precSYS

5-axis micro processing

The precSYS **micromachining sub system** enables ultra-short-pulsed laser micro processing of flexibly variable geometries, e.g. fabrication of positively/negatively conical or ideal cylindrical, round or elliptical drill holes with high aspect ratios. The precSYS combines leading-edge high-end scan technology, integrated control, embedded PC and user-friendly software. This enables laser micro processing with ultimate dynamic performance and precision.

Its graphical user interface facilitates straightforward creation and testing of micro-processing jobs. precSYS's robust, innovative construction ensures maximum dependability in industrial applications. Its compact, modular design and specially adapted hardware and software interfaces allow easy, optimal integration into customer-specific laser machines and networked production environments (industry 4.0). precSYS offers observation ports for process-monitoring and beam-monitoring add-ons.

SCANLAB ensures time-efficient system alignment and precise system operation thanks to factory default settings and calibration as well as automatic fine-adjustment.

Key advantages:

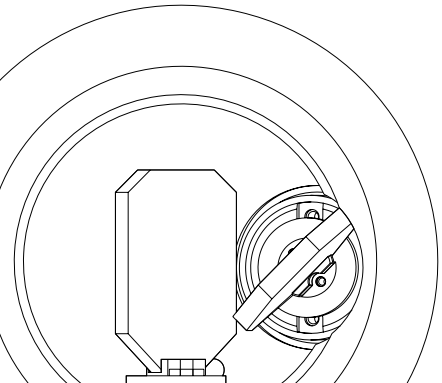
- User-friendly creation of micro-processing operations with 3D visualization
- Flexible USP processing with defined variable angle of incidence
- Maximum dependability and stability for highest precision
- 515 nm variant for even more precise laser processing
- Speed-independent contour fidelity thanks to innovative control algorithms
- Designed for usage in industrial serial production
- Ethernet and EtherCAT control interfaces
- Highly integrated solution with embedded PC
- Ultra-precise pre-calibration and alignment software
- Automatic fine adjustment (system monitoring)
- Comprehensive on-site customer service

Typical applications:

- Drilling
- Ablation
- Structuring
- Cutting

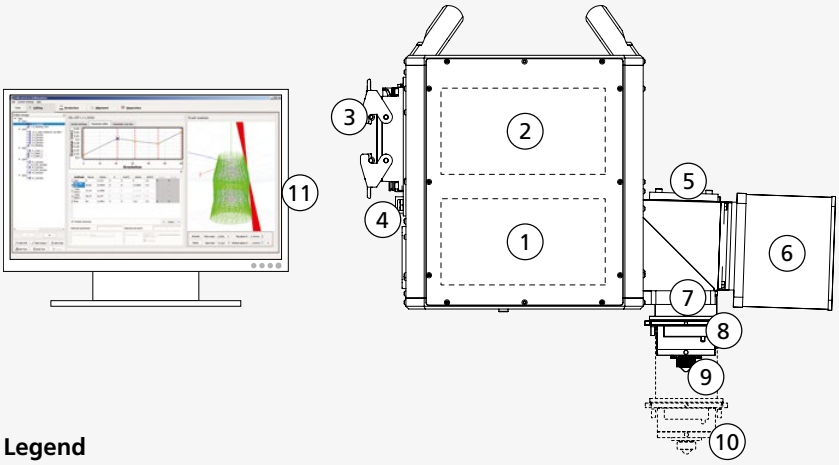
Typical industries:

- Automotive
- Electronics
- Textiles
- Medical technology
- Precision engineering



SCANLAB
innovators for industry

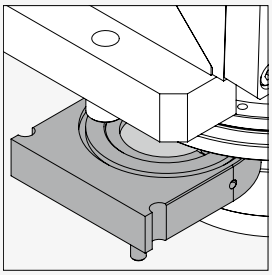
System Overview (standard version with no options)



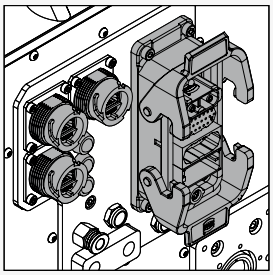
Legend

1 Gas-purged 5-axis scan unit (x, y, z, incidence angles α, β) with purge gas monitoring
2 Control electronics and embedded PC
3 Ethernet, EtherCAT and industrial connector (connections for power, PLC, laser and remote access) and status LEDs
4 Water cooling for thermal stability (galvo axes and electronics separately cooled)
5 Process monitoring interface
6 Beam position measuring unit (Automatic Fine Adjustment)
7 Objective
8 Protective glass drawer for fast and safe replacement
9 Process gas nozzle (adjustable in x, y, z)
10 Variant with the beam exit extended downward available on request
11 Software and graphical user interface (GUI)

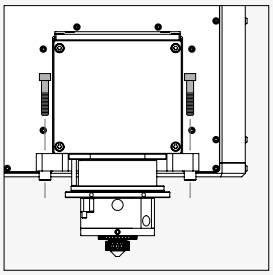
High industrial suitability



Drawer for replaceable protective glass



Industry-proven connectors (Ethernet, EtherCAT, power, PLC, laser) and status LEDs



Mounting holes near objective for precise positioning of the beam exit (3-point support)

Principle of Operation

precSYS lets you 3D-position the focal spot onto workpieces with precise tracking of angles of incidence (AOI). You can simultaneously vary progression of focal motion, angles of incidence and laser intensities etc.

High-end scan technology with small mirror rotation angles and low moving masses ensure highly dynamic processing with trepanning or precession frequencies up to 650 Hz (39000 rpm). The system works without any rotary optics.

Advanced digital encoders, control algorithms and application-optimized servo control enable contour-true, speed-independent processing with maximum precision. The system is servo-regulated for stable positioning at precession frequencies up to 650 Hz. Specially conceived for USP precision processing, the optical path is polarization-maintaining and accommodates pulse energies up to 300 µJ at 1030 nm and 65 µJ at 515 nm.

System Design

Active water cooling of beam-guidance components (including galvo axes) and of spatially separated electronics makes the system robust against load-dependent temperature fluctuations. Moreover, the system's innovative beam guidance provides suitability for up to 50 W lasers. A sealed, gas-purged optical beam path (overpressure) guarantees optimum cleanliness even in harsh industrial conditions – thereby enhancing system service life and processing accuracy.

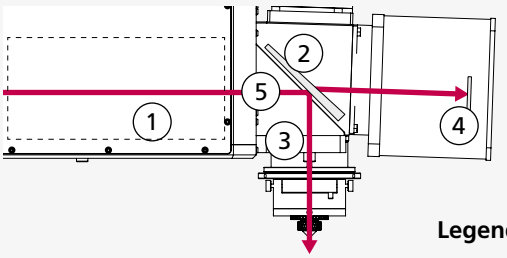
Automatic Fine Adjustment

precSYS's factory-precalibrated beam position measurement unit can be used for monitoring the system's beam position. If the beam position exceeds the application-specific tolerance limit, then the software can be used to readjust the beam back to its original zero position by the system-internal five galvo axes.

Advantages:

- Beam position stabilization close to the working field minimizes deviations along the beam path from laser to workpiece
- Lastingly reproducible process results without complicated effect analysis and manual readjustment
- Beam position monitoring via maintenance software program
- Automatic readjustment of beam position and angle via the DrillControl software (regulation via system-internal galvo axes)
- Supports precSYS alignment during commissioning and servicing

Automatic fine adjustment



Legend

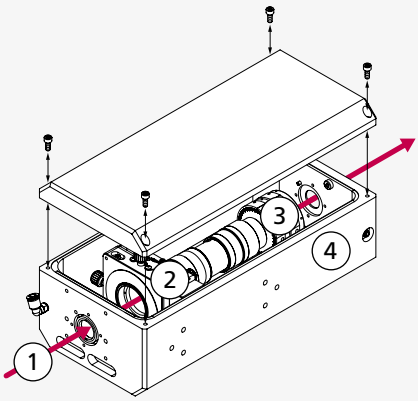
1 Five galvo axes
2 Beam splitter
3 Objective
4 Beam position measurement unit (DrillControl software controlled)
5 Laser beam path

Options

Beam conditioning components

- For adapting the entrance beam's diameter and divergence, as well as adjusting circular polarization within the image field
- Alternatively as beam conditioning unit without housing and gas purging

Beam conditioning unit



Legend

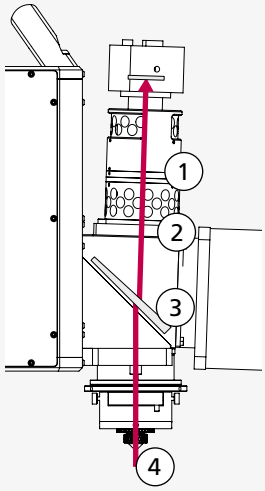
1 Laser beam
2 Beam expander with positioner (x, y, angle), beam expansion factor 0.25 ... 4 divergence adjustable
3 Polarization unit (λ/2 and λ/4 wave plate)
4 Housing with purge gas connector and protective windows

Components for optical process monitoring

SCANLAB offers a precSYS-matched camera objective with optional color filters for an observation wavelength of 880 nm ± 10 nm (Observation also possible at other wavelengths) and attachments to increase resolution. Additionally, customer-supplied components can be installed at the process observation port.

Further customer-specific solutions on request.

Components for optical process monitoring



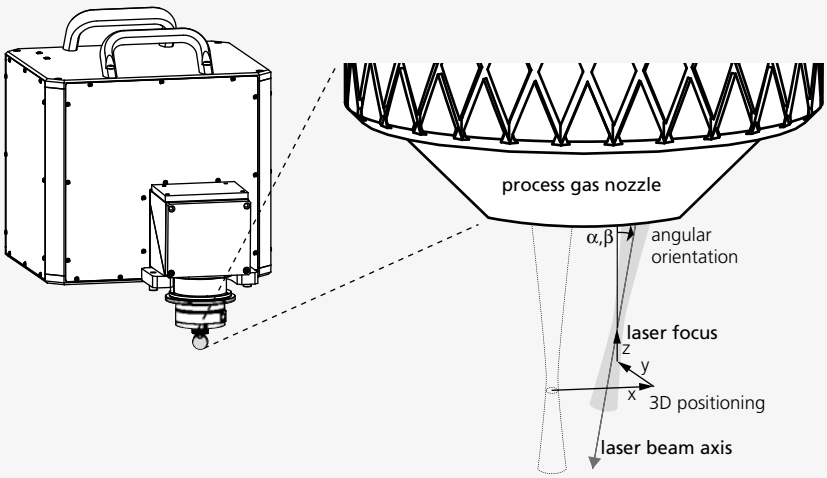
Legend

1 Camera objective, optionally with color filter
2 Adapter
3 Beam splitter
4 Observation beam path

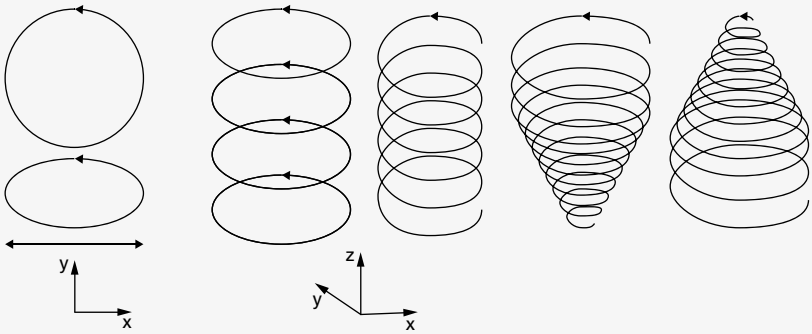
Innovation

With precSYS's patented technology, a stable, purely galvo-based 5-axis micromachining subsystem for high-precision manufacturing processes in series production has been realized for the first time.

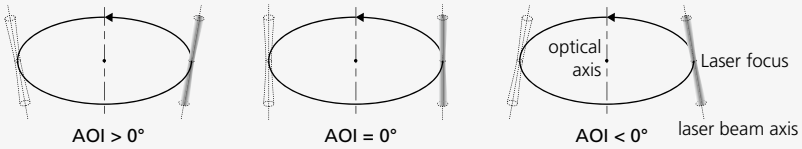
5-Axis Laser Focus Positioning Possibilities



2D and 3D laser focal motion examples



Angle of incidence (AOI) during laser focal motion



Flexible Processing

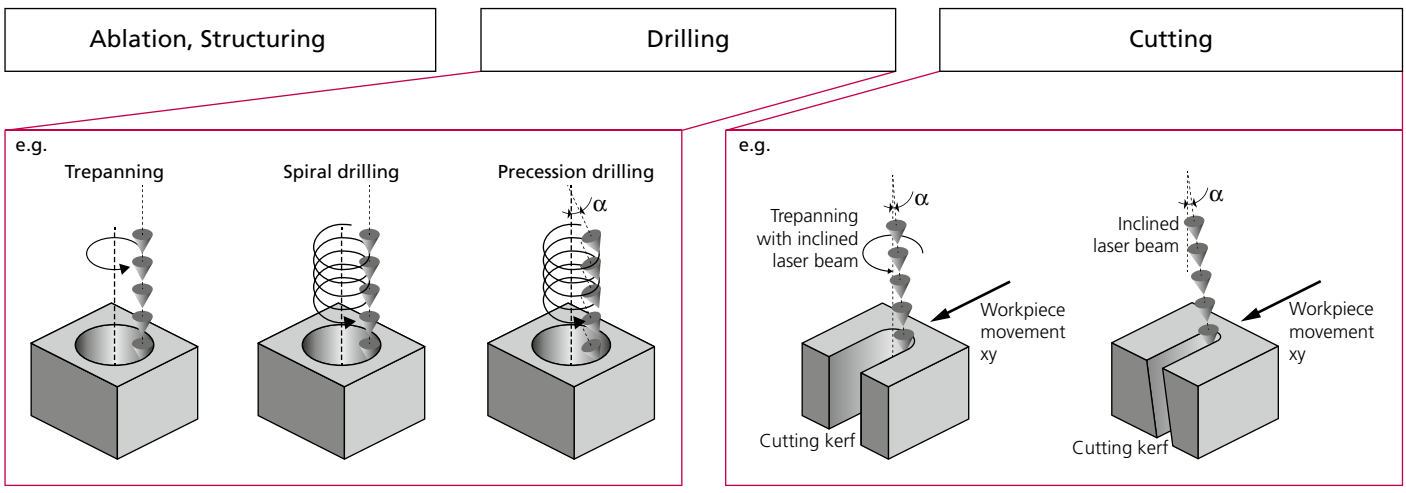
Due to precSYS's possibility to position the laser beam in 5 axis (x, y, z, α, β), it offers highest flexibility for process development.

Circular, elliptical or linear trajectories can be defined in 2D or 3D (examples are shown in the lower left figure). For any geometry, the incidence angle will be controlled as specified during trajectory motion. Thus, precSYS can precisely execute trajectories suitable for drilling, cutting or ablation with defined laser beam tilting.

For example, precession drilling – in contrast to typical trepanning and spiral drilling – allows processing with a helically moved and simultaneously tilted laser beam, e.g. to practically eliminate beam-caustic effects at entry edges. In this way, the precSYS's high precession frequencies even enable production of deep bore holes with high aspect ratios and vertical walls at one-second intervals.

A similar effect can also be exploited when structuring or cutting walls with vertical or negative-tapered defined profiles.

High-precision processing is possible with the full +/- 7.5° range of incidence angles in circular image fields up to 2.5 mm in diameter. Typically employed pulse lengths are in the USP range of 250 fs – 25 ps. In addition, markings can be created within an image field of up to 5 mm in diameter.



DrillControl software

An intuitive graphical user interface (GUI) with 3D job visualization helps you easily create and simulate processing jobs. Communication between DrillControl or system control and DrillServer occurs over Ethernet with TCP/IP or via the EtherCAT interface. Factory calibration enables description of laser motion directly in metric units within precSYS's cartesian image field coordinate system.

The software depicts processing steps in 3D and enables straightforward job programming, as well as varying the diverse process parameters.

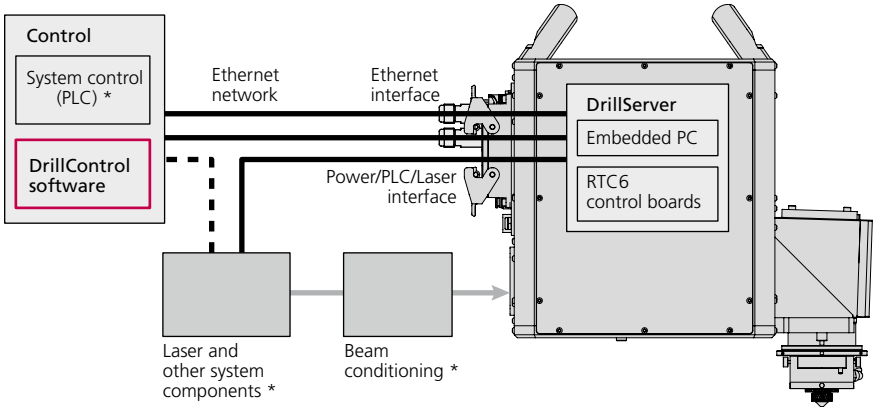
Job designer

- Definition of process sequences with visualization of the 3D laser path
- Management of process jobs on the precSYS system (embedded PC)
- Comprehensive simulation and testing possibilities
- Parameter relationships displayed as lists and diagrams
- No job size limitation
- Control of up to 10 digital and 2 analog outputs with freely definable ramps for setting additional parameters (e.g. laser power or process gas pressure)
- Diagnostics panel (galvo status, galvo temperature, etc.)
- Software-based adjustments
  - aligning the focal plane to the precession plane
  - global offsets, scalings and rotations for the laser focus path
  - characteristic curves for adjusting the laser power control parameters

Functionality for Production

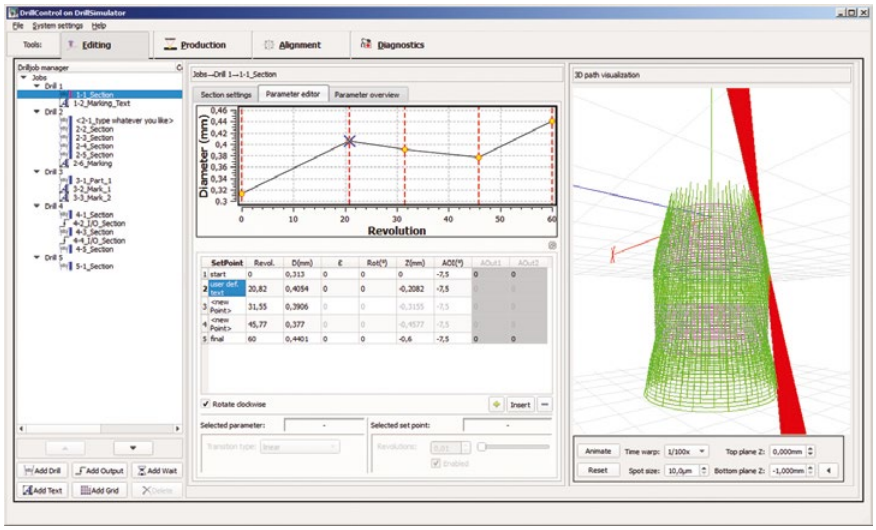
- Additional user interface for production operation
- Easy management of one or several systems via one software
- **Remote control** via Ethernet or EtherCAT for integration in system control (PLC): Simple protocol for defining, selecting and running jobs (job definition via XML including validation) and for parameter adaption for compensating workpiece tolerances (e.g. offsets)

System integration and control

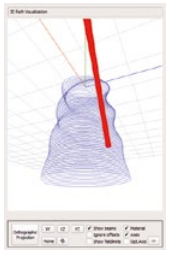


* Certain system components (e.g. lasers, electrically-switchable gas valves, motorized polarization plates, motorized beam expanders) are typically not provided by SCANLAB.

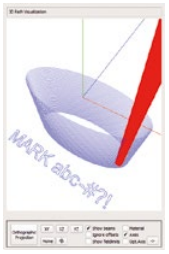
DrillControl graphical user interface



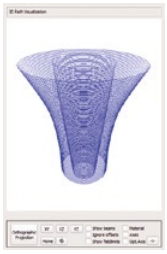
3D visualisation of the laser focal motion



Screw geometry with negative cone

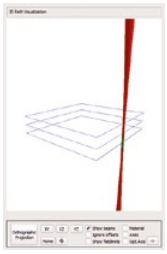


Ellipse with marking

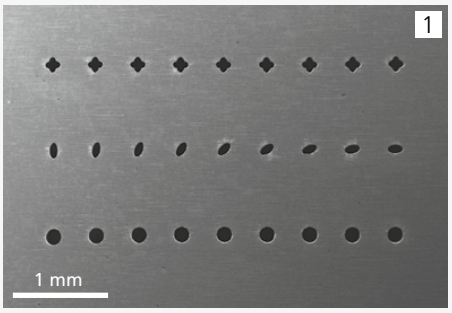


Linear inner cone, interpolated outer cone

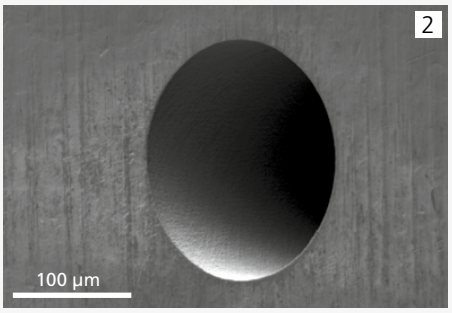
Geometric flexibility via overlapping ellipses and circles (modular approach)



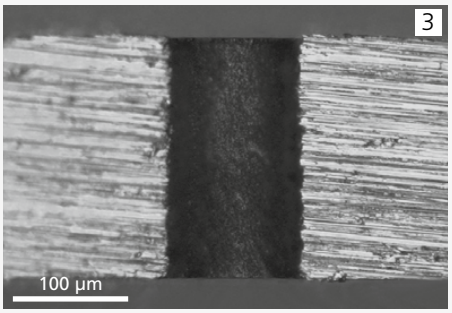
Lines with variable z positions and AOI ≠ 0°



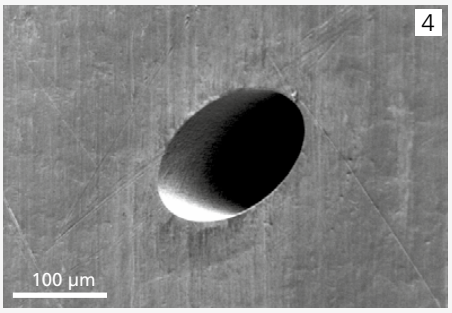
Flexible geometries in 300-µm-thick steel (SEM image, exit side)



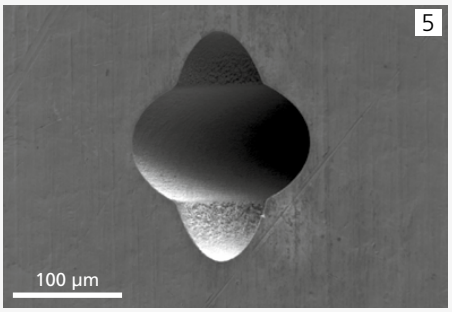
Ideally-formed round single bore hole with 200 µm diameter from figure 1 magnified (SEM image)



Cross section of a 100-µm bore hole in 200-µm thick steel with perpendicular wall contour (zero taper), process time 1 s



Detail of figure 1: Elliptical bore hole, 190 µm long, 110 µm wide (SEM image)



Detail of figure 1: Geometric flexibility achieved by two overlapping ellipses 190 µm long and 110 µm wide, each (SEM image)

Processing Results

precSYS 5-axis material processing enables machining of fine geometries in the sub-millimeter range with high aspect ratios and quick process times, using ultra short pulsed laser beams. Typical micro applications are ablation, structuring, drilling and cutting.

precSYS's high-end scan technology and innovative calibration facilitate dynamic, highly-precise traversal of defined paths throughout the entire 2.5 mm circular working field. Fabrication is also possible outside the optical axis. Thus, no XY translation stage is needed for workpiece positioning while processing bore-hole arrays in the image field. You can assign individual jobs to each specific bore hole, i.e. for processing with individual parameter settings.

Helical processing with defined laser beam tilting allows fabrication of high quality bore-hole entries and exits that are clean-cut, burr-free and molten-free. This enables creation of – for example – precise positively conical (V-shaped) and negatively conical (Λ-shaped) or ideally cylindrical (II-shaped) bore wall contours with high aspect ratios.

precSYS lets you execute not only 3D geometries, but also 2D marking. In addition to processing of circular, elliptical or linear laser motion paths, you can also easily mark text with various fonts and font sizes in a 5 mm circular working field (e.g. for labeling during process development).

In addition, more complex geometries such as ellipses or squares with perpendicular edge contours can be fabricated. For example, figure 7 shows a 4 x 4 square array in ceramic with 30-µm side lengths and a 1:10 aspect ratio. Thanks to factory pre-calibration, the squares are precisely positioned within the image field to maintain a defined 10-µm wall thickness across the entire array.

When the required geometry exceeds the image field of 2.5 mm in diameter, supplementary external axes can be employed below the precSYS for workpiece guidance. Figure 9 shows a cutting application where segments with vertically-contoured walls were cut out of a 200-µm-thick brass

component. The wall quality is characterized by homogenous, defect-free surfaces with sharp edges.

Quality

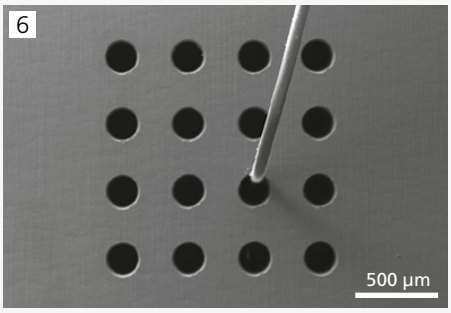
The high quality, dependability and industrial suitability of SCANLAB's scan solutions are the result of long-standing experience in developing and manufacturing galvanometer scanners and scan systems. SCANLAB scan heads have been deployed by industry in large quantities for many years. Each individual scan head earns approval for customer delivery only after first passing the *SCAN*check endurance test.

Customer Service

This highly integrated system features a product-specific customer service:

- Local support for precSYS commissioning by an experienced service technician
- On-site maintenance and repairs
- Comprehensive training for efficient usage of software and performance of maintenance work
- Installation of software updates
- Remote servicing and error diagnostics (remote interface)
- Technical support via phone service

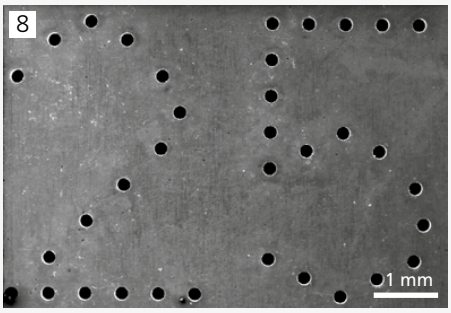
200-µm bore holes in steel – compared to a human hair, fabricated with fixed workpiece position, without an XY translation stage (SEM image)



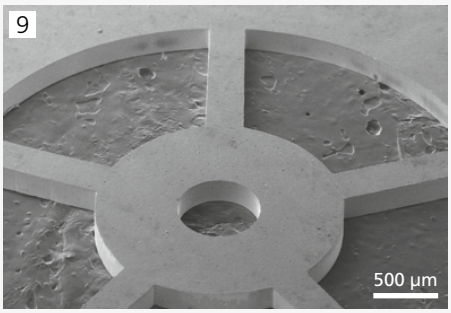
Detail of a 4 x 4 square hole array in ceramic
- Square geometry: 30 µm x 30 µm
- Depth: 300 µm, Aspect ratio: 1:10
- Perpendicular wall contour
- Corner-rounding radius: < 4 µm
- Wall thickness: 10 µm

(SEM image)

200-µm bore holes in 300-µm thick steel (entrance side), fabricated via workpiece positioning with an XY translation stage (SEM image)



Cutting application with perpendicular cutting edge contour in 200-µm thick brass (SEM image)



Marking pattern for labeling
- Characters: 0.5 mm font size, SimpleStraight3 font
- Circle diameters: 0 mm, 0.1 mm, 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm

Specifications

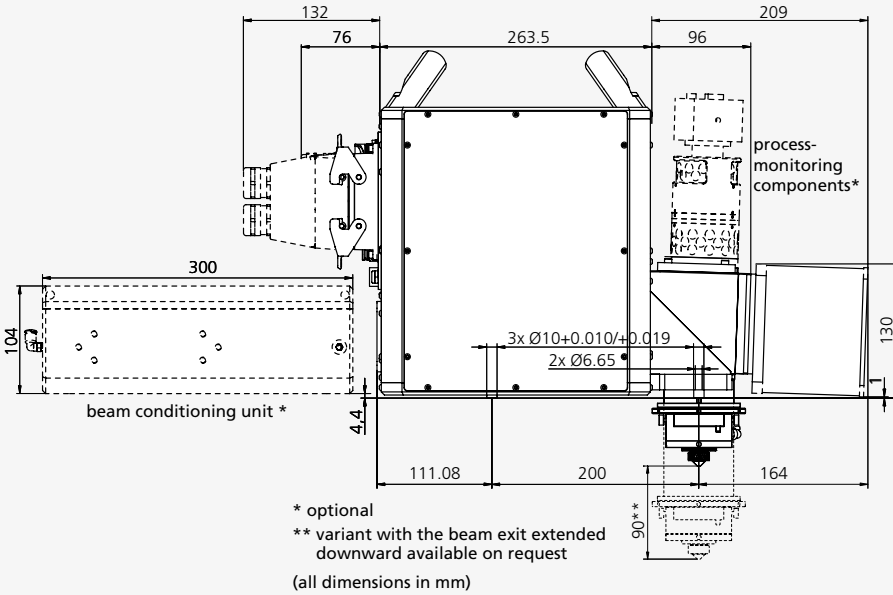
Wavelength	1030 nm	515 nm (Standard)	515 nm (min. focus diameter)
Clear aperture at entrance	4 mm	4 mm	4 mm
Typical entrance beam diameter ($1/e^2$)	2 mm	2 mm	2.5 mm
Typical focus diameter in image field ($1/e^2$) for M^2 = 1.2	20 µm	10.2 µm *	8.2 µm *
Minimum focus diameter in image field ($1/e^2$) for M^2 = 1.2	15 µm	8.2 µm *	tbd
Typical convergence angle of focused beam (full opening angle at $1/e^2$ level)	0.08 rad	0.08 rad	0.1 rad
Maximum angle of incidence (AOI)	± 7.5°	± 7.5° *	± 7.0° *
Trepanning / precession frequency (for max. AOI and Ø 100 µm)	≤ 650 Hz (39 000 rpm)	≤ 650 Hz (39 000 rpm)	≤ 650 Hz (39 000 rpm)
Typical pulse energy	≤ 300 µJ	≤ 65 µJ	≤ 100 µJ
Typical average power	≤ 50 W	≤ 50 W	≤ 50 W
Typical pulse length	250 fs – 25 ps (up to cw)	250 fs – 25 ps (up to cw)	250 fs – 25 ps (up to cw)
Objective focal length	75 mm	75 mm	75 mm
Effective focal length	25 mm	25 mm	25 mm
Working field size (diameter, depending on nozzle opening)			
- Precession processing	≤ 2.5 mm	≤ 2.5 mm	≤ 1.5 mm
- Marking	≤ 5 mm	≤ 5 mm	≤ 5 mm
Maximum focus range in z direction	± 1.0 mm	± 1.0 mm	± 1.0 mm
Maximum focus speed in z direction	10 mm/s	10 mm/s	10 mm/s
Theoretical position resolution in xy image field	17 nm	< 20 nm	< 20 nm
Repeatability in image field **	≤ 0.5 µm	≤ 0.5 µm	≤ 0.5 µm
Theoretical resolution of incidence angle	2 µrad	2 µrad	2 µrad
Focus polarization (after beam conditioning)	circular	circular	circular
Weight	approx. 30 kg	approx. 30 kg	approx. 30 kg
Observation port wavelength	880 nm ± 10 nm; 1200 nm - 1400 nm	820 nm - 890 nm; 1230 nm - 1370 nm	820 nm - 890 nm; 1230 nm - 1370 nm
Axes	5 factory calibrated axes (x, y, z coordinates and 2 incidence angles α, β)		
Power supply requirements	30 V – 33 V, max. 6 A		
Data and control interfaces	Ethernet (DrillControl, remote interface for PLC/machine control, XML job definitions), EtherCAT, external job start/stop trigger		
Control of Peripherals (e.g. laser power or process gas pressure)*	2-bit digital output 8-bit digital output (PLC) Two 12-bit analog outputs (0 … 10 V) with freely definable ramp profiles Job Busy output		
Cooling	water, 25 °C		
Purge gas (for optical beam path)	synthetic air according to ISO 8573-1:2010, class [1:2:1] (other gas types on request)		
Process gas	freely selectable, max. 6 bar, 1 mm process gas nozzle opening ***		
Replaceable protective glass (for fast-replacement drawer)	yes		
Software	DrillControl (graphical user interface), DrillServer (on embedded PC)		

* Certain system components (e.g. lasers, electrically-switchable gas valves, motorized polarization plates, motorized beam expanders) are typically not provided by SCANLAB.

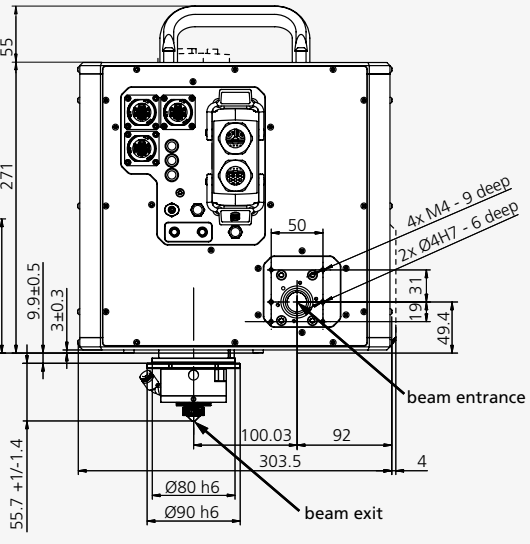
** Deviation of diameter and roundness over 6 hours operation load (for AOI = -7.5° ... 7.5°; Ø 0.09 mm ... 0.3 mm; f = 50 Hz ... 650 Hz; z = -1 mm ... +1 mm)

*** Other nozzle openings are optionally available if needed. * valid for lasers with a spectral bandwidth < 1.5 nm

Side view precSYS



Beam Entrance Side



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