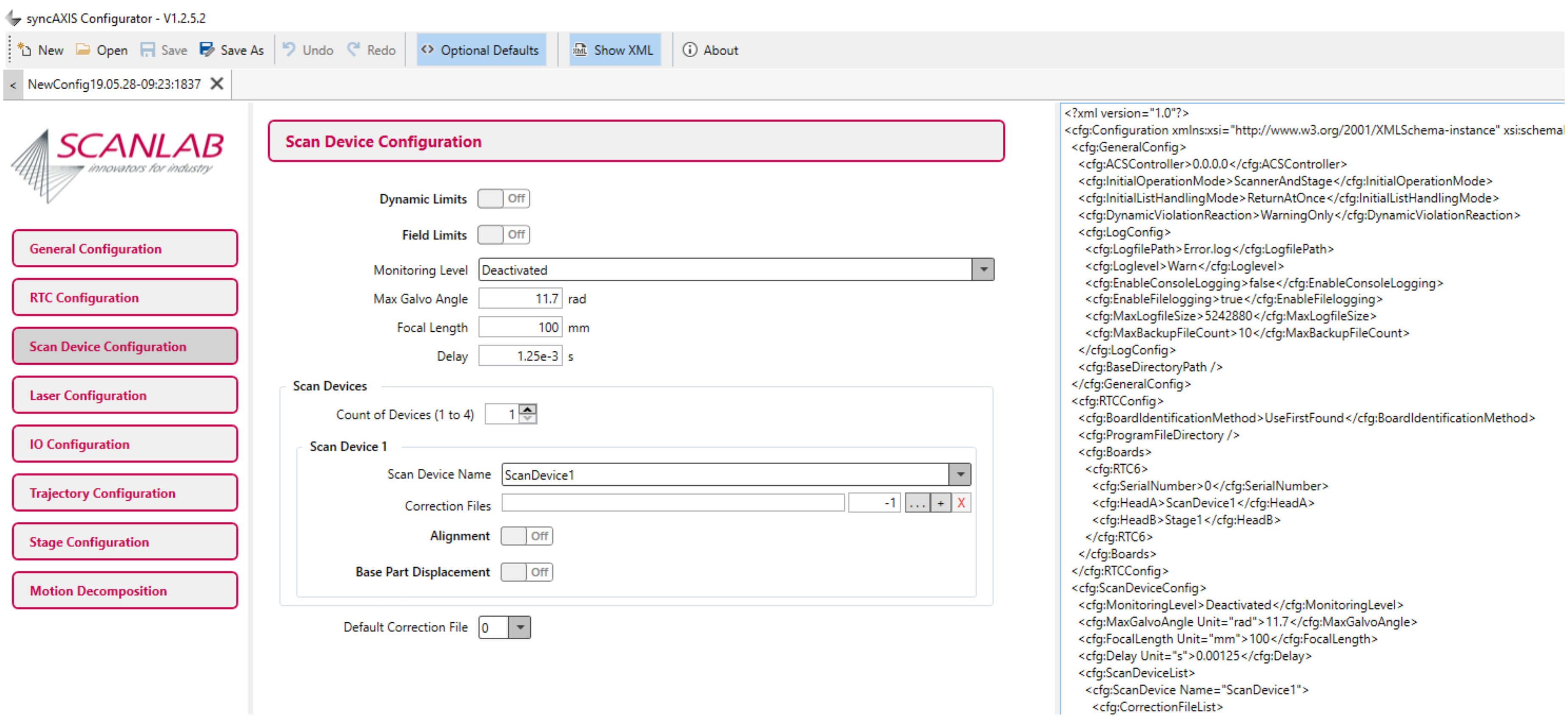
```
        ########################################################################
        ##                                                                    ##
        ##       Welcome to the syncAXIS control Installation Project         ##
        ##                                                                    ##
        ##         This program demonstrates the implementation of            ##
        ##        the syncAXIS control software for controlling XL SCAN.      ##
        ##                                                                    ##
        ##    Before starting the program, make sure the syncAXISConfig.xml   ##
        ##      file is correctly set (i.e. adding the ACS controllers IP     ##
        ##                  address and correction file path)                 ##
        ##     and placed in a specified location or the execution directory. ##
        ##                                                                    ##
        ########################################################################

Please choose one of the following options:
Enter 0: "Leave application". (EXIT)
Enter 1: "Initialize an instance from an XML file". (INIT)
Enter 2: "Check for correct laser configuration by firing the laser manually without any motion". (CHECK_LASER_FIRING)
Enter 3: "Execute a reference run with each scanner and stage to check for correct configuration". (REFERENCE_RUN)
Enter 4: "Mark a test pattern (SCANLAB logo) with the current settings". (TEST_MARKING)
Enter 5: "Execute marking of a scanner calibration grid in ScannerOnly-mode". (SCANNER_CALI)
Enter 6: "Execute marking of a stage calibration grid in StageOnly-mode". (STAGE_CALI)
Enter 7: "Mark a grid in combined motion for evaluation of combined accuracy". (COMBINED_ACCURACY)
Enter 8: "Draw a marking pattern for checking the laser delays". (CHECK_LASERDELAYS)
Enter 9: "Execute an accuracy test pattern consisting of a circle grid pattern in
          ScannerOnly and a cross grid pattern in StageOnly-mode that can be compared". (CHECK_CALIBRATIONS)
Enter 10: "Draw a marking pattern for checking the system delays (should be good by default.
          Please contact SCANLAB in case they are not)". (CHECK_SYSTEMDELAYS)
Enter 11: "Change settings of the job like speed, offset, etc.". (CHANGE_SETTINGS)
Enter 12: "Delete instance without terminating the application". (DELETE_INSTANCE)
Enter 13: "Check for errors". (CHECK_FOR_ERRORS)
Please enter:
```

Software tools for XL *SCAN* system setup

B) sync*AXIS* Configurator providing a GUI tool

helping the user creating XML configuration file for sync*AXIS*

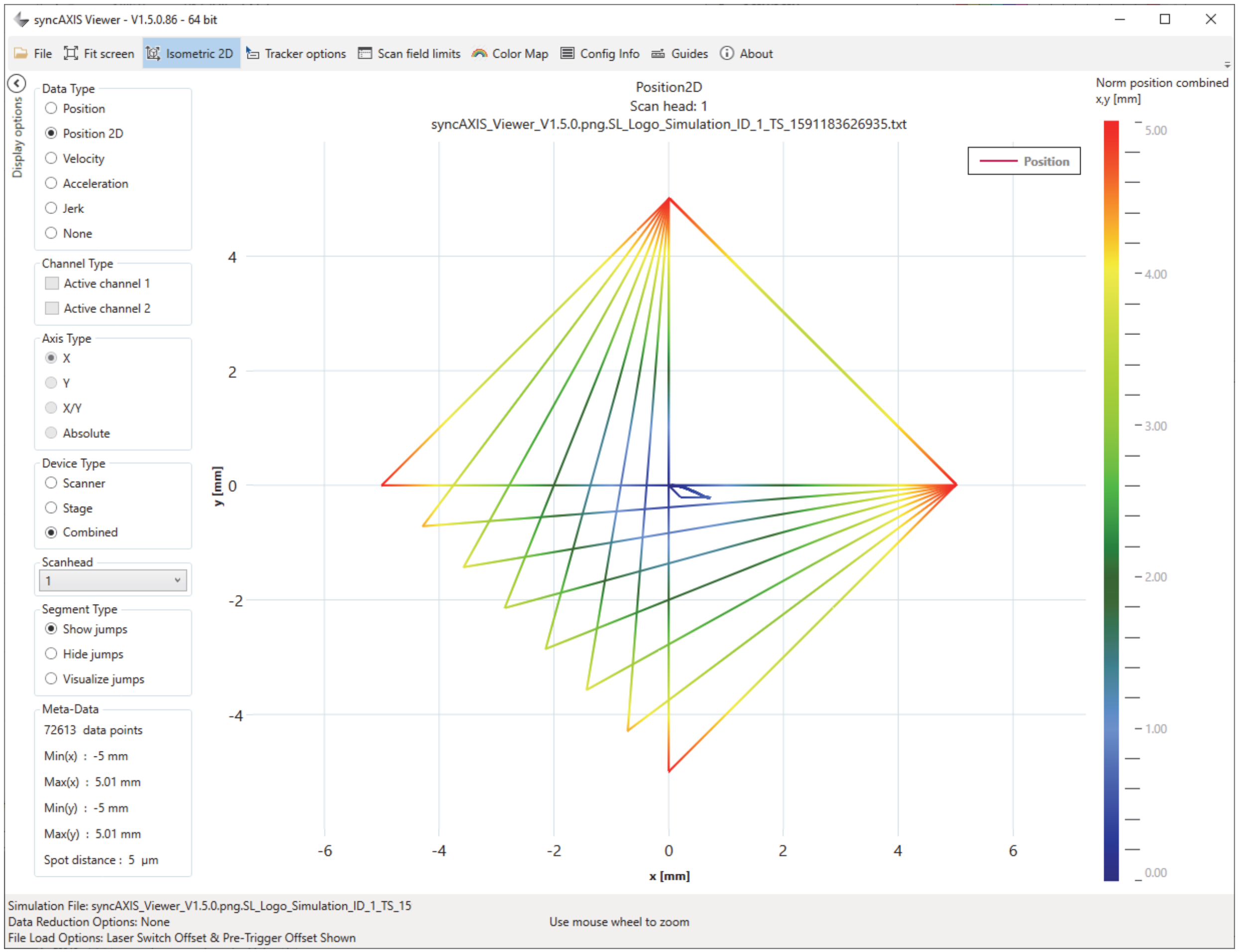
=> *in particular, parameter setting for scanner-stage motion distribution amongst others*



Software tools for XL *SCAN* system setup

C) sync*AXIS* Viewer providing a GUI tool

for reviewing simulation results and offline parameter optimization without laser



Typical parameters to be optimized for minimized error and avoidance of limit breach:

- JumpSpeed & MarkSpeed
- Blending Mode & Parameters
- Stage Velocity, Acc., and Jerk
- FilterBandwidth*
- etc.

* : *This parameter determines the motion path distribution between scanner and stage.*

Software tools for XL *SCAN* system setup

Two choices for the user's application development:

Choice 1: writing an own application program by using the C++ or C# API provided in form of

D) sync*AXIS*.dll

=> recommendable to the users experienced in machine control SW development (in particular, in RTC programming)

or

Choice 2: kick-starting the immediate validation tests and prototyping by using the GUI of

E) ACS SPiiPlus SPC (optional and not included in sync*AXIS* control SW package)

=> recommendable to inexperienced users or those user who just want to save time and resources during the pre-development phase

=> sync*AXIS*.dll, sync*AXIS* Configurator, and sync*AXIS* Viewer are included in **ACS SPiiPlus SPC**.

=> **ACS SPiiPlus SPC** also offers an SDK for the user to write own applications programs.

Software tools for XL *SCAN* system setup

D) sync*AXIS*.dll (C++ and C# API)

API offers the following functions:

- Extensive configuration possibilities
- Defining, labeling, loading, and executing laser processing jobs
- Job status monitoring
- Registering event callbacks
- Simulation of job execution

Functions are categorized into

A) configuration functions,
B) control functions,
C) job functions, and
D) utility functions

Motion parameters to be set by the user

- Max. velocity of stage
- Max. acceleration of stage
- Max. jerk of stage
- Mark speed
- Jump speed
- Low-pass filter bandwidth for stage motion part
- etc.

Software tools for XL *SCAN* system setup

D) sync*AXIS*.dll (C++ and C# API) – overview of configuration & control functions

Configuration Functions (slsc_cfg_*)

syncAXIS control instance: Create
slsc_cfg_initialize_from_file

Copy and set to simulation mode
slsc_cfg_initialize_copy

syncAXIS control instance: Is running

Reinitialize
slsc_cfg_reinitialize
slsc_cfg_reinitialize_from_file

To query properties

To query the sync*AXIS*-DLL version
slsc_cfg_get_sync_axis_version

To query the configuration
slsc_cfg_get_trajectory_config

To query the syncAXIS control instance state ("traffic light color")
slsc_cfg_get_operation_status

To query the operating mode (positioning stage and/or scan head)
slsc_cfg_get_mode

To query current configuration values (having a correspondence to syncAXISConfig.xml)
slsc_cfg_get_calculation_dynamics_jump_scan_device »LIST
slsc_cfg_get_calculation_dynamics_mark_scan_device »LIST
slsc_cfg_get_calculation_dynamics_stage
slsc_cfg_get_dynamic_limits_scan_device
slsc_cfg_get_dynamic_limits_stage
slsc_cfg_get_dynamic_violation_reaction
slsc_cfg_get_field_limits_scan_device
slsc_cfg_get_field_limits_stage
slsc_cfg_get_scan_device_dynamic_monitoring_level
slsc_cfg_get_simulation_setting
slsc_cfg_get_stage_dynamic_monitoring_level

To change properties

To change the return behavior of Job functions (slsc_list_*)
slsc_cfg_set_list_handling_mode
slsc_cfg_set_list_handling_mode_with_context

To change the configuration (as of next Job)
slsc_cfg_select_heuristic
slsc_cfg_set_bandwidth
slsc_cfg_set_jump_speed »LIST
slsc_cfg_set_mark_speed »LIST
slsc_cfg_set_trajectory_config

To change the operating mode (positioning stage and/or scan head)
slsc_cfg_set_mode

Which Callback function to call at which sync*AXIS*-DLL-internal event
slsc_cfg_register_callback_job_start_planned
slsc_cfg_register_callback_job_progress_planned
slsc_cfg_register_callback_job_end_planned
slsc_cfg_register_callback_job_loaded_enough
slsc_cfg_register_callback_job_is_executing
slsc_cfg_register_callback_job_finished_executing

Temporarily release positioning stage and reacquire
slsc_cfg_release_stage (deprecated)
slsc_cfg_acquire_stage (deprecated)

To specify a target positioning stage
slsc_cfg_select_stage

To change target point coordinates (as of next Job)
slsc_cfg_set_rot_and_offset_2d »LIST (angle & offset value)
slsc_cfg_set_matrix_and_offset »LIST (transformation matrix & offset value)

To configure, switch on/off "Contour-dependent speed calculation"
slsc_cfg_set_contour_dependent_speed_control_2d »LIST

To apply Matrix/Offset to the set trajectory for scan device
slsc_cfg_set_part_displacement

To change current configuration values (having a correspondence to syncAXISConfig.xml)
slsc_cfg_set_calculation_dynamics_jump_scan_device »LIST,
slsc_cfg_set_calculation_dynamics_mark_scan_device »LIST,
slsc_cfg_set_calculation_dynamics_stage, slsc_cfg_set_dynamic_limits_scan_device,
slsc_cfg_set_dynamic_limits_stage, slsc_cfg_set_dynamic_violation_reaction,
slsc_cfg_set_field_limits_scan_device, slsc_cfg_set_field_limits_stage,
slsc_cfg_set_scan_device_dynamic_monitoring_level,
slsc_cfg_set_simulation_setting, slsc_cfg_set_stage_dynamic_monitoring_level

»LIST: corresponding Job function available.

syncAXIS control instance: Delete
slsc_cfg_delete

Control Functions (slsc_ctrl_*)

syncAXIS control instance: Is running

Job execution
To start:
slsc_ctrl_start_execution(**)
To cancel:
slsc_ctrl_stop_controlled(*)
slsc_ctrl_stop(*)

Value of a free variable on the RTC6
To set:
slsc_ctrl_set_free_variable(*)
To query:
slsc_ctrl_get_free_variable(*)

To query the state of the Input buffer
slsc_ctrl_is_list_input_buffer_full(*)

To query the status of the Job execution
slsc_ctrl_get_exec_state(*)

To query errors
slsc_ctrl_get_error(*)
slsc_ctrl_get_error_count(*)

To query measured signals
slsc_ctrl_get_value(*)

Only in simulation mode!
slsc_ctrl_get_syncaxis_simulation_filename(*)
To query a simulation file name.

To change the laser signal output
yes: slsc_ctrl_enable_laser(*)
no: slsc_ctrl_disable_laser(*)

To use another correction file
slsc_ctrl_get_job_characteristic(*)

To influence laser pulse output by HalfPeriod/PulseLength
slsc_ctrl_set_laser_pulses

For a Job-ID: to return the value of a Job characteristic which has been calculated by the Trajectory planning
slsc_ctrl_get_job_characteristic(*)

To immediately position the galvanometer scanners
slsc_ctrl_move_scanner_abs(***)

To immediately position the positioning stage
slsc_ctrl_move_stage_abs(***)

To immediately switch the laser on/off
On: slsc_ctrl_laser_signal_off(***)
Off: slsc_ctrl_laser_signal_on(***)

To immediately send 1 correction file to the RTC6
slsc_ctrl_refresh_correction_file(*)

Only in Jobs started by slsc_list_begin_absolute!
To immediately release positioning stage:
slsc_ctrl_unfollow(*)
To immediately reacquire positioning stage:
slsc_ctrl_follow(*)

To query set/actual position of
positioning stage: slsc_ctrl_get_stage_position(*)
scan device: slsc_ctrl_get_scan_device_position(*)

To set signals
At analog output port
slsc_ctrl_write_analog_x(***)

At digital output port
slsc_ctrl_write_digital_out(***)
slsc_ctrl_write_digital_out_mask(***) (per bit mask)

(*) This function is allowed in all operation modes (see slsc_OperationMode).
(**) This function is *not* allowed in Mode "Manual Positioning".
(***) This function is *only* allowed in Mode "Manual Positioning".

ACS MOTION CONTROL

SCANLAB innovators for industry

Software tools for XL *SCAN* system setup

D) sync*AXIS*.dll (C++ and C# API) – overview of job & utility functions

Job Functions (slsc_list_*)

Special case (for Module recording):
slsc_list_begin_module

Job: Formal beginning
slsc_list_begin
slsc_list_begin_relative

Special case (for slsc_ctrl_unfollow/ slsc_ctrl_follow):
slsc_list_begin_absolute

Job: Elements

To define jumps to target coordinates
slsc_list_jump_abs, slsc_list_jump_abs_min_time
slsc_list_para_jump_abs[(a)], slsc_list_para_jump_abs_min_time[(a)]

To define markings to target coordinates

Circles/arcs
slsc_list_circle_2d_abs
slsc_list_dashed_circle_2d_abs
slsc_list_para_circle_2d_abs[(a)]
slsc_list_para_dashed_circle_2d_abs[(a)]
slsc_list_multi_para_circle_2d_abs[(b)]
slsc_list_multi_para_dashed_circle_2d_abs[(b)]
slsc_list_arc_abs
slsc_list_dashed_arc_abs
slsc_list_para_arc_abs[(a)]
slsc_list_para_dashed_arc_abs[(a)]
slsc_list_multi_para_arc_abs[(b)]
slsc_list_multi_para_dashed_arc_abs[(b)]

Vectors
slsc_list_mark_abs
slsc_list_dashed_mark_abs
slsc_list_para_mark_abs[(a)]
slsc_list_para_dashed_mark_abs[(a)]
slsc_list_multi_para_mark_abs[(b)]
slsc_list_multi_para_dashed_mark_abs[(b)]

Special case:
slsc_list_wait_with_laser_off
slsc_list_wait_with_laser_on (supplemented by slsc_list_suppress_spotdistance_control & slsc_list_unsuppress_spotdistance_control)

(a) for simple Ramps
(b) for more complex Ramps

To set signals
At analog output port
slsc_list_write_analog_x

At digital output port
slsc_list_write_digital_out
slsc_list_write_digital_out_mask (per bit mask)

To set the value of a free variable on the RTC6
slsc_list_set_free_variable

To change the jump speed = JumpSpeed value (only current Job)
slsc_list_set_jump_speed »CFG

To switch on/off the processing of arguments ParaTarget and MultiParaTarget (for Ramps) of the slsc_list_[para/multi_para]*-functions (only current Job)
slsc_list_para_enable
slsc_list_para_disable

To change the marking speed = MarkSpeed value (only current Job)
slsc_list_set_mark_speed »CFG

To change the minimal marking speed = MinimalMarkSpeed value (only current Job)
slsc_list_set_min_mark_speed

To change the ApproxBlendLimit value (only current Job)
slsc_list_set_approx_blend_limit

To switch on/off the "Contour-dependent speed calculation"; to change the speed determination (only current Job)
slsc_list_set_contour_dependent_speed_control_2d »CFG

To change target point coordinates (only current Job)
slsc_list_set_rot_and_offset_2d »CFG
(angle & offset value)
slsc_list_set_matrix_and_offset »CFG
(transformation matrix & offset value)

To integrate a Module ("play back")
slsc_list_playback_module
slsc_list_para_playback_module

To shift the "Laser Active" Operation
slsc_list_set_laser_on_move

To influence laser pulse output by HalfPeriod/PulseLength
slsc_list_set_laser_pulses

To changeTrajectory planning values (only current Job)
slsc_list_set_calculation_dynamics_jump_scan_device »CFG
slsc_list_set_calculation_dynamics_mark_scan_device »CFG

»CFG corresponding Configuration function available.

Job: Formal end
slsc_list_end

Utility Functions (slsc_util_*)

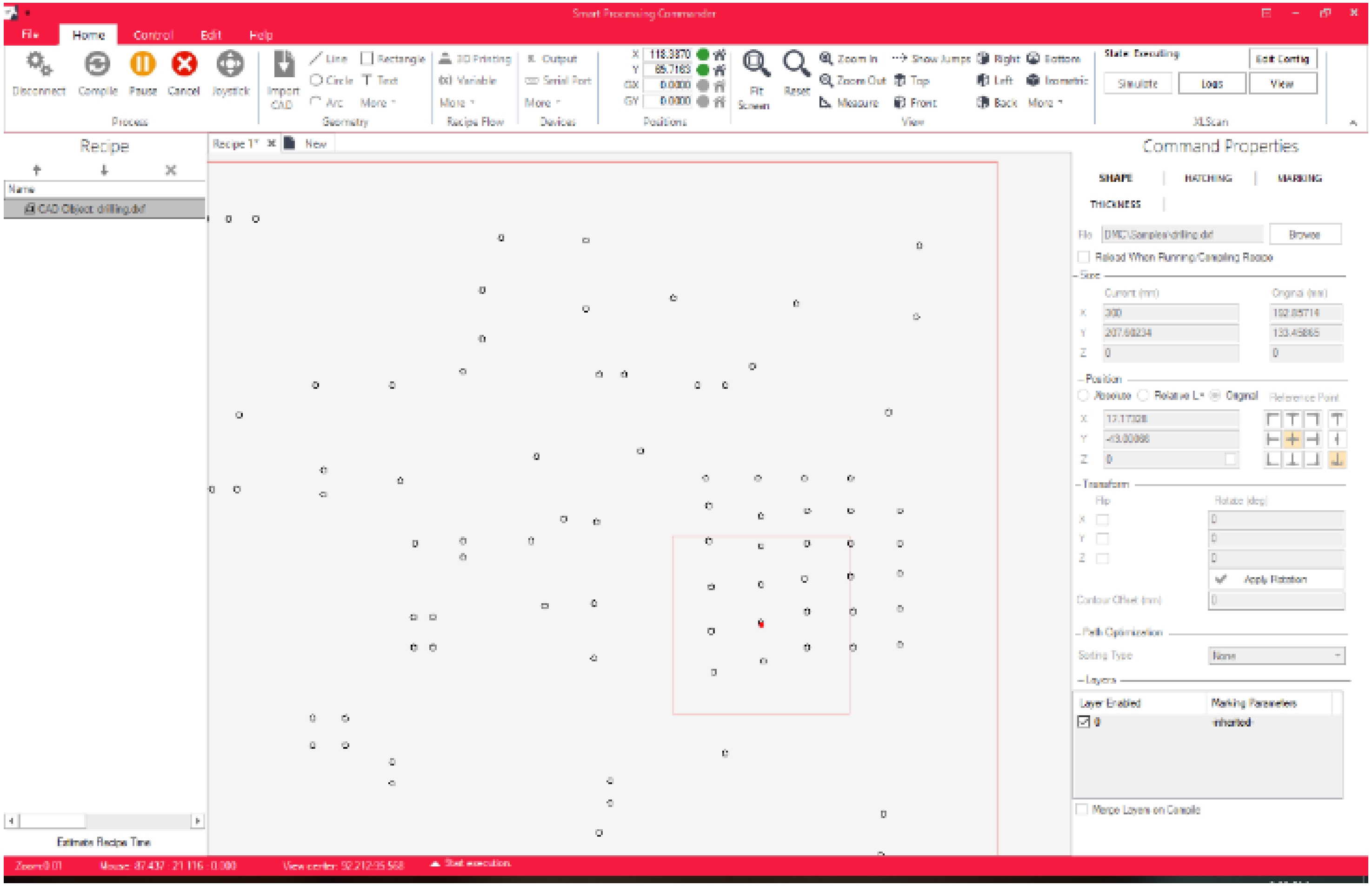
"Hard" reset of RTC6 PCI Express Boards:
slsc_util_reset_pcie

syncAXIS control instance:
Is NOT running

Software tools for XL *SCAN* system setup

E) ACS SPiiPlus SPC (optional and not included in sync*AXIS* control SW package)

Cf. [XL SCAN with SPiiPlusSPC - YouTube]() and
https://acsmotioncontrol.com/products/application-development/spiiplusspc/



Why XL *SCAN*?

Why XL *SCAN*?

Achievability of High Accuracy + High Throughput together at the same time

- **High Accuracy** via:
  - Zero encoder delay error (in communication between scanner and stage)
  - Minimized contour error (i.e. deviation of actual traj. from set traj.) within the exploitable maximum dynamics of scanner and stage
  - No stitching errors
  - Velocity- and position-based automatic laser control without extrapolation error, i.e.,
    - the simultaneous control of spot distance & laser power (e.g. by analog control or pulse length)
    - features extreme fine-tuning in laser control such as laser power ramping and vector- or contour-dependent adjustment of spot distance

- **High Throughput** (up to 40 % more compared to conventional systems) via:
  - Highly dynamic processes without vibration of table
  - Parallelization of laser processing to be controlled by one single PC => by multi-(SW-)instance and multi-head extension features

How does XL *SCAN* work?

How does XL *SCAN* work?

The <u>Major Challenge</u> in usual encoder-based On-the-Fly processing is:

the trade-off between throughput and accuracy being unavoidable due to the following facts:

- Galvanometer scanners very rapid, but usually less accurate than stage (at typ. focal lengths ≥ 100 mm for instance)
- Stages usually very precise, but much slower than galvanometer scanners

=> Consequently, **encoder-based communication** between stage control and scanner control **necessarily leads to time lag and position deviation** between stage and scanner during acceleration and deceleration phases.

How does XL *SCAN* work?

Solution

- **Exact trajectory planning ahead of time** by sync*AXIS* control software, i.e.:

  Planning of a velocity profile for a given geometry of marking path taking the boundary conditions and physical limitations (velocity, acceleration, and jerk limits) of both stage and scanners into account + jump duration calculation

- **Automated decomposition of planned motion path** into stage and scanner parts with *perfect synchronization between the stage motion and scanner motion and *perfect synchronization to laser control

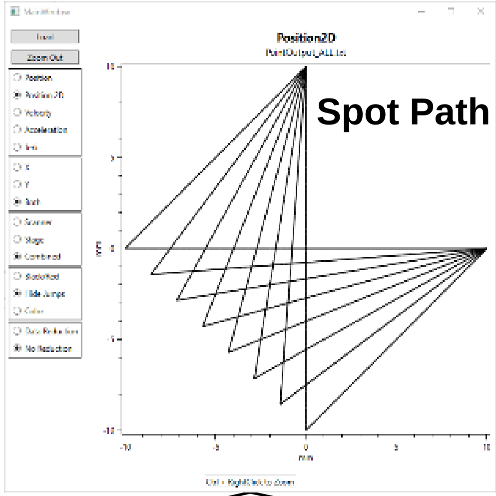
* : *due to the complete knowledge about the future trajectory*

allowing for

- the optimization of acceleration and velocity profile for the highest precision and **maximal exploitation of the system's dynamic potential**
  => result: "**set trajectory = actual trajectory**" within the given dynamic limits
- the adaptation of laser control (spot distance and pulse energy) to the velocity and acceleration profile at every position along the trajectory

How does XL *SCAN* work?

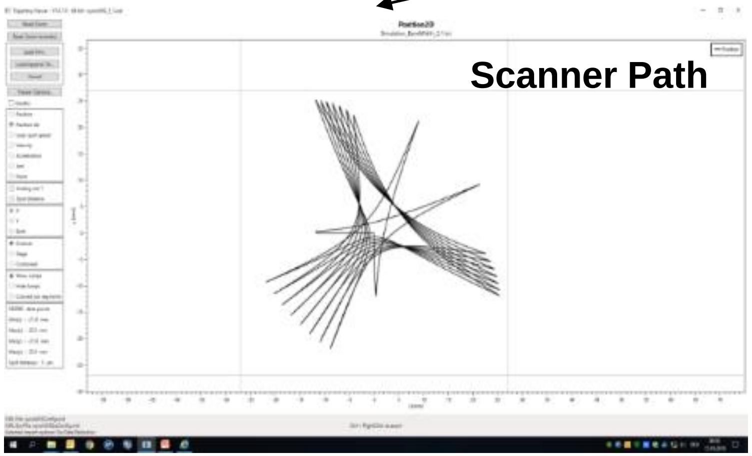
Motion Path Decomposition

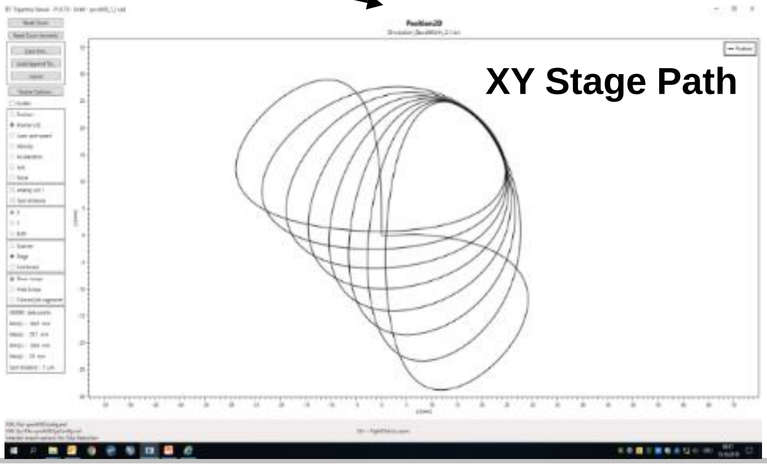


Motion path decomposition works with a filter assigning

⇒ low-freq. motions to the stage

⇒ high-freq. motions to the scanner

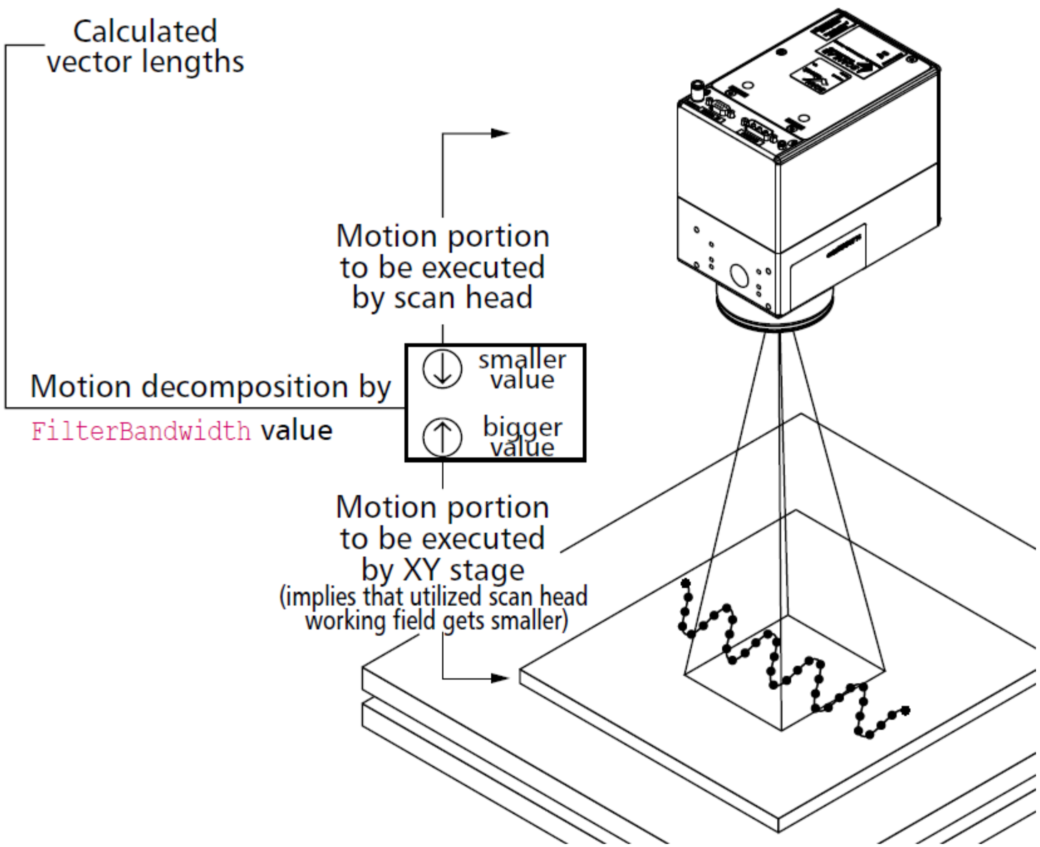




How does XL *SCAN* work?

Motion Path Decomposition

With **adjustable low-pass filter bandwidth** to vary the motions assigned to scanner and stage

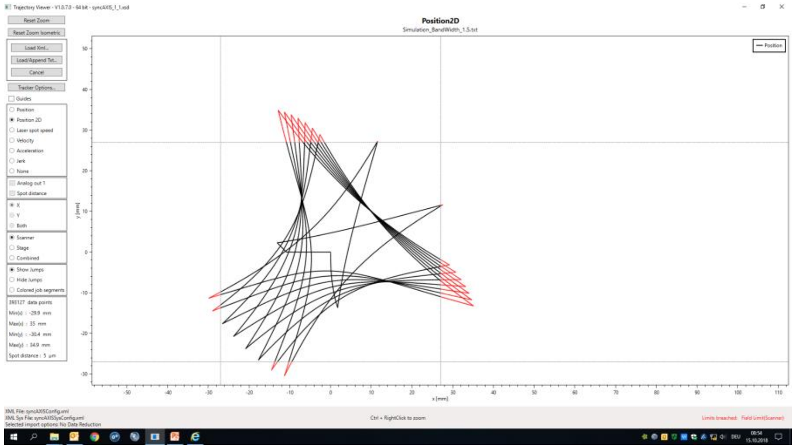


Depending on the process constraints, users may set their aim at:

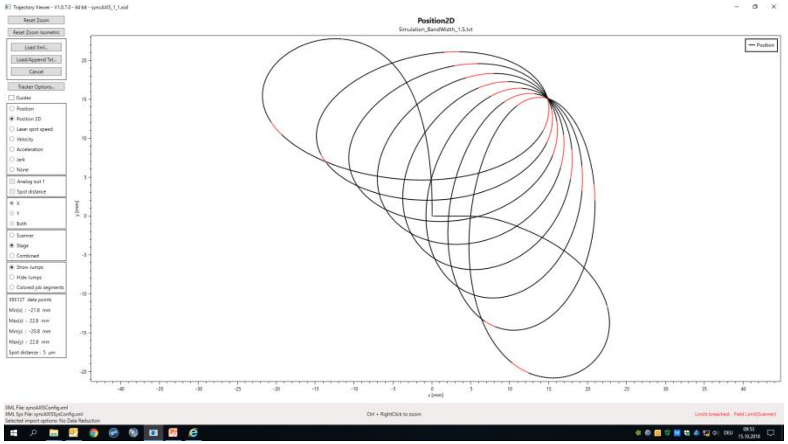
- minimized work load on the stage load in order to reduce inaccuracies possibly resulting from vibrations of the stage
- minimized area of utilization within the scanner's field of view in order to reduce inaccuracies possibly resulting from focusing optics and/ or imperfections in scanner's field calibration
- minimized process time by max. utilization the scanners' and stage's dynamic capabilities.

How does XL *SCAN* work?

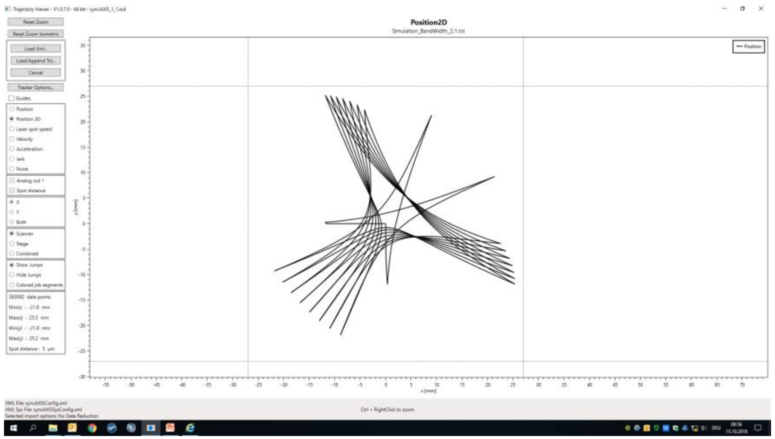
<u>Motion Path Decomposition</u> (Example with f = 100mm f-theta optics providing FoV = 54mm)



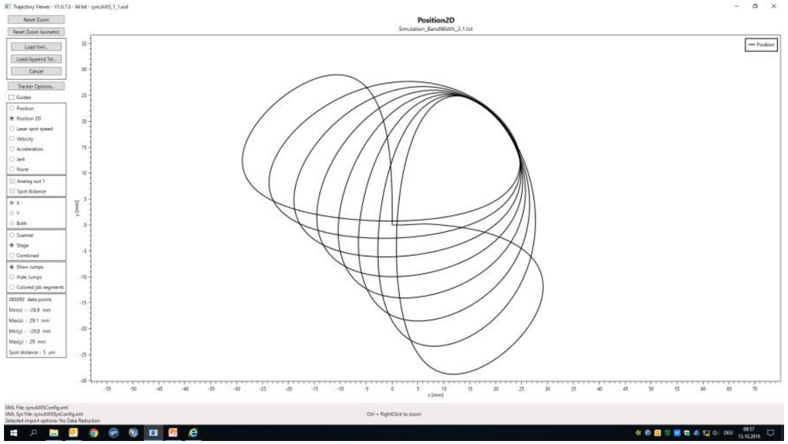
Scanner Motion @ FilterBandwidth = 1.5 Hz



Stage Motion @ FilterBandwidth = 1.5 Hz



Scanner Motion @ FilterBandwidth = 2.1 Hz



Stage Motion @ FilterBandwidth = 2.1 Hz

Test at SCANLAB

Test at SCANLAB

Scan system specifications

Scanner: excelli*SCAN* 14

Focusing optics: f = 100 mm telecentric f-theta objective

Field of view: 54 mm x 54 mm

Dynamics: $v_{max.} = 20\ m/s$
$a_{max.} = 32\ 000\ m/s^2$

Dynamic following error: typ. 3 µm (conservative estimation*)
* : *valid for acceleration-limited control by standard RTC6.dll Note that the value depends on focal length and the utilized area within the FoV (i.e., the distance from the FoV center).*

XY stage specifications

Field of motion: 300 mm x 300 mm

Dynamics: $v_{max.} = 1\ m/s$
$a_{max.} = 10\ m/s^2$
$j_{max.} = 100\ m/s^3$

Dynamic following error: typ. 1.5 µm (conservative estimation**)
** : *valid for the case of utilizing the max. stage dynamics*

Test at SCANLAB

Static error of scanner

	x-axis	y-axis	radial
Min.	-2.0 µm	-5.0 µm	0.0 µm
Max.	5.0 µm	1.0 µm	5.4 µm *
Standard deviation	1.3 µm	1.1 µm	1.4 µm
Mean	0.9 µm	-0.7 µm	1.6 µm

Static error of XY stage

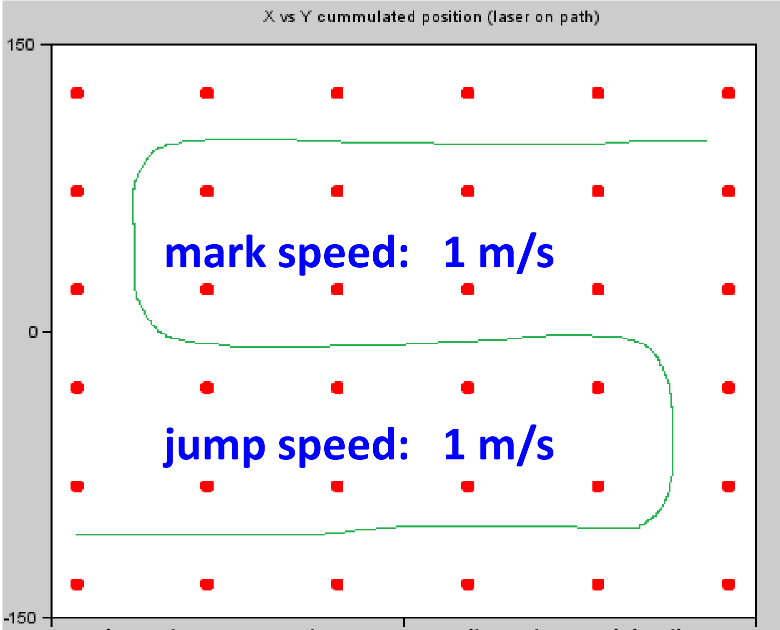
	x-axis	y-axis	radial
Min.	-4.2 µm	-5.1 µm	0.0 µm
Max.	6.1 µm	4.7 µm	6.6 µm *
Standard deviation	1.6 µm	1.8 µm	1.2 µm
Mean	0.1 µm	0.8 µm	2.2 µm

*** : Imperfections in the scanner´s field calibration and in the stage´s error mapping were left to remain as they were.**

Accuracy achieved in synchronized motion

	x-axis	y-axis	radial
Min.	-7.8 µm	-9.7 µm	0.0 µm
Max.	8.9 µm	4.1 µm	11.0 µm **
Standard deviation	2.9 µm	3.1 µm	2.6 µm
Mean	-0.8 µm	-3.5 µm	4.9 µm

Stage motion: meander-shaped pattern
Scanner motion: p-to-p jumps in zig-zag pattern
Grid points in 288 mm x 288 mm
Stage dynamics: 50% reached
Field of view: 75 % utilized



schematic representation not true to dimensions and details

**** : approx. equal to the sum of scanner´s and stage´s static errors**

Test at SCANLAB

Accuracy achieved in synchronized motion

	x-axis	y-axis	radial
Min.	-7.8 µm	-9.7 µm	0.0 µm
Max.	8.9 µm	4.1 µm	11.0 µm **
Standard deviation	2.9 µm	3.1 µm	2.6 µm
Mean	-0.8 µm	-3.5 µm	4.9 µm

Stage motion: meander-shaped pattern
Scanner motion: p-to-p jumps in zig-zag pattern
Grid points in 288 mm x 288 mm
Stage dynamics: 50% reached
Field of view: 75 % utilized

mark speed: 1 m/s @ f = 100 mm

jump speed: 1 m/s @ f = 100 mm

**** : approx. equal to the sum of scanner´s and stage´s static errors**

Test at SCANLAB

CONCLUSION:

Limit to the total accuracy of XL *SCAN*
= $\mathbf{StatErr_{scanner} + StatErr_{stage}}$
(i.e. the sum of STATIC pos. errors)

No additional error contributions are present in XL *SCAN*
such as

- dynamic following errors
- any encoder-induced errors (such as those resulting from tracking delay in case of feedback-based scanner-stage synchronization)
- etc.

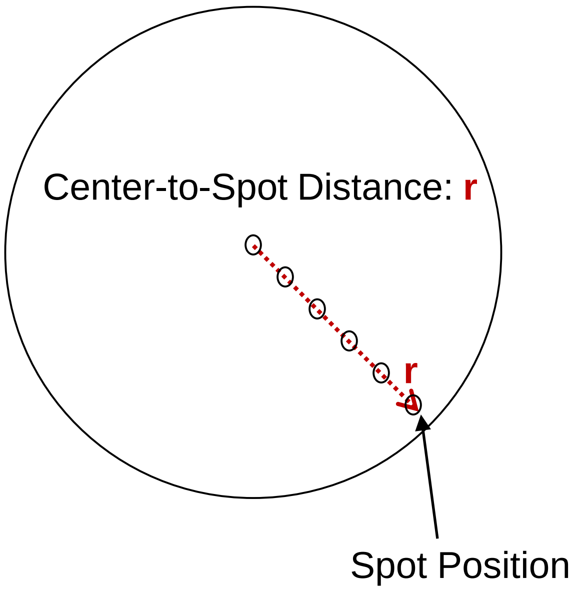
due to **exact trajectory planning (based on jerk-limited control)** and **appropriate motion distribution** between scanner and stage

Test in collaboration with Pulsar Photonics and Holo/Or

Test in collaboration with Pulsar Photonics and Holo/Or

Accuracy Evaluation in multi-beam jump-and-shoot tests

=> cf. Variable multibeam tool enables high accuracy and throughput | Laser Focus World



Comparison between two setups in their positioning accuracy

First setup:

- standard scan head with a focal length of 100 mm **without a stage operating in synchronization to the scan head**
- The positioning of the spots was carried out with ample time between the shots in order for the galvanometer mirrors to settle into their position. This is a quasi-static approach
- The position error was measured using a coordinate measurement machine

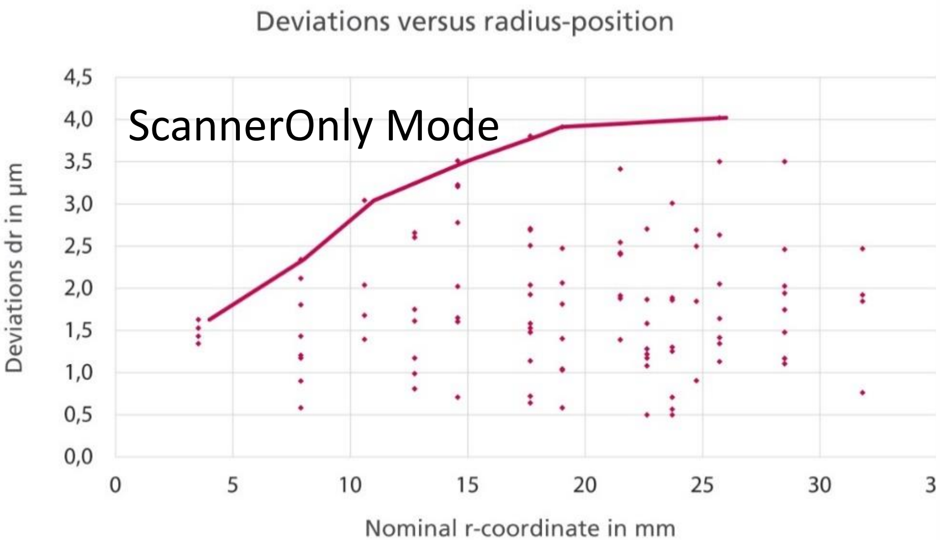
Second setup:

- combined processing using a scan head with focal length of 100 mm and a synchronized mechanical stage (**XL *SCAN***)
- 10,000 shots fired at the workpiece
- The positioning occurs with a processing rate of 2600 Hz and is therefore highly dynamical

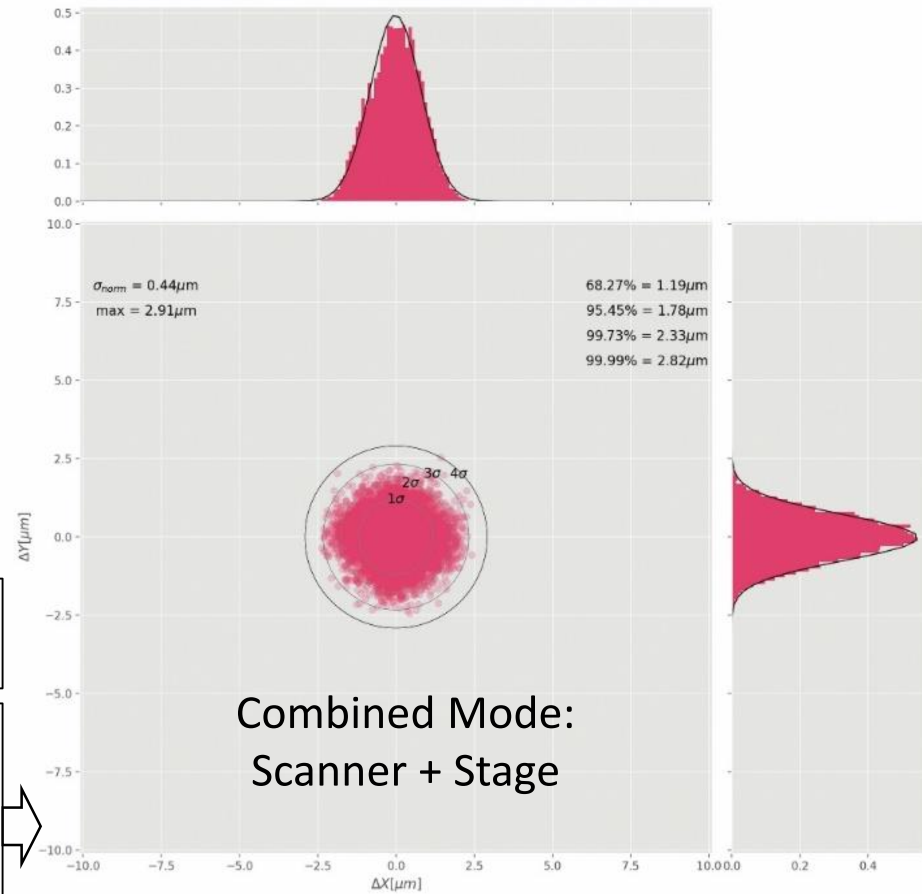
Test in collaboration with Pulsar Photonics and Holo/Or

Accuracy Evaluation in multi-beam jump-and-shoot tests

=> cf. [Variable multibeam tool enables high accuracy and throughput | Laser Focus World]



ScannerOnly Mode: position deviation is increasing with the radial position from approx. 2µm to approx. 4µm.



Combined Mode: 99.99% (4σ) show a position error below 1,5µm.
This shows how the combination with a synchronized stage can not only increase the processing area but also improve the position accuracy.

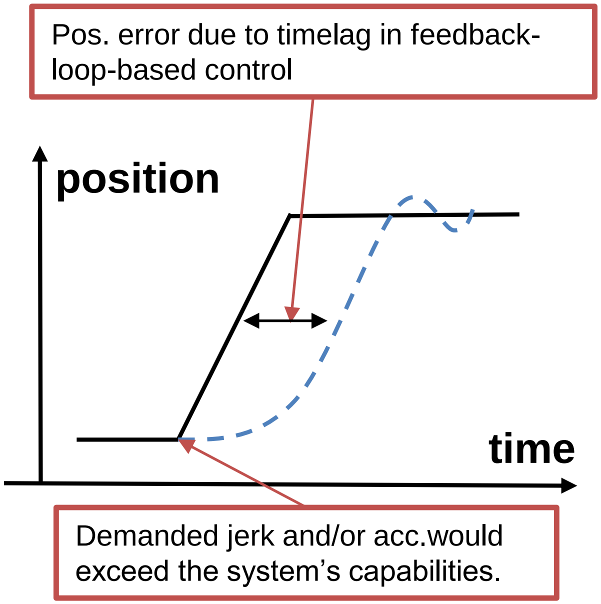
Achievability of High Accuracy

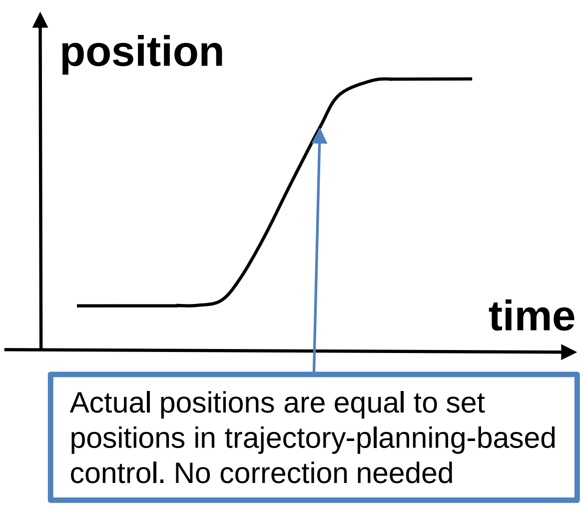
Achievability of High Accuracy

- **Demonstrated with test results**
  - Trajectory planning ensures **ZERO** additional dynamic error.
  - **No feedback loop is necessary**

    With conventional control
    - Commanded set points can demand accelerations / jerks that are physically impossible to achieve (e.g. acceleration limit due to the limitation on the available current)
    - Result: actual position will not be equal to the set-point position during acceleration and will need time to minimize discrepancy after acceleration

    With trajectory planning
    - Algorithm ensures that dynamic limitations will not be breached
    - Result: only set-points that are possible to be reached in iteration are commanded



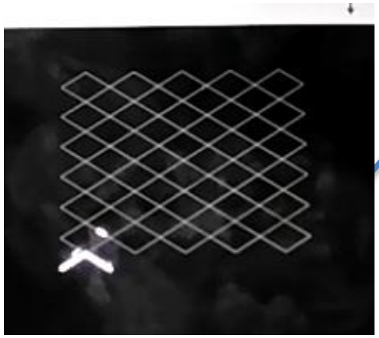


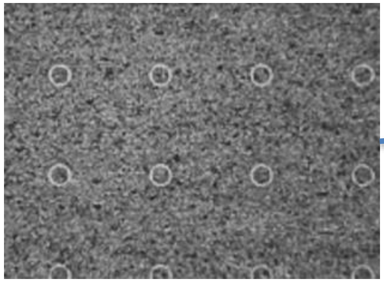
- **Additional information**
  - Stage has internal feedback loop.
  - Galvanometer scanner has internal feedback loop.
  - A feedback loop between stage and scan head would have a time lag that would prevent precision machining. For instance, 10ms time lag would lead to 300mm deviation at 30m/s scan speed.

Further Tests at SCANLAB

Further Tests at SCANLAB

Throughput improvement





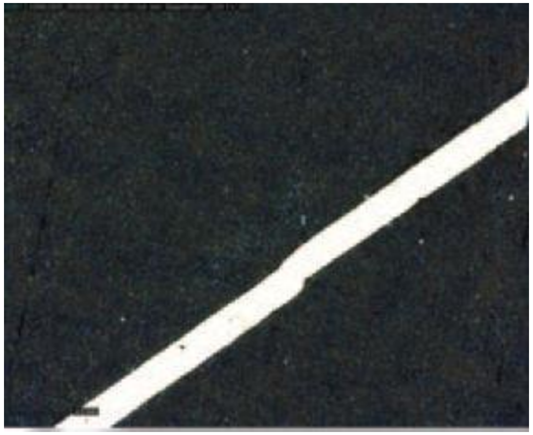
Application	Time (tiling/stitching and scan)	Time (combined motion)	Percentage saved
Circles	5.63 s	3.30 s	41%
Diamond shaped pattern	3.92 s	2.96 s	24%
Hole drilling (jump & shoot)	5.2 s (estimated)	4.42 s for 10,000 holes	15%
Hole drilling (repeated circles / trepanning)	12,2 s (estimated)	11,86 s for 5,000 holes	2 %

Cf. www.youtube.com/watch?v=CeAe0mbYMUE

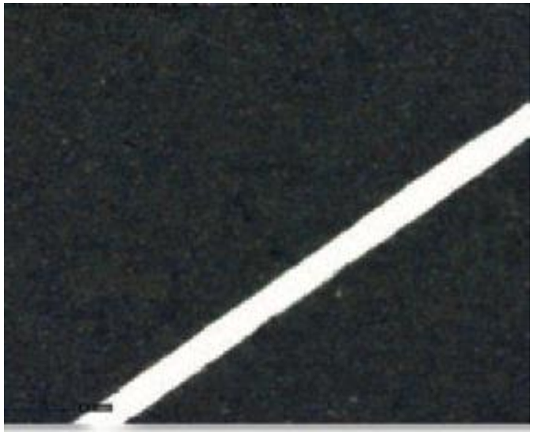
Further Tests at SCANLAB

Stitching error check in diamond shaped pattern

The need for dividing working fields into individual tiles is with XL *SCAN* abolished. Risk for stitching errors is eliminated with all-in-one processing.



Large field scanning with "Stitch and Scan"



Large field scanning with XL *SCAN*

Cf. www.youtube.com/watch?v=CeAe0mbYMUE

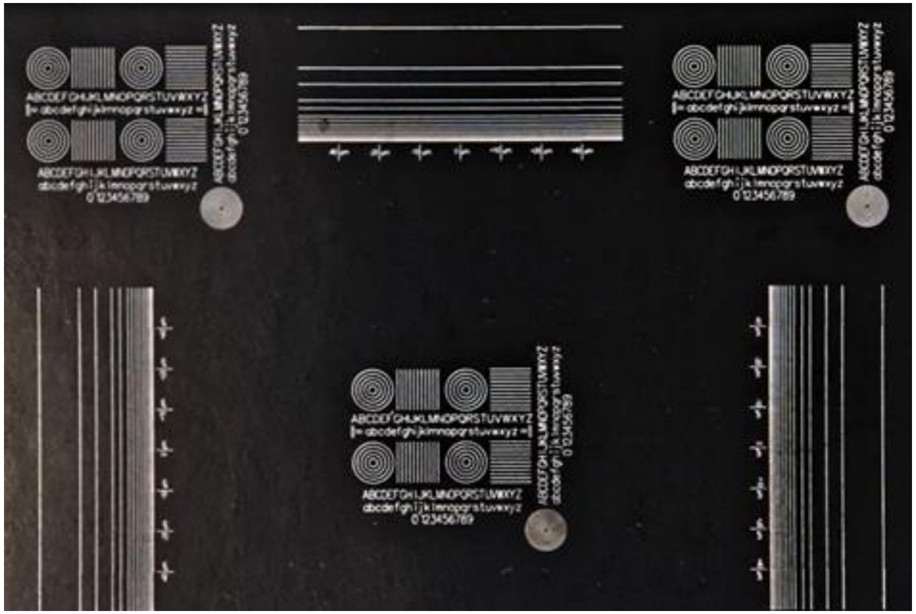
Further Tests at SCANLAB

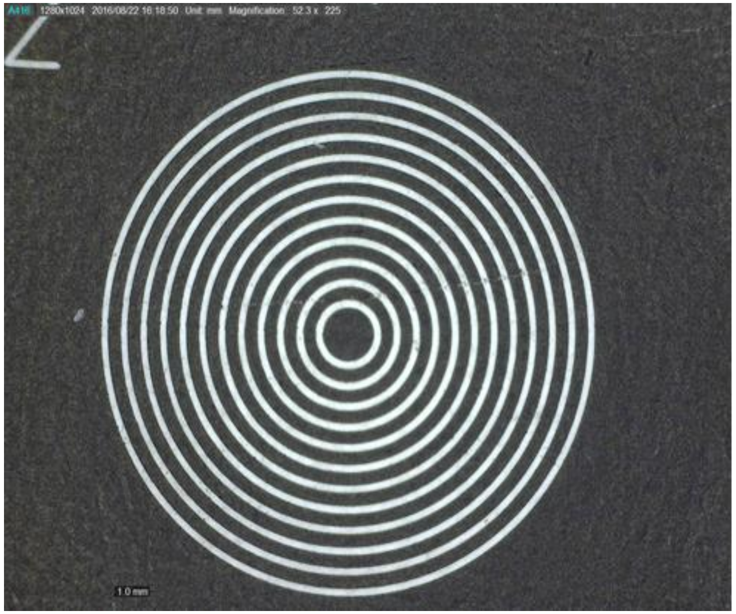
Examination of vibrations

Tests at two different filter bandwidths

→ The larger filter bandwidth, the larger and more aggressive motion portion assigned to the stage

→ However, no negative effect from increased vibrations visible for motions executed with larger filter bandwidth (thanks to trajectory planning / jerk-limited control)





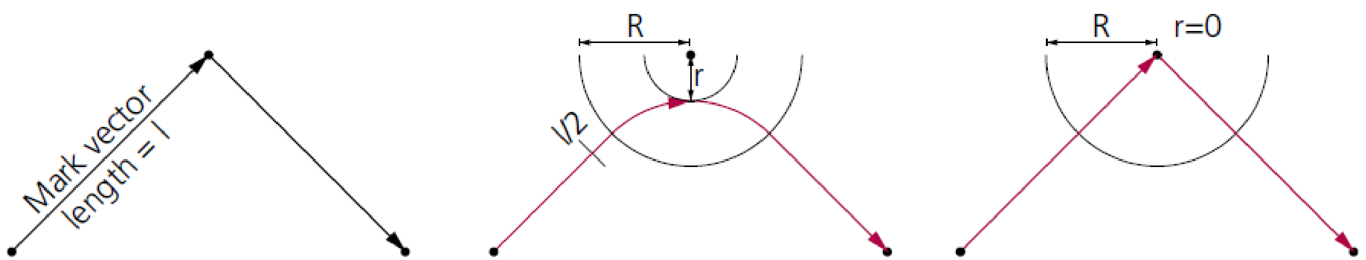
Cf. www.youtube.com/watch?v=CeAe0mbYMUE

Example features
providing benefits to the users

Example features providing benefits to the users

Example Feature 1: Blending

- Full control of „blending“ at a corner with small radius of curvature
- Define in metric units the accuracy of corner
- Possibility to tune accuracy vs. velocity
- Full control of laser energy in corner (see next slide)



Mark vectors as programmed (black)

Marking result (red) with R>0 and r>0

Marking result (red) with r=0

R = MaxBlendRadius
r = ApproxBlendLimit

ACS MOTION CONTROL

SCANLAB innovators for industry

Example features providing benefits to the users

Example Feature 2: Automatic Laser Control

- Simultaneous control of spot distance (“Spot Distance Control”) and pulse energy (“Power ramping”)
- Possibility to keep the laser exposure constant along the user-defined spot positions
- Speed-dependent ramping of laser parameters
- Vector- & intravector-defined ramping of laser parameters
- Deflection-angle-dependent control of laser parameters

=> enabling to keep the energy density distribution constant despite the spot size variations resulting from non-telecentric f-theta optics

The applicability of precise Spot Distance Control feature is only given for lasers equipped with external trigger functionality (a.k.a. “pulse-on-demand”).

Example features providing benefits to the users

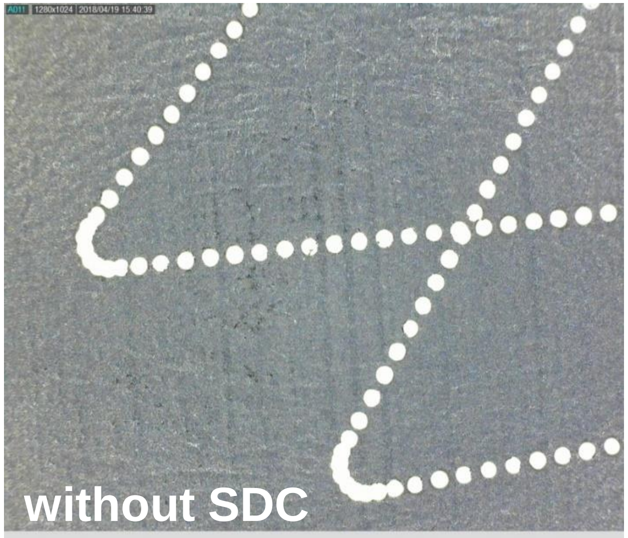
Example Feature 2: Automatic Laser Control

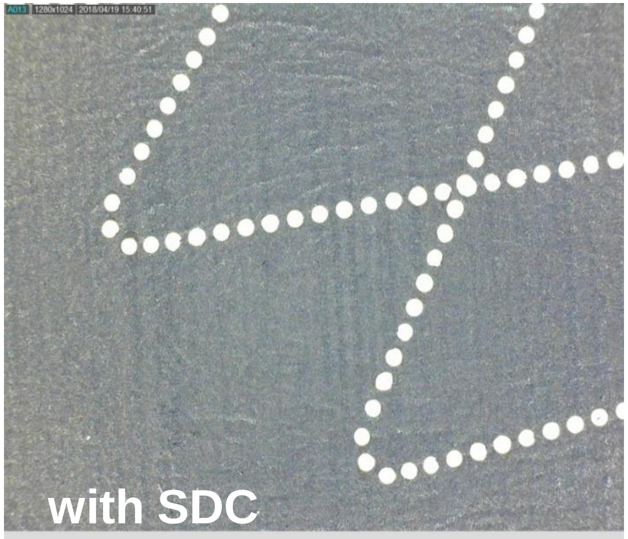
Spot Distance Control (SDC)

- **As Standard Feature of RTC6 + excelli*SCAN***
  => available even outside of XL SCAN package
  => based on feedback position from scanner which makes high-accuracy spot positioning very challenging in the phases of high acceleration and deceleration

- **As Standard Feature of XL *SCAN* (SDC based on trajectory planning in sync*AXIS*)**
  => significantly more accurate spot positioning based on the real spot speed on the workpiece
  => interpolation in 10µs cycle at 64MHz resolution
  => Example: max. spot distance variation of +/- 2.5% at the pulse repetition. rate of 800 kHz

regardless of acceleration or deceleration





Example features providing benefits to the users

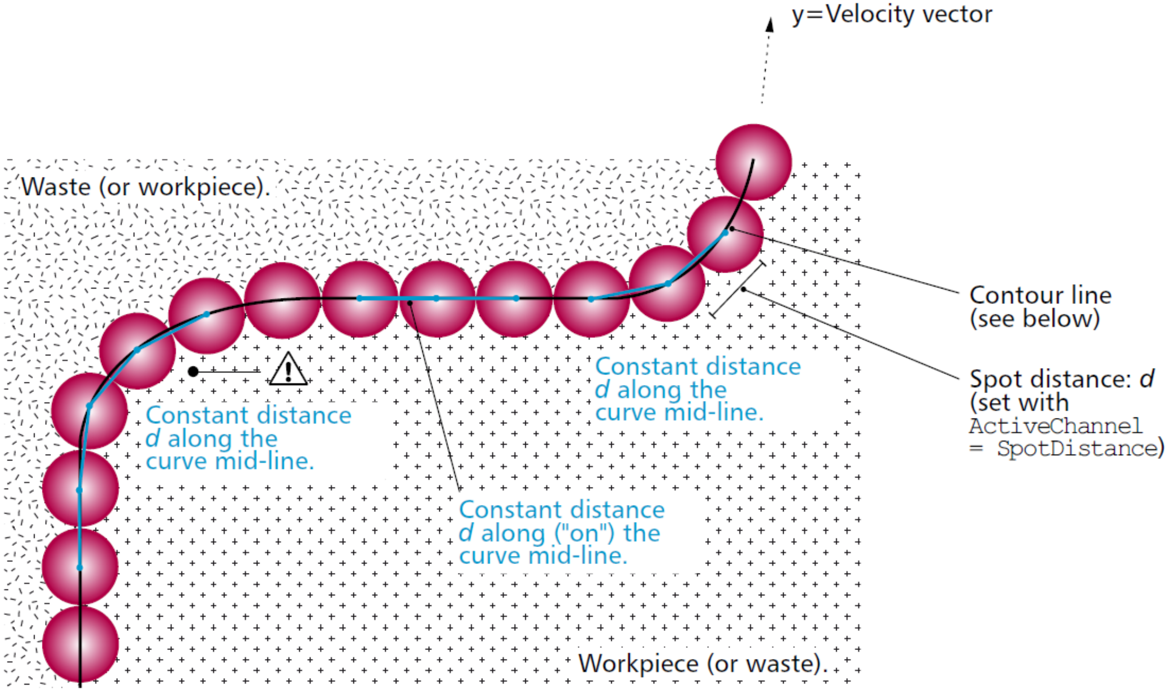
Example Feature 2: Automatic Laser Control

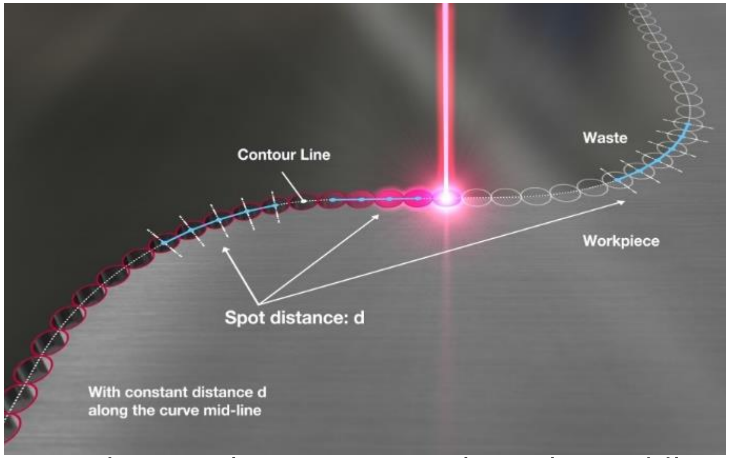
Spot Distance Control (SDC)

Operation Mode: contour-dependent SDC

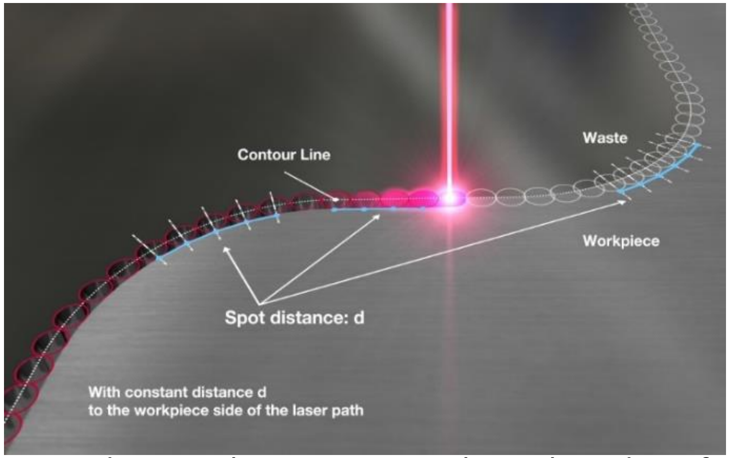
=> Constant spot distance can be defined

- either for the center of the spot
- or for the edge of the spot that meets the work piece.





Spot distance kept constant along the middle of laser spot's track



Spot distance kept constant along the edge of laser spot's track lying on the workpiece side (opposite to the waste side)

Example features providing benefits to the users

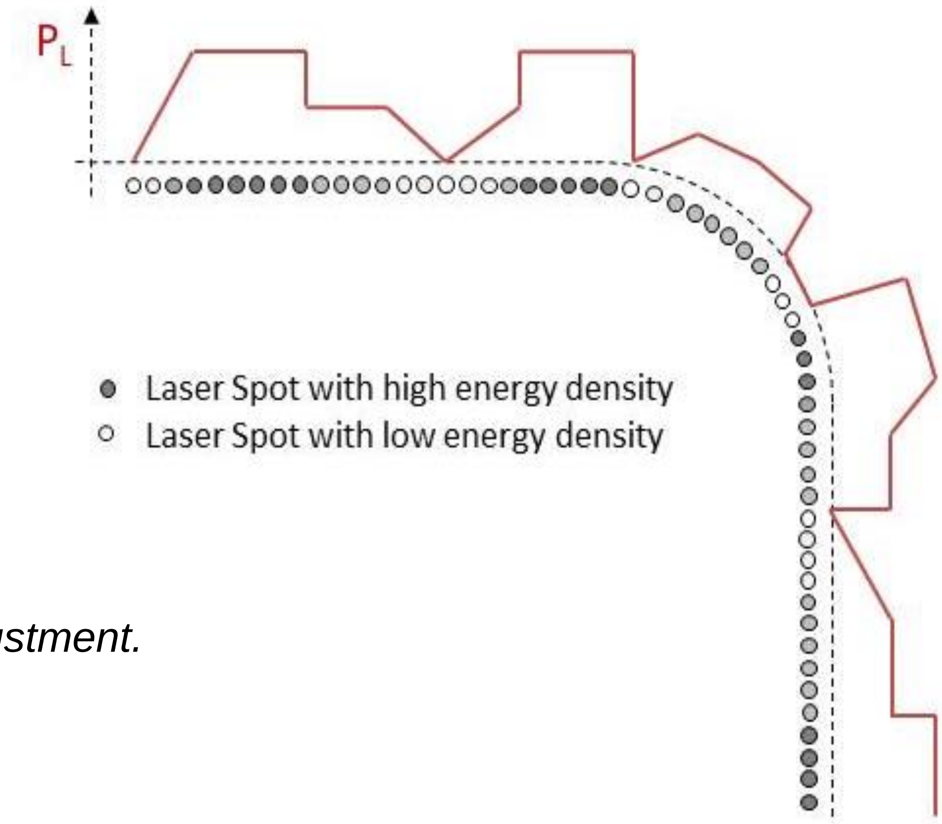
Example Feature 2: Automatic Laser Control

Laser Power Ramping (vector- & intravector-defined control)

=> Control signals can be ramped according to the user' demands along

- straight marking path or
- curved marking path or
- jumps

for two different laser control signals individually.



*This is just **one example** for pulse energy adjustment.*
Spot distance adjustment is also possible.

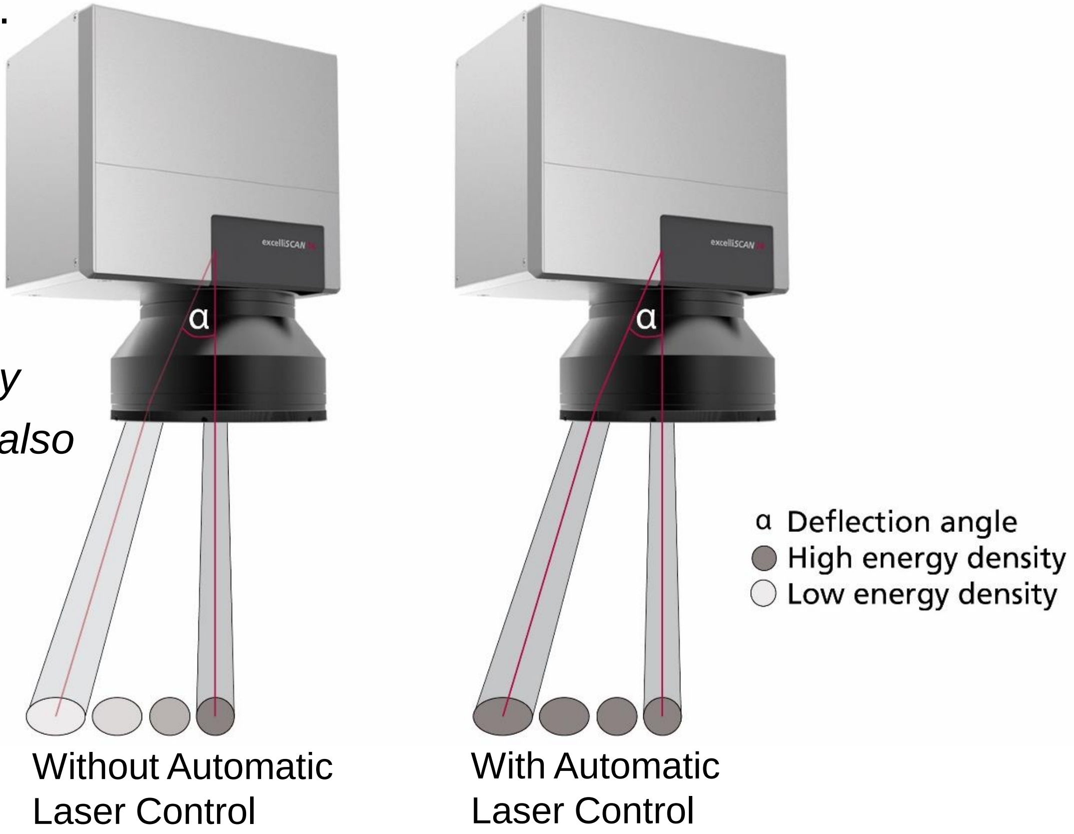
Example features providing benefits to the users

Example Feature 2: Automatic Laser Control

Deflection-Angle-Dependent Laser Control

=> Deflection-angle-dependent laser control serves the purpose of keeping the energy density constant through out the entire field of view of the scan head, even if spot size varies along laser paths.

*This is just **one example** for pulse energy adjustment. Spot distance adjustment is also possible.*



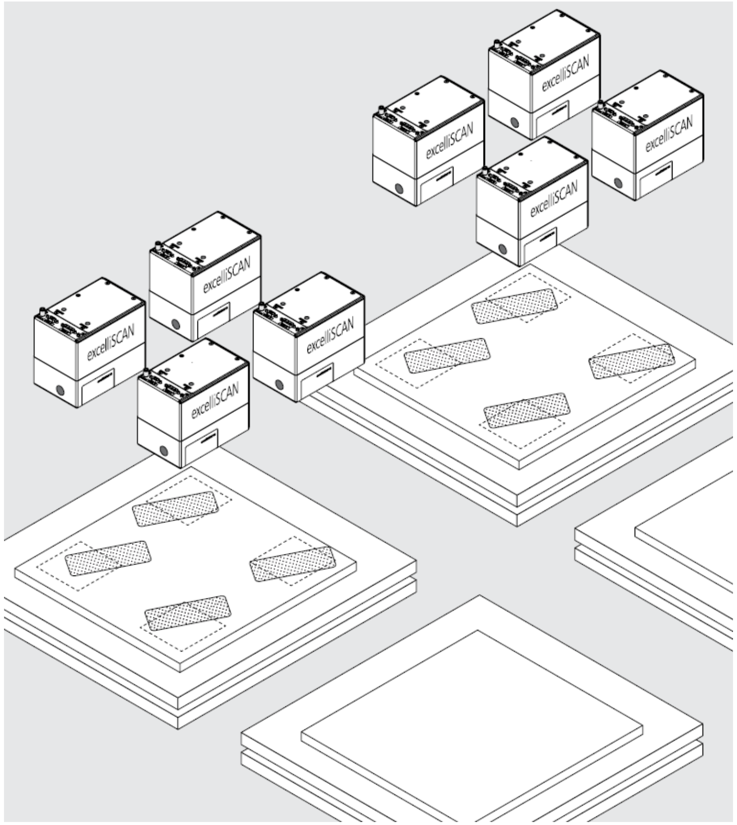
Example features providing benefits to the users

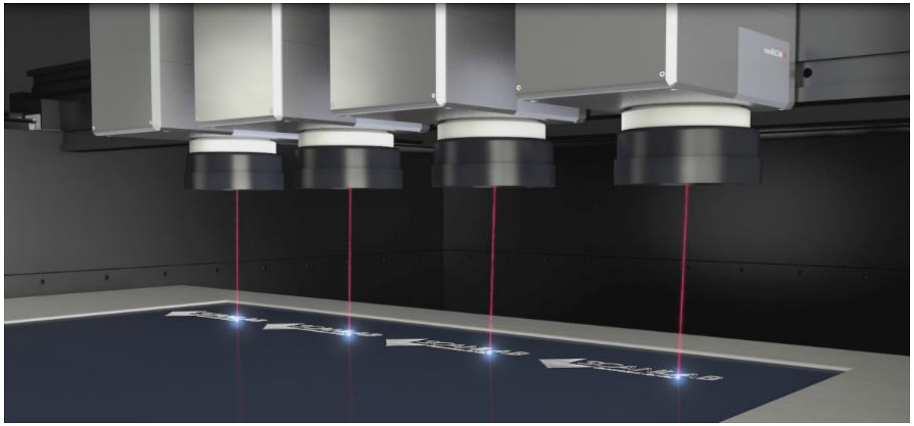
Example Feature 3: Multi-Head Option

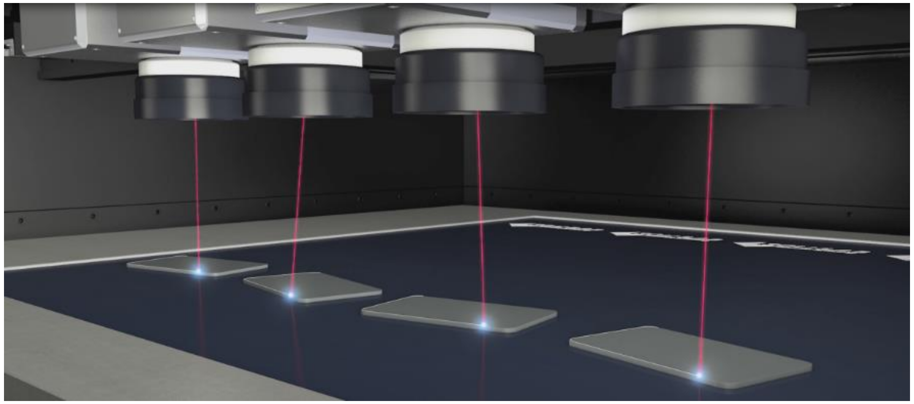
=> Available for up to max. 4 scan heads working in the same motion pattern

=> Each scan head´s center positioning (in XY-plane) freely selectable

=> Adjustable workpiece orientation for each scan head





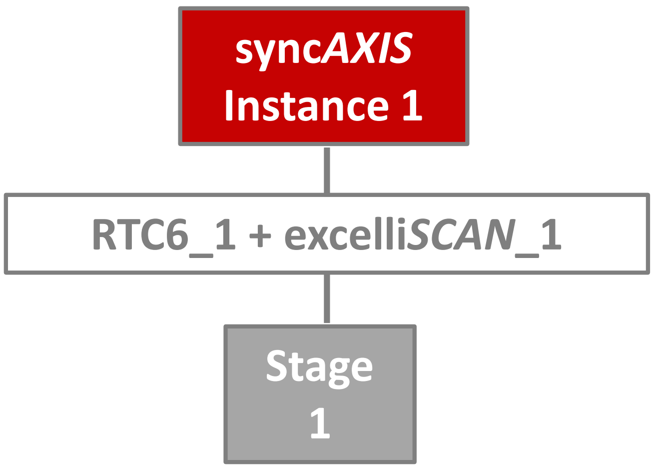


Possible Configurations

Possible Configurations of XL *SCAN*

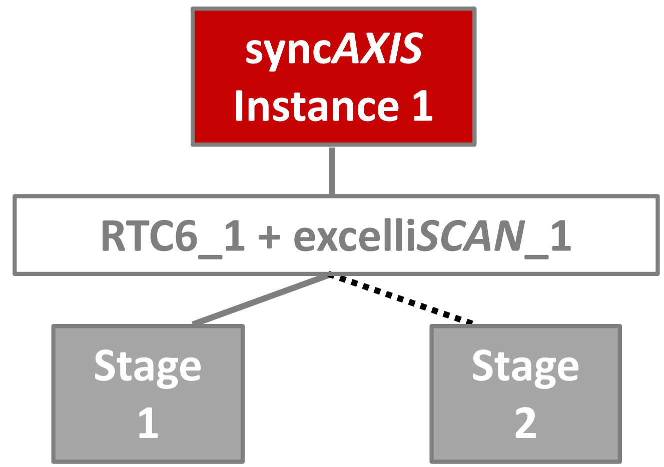
A. Configurations with Single Software Instance and Single Scan Head

A-1. with Single Stage



Single Software Instance with
Single Scan Head
Single RTC6 + Single SLEC
Single Stage

A-2. with Multiple Stages

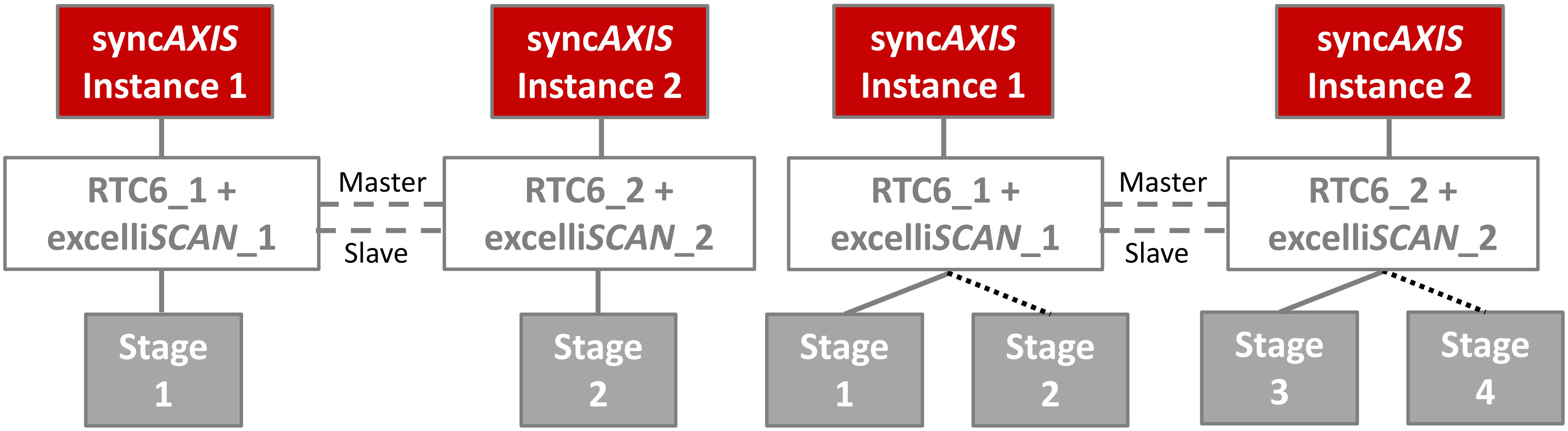


Single Software Instance with
Single Scan Head
Single RTC6 + Single SLEC
Multiple Stages

Possible Configurations of XL *SCAN*

B. Configurations with Multiple Software Instances and Multiple Scan Heads (BUT 1 Scan Head per Instance)

B-1. with Single Stage | **B-2. with Multiple Stages**



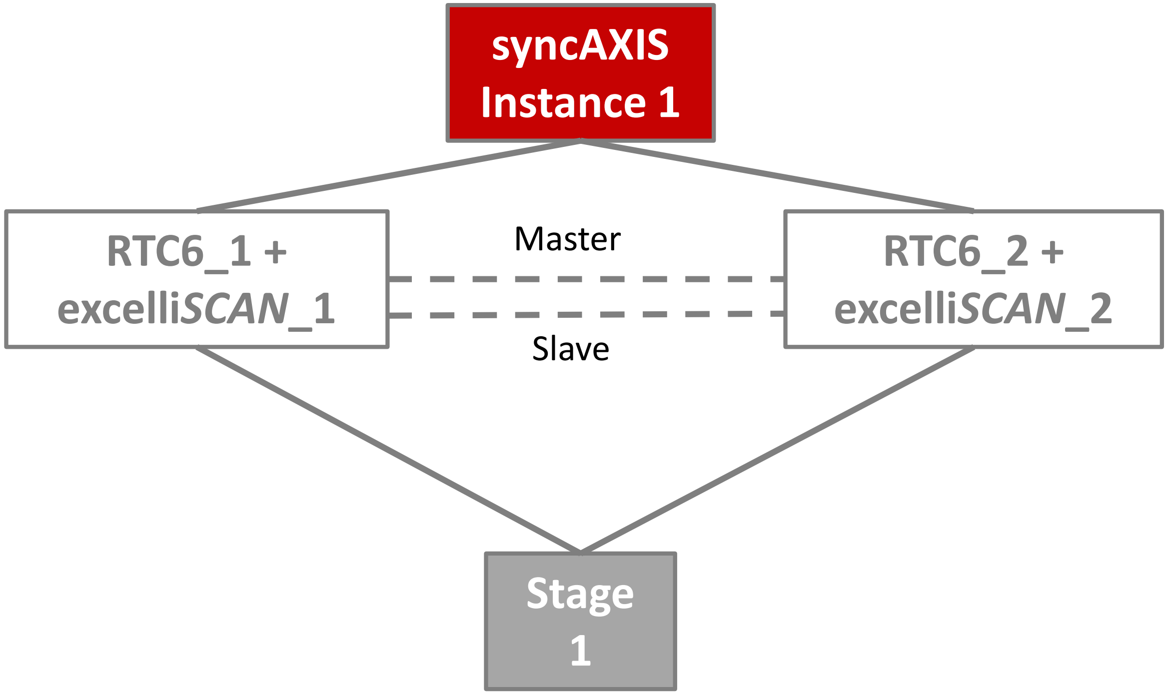
Multiple Software Instances with
Multiple Scan Heads (1 Scan Head per Instance)
Multiple RTC6s + Multiple SLECs (1 SLEC per RTC6)
Single Stage per Scan Head

Multiple Software Instances with
Multiple Scan Heads (1 Scan Head per Instance)
Multiple RTC6s + Multiple SLECs (1 SLEC per RTC6)
Multiple Stages per Scan Head

Possible Configurations of XL *SCAN*

C1. Configurations with Single Software Instance and 2 Scan Heads per Instance

Note: Each RTC6 board is equipped with two scan head connectors (for comm. via SL2-100 protocol).

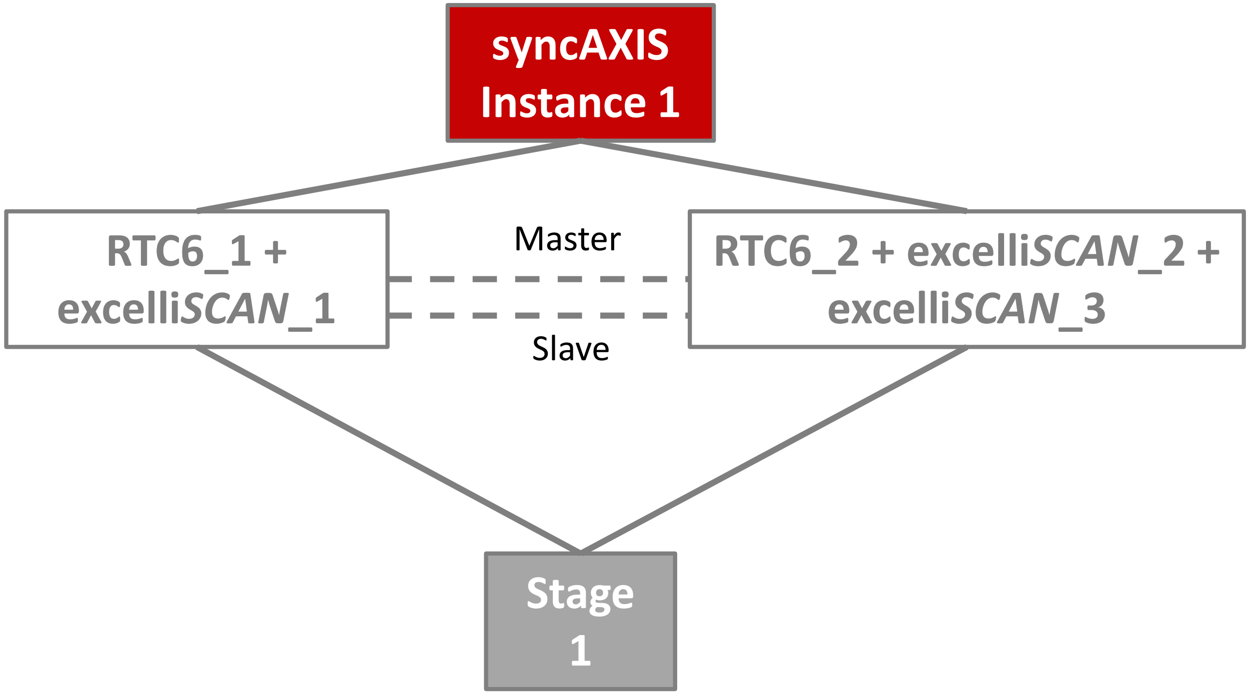


Single Software Instance with
2 Scan Heads + 2 RTC6s + 1 SLEC + Single Stage
per Instance

Possible Configurations of XL *SCAN*

C2. Configurations with Single Software Instance and 3 Scan Heads per Instance

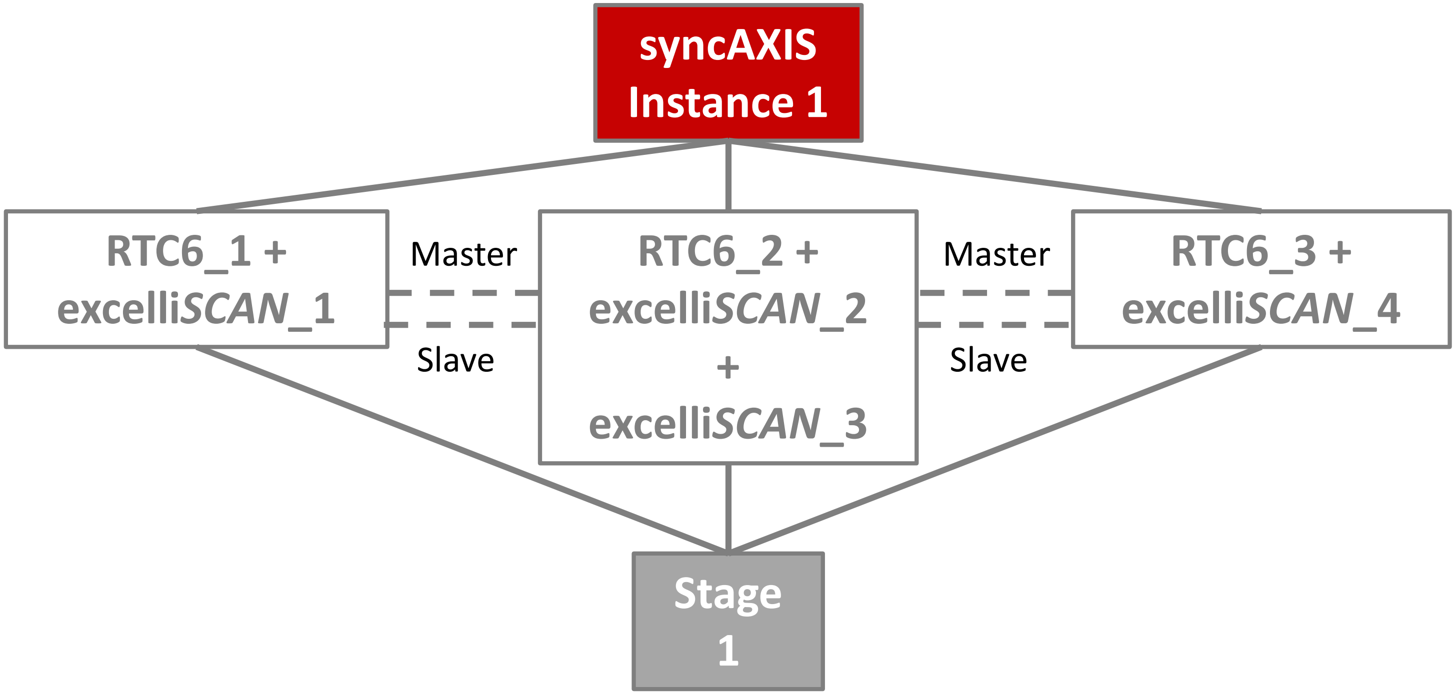
Note: Each RTC6 board is equipped with two scan head connectors (for comm. via SL2-100 protocol).



Single Software Instance with
3 Scan Heads + 2 RTC6s + 1 SLEC + Single Stage
per Instance

Possible Configurations of XL *SCAN*

C3. Configurations with Single Software Instance and 4 Scan Heads per Instance
Note: Each RTC6 board is equipped with two scan head connectors (for comm. via SL2-100 protocol).



Single Software Instance with
4 Scan Heads + 3 RTC6s + 1 SLEC + Single Stage
per Instance

Further Information

Further Information

Product Overview:

www.scanlab.de/en/products/advanced-scanning-solutions/xl-scan

Product Brochure:

www.scanlab.de/sites/default/files/2020-07/20_XLSCAN_syncAXIS_scanning%20solution.pdf

Video:

www.youtube.com/watch?v=CeAe0mbYMUE

Further Reading:

www.photonics.com/Articles/Motion_Control_Solutions_for_High-Precision/a65146

www.laserfocusworld.com/lasers-sources/article/14201504/variable-multibeam-tool-enables-high-accuracy-and-throughput

Software Download Links:

www.scanlab.de/en/downloads/software/syncaxis

www.acsmotioncontrol.com/products/application-development/spiiplusspc/