PM series
Polygon mirror scanner

Manual

MOEWE Optical Solutions

April. 2020

Safety information

The scanner is turned on as soon as the power supply applies a voltage.

Before the first start, read the installation guide in chapter 3 of this manual.

The scanner contains sensible optics. Avoid any contact with hands and tools to the aperture window, the focusing optic or optics inside the housing. Handle with gloves very carefully.

Danger! Avoid direct and scattered laser radiation of eye or skin.

For a safe use, read the manual of your laser carefully.

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1 Working with a polygon mirror scanner of the PM series

Thank you for choosing a polygon mirror scanner from MOEWE Optical Solutions.

1.1 PM Series overview

The polygon mirror scanner is a deflection unit developed for high speed laser material processing, providing beam deflection velocities up to 1000 m/s, depending on the used laser objective. As shown in Figure 1a, the scanner is divided in an optical section and an electronics section, which are spatially separated by the construction.

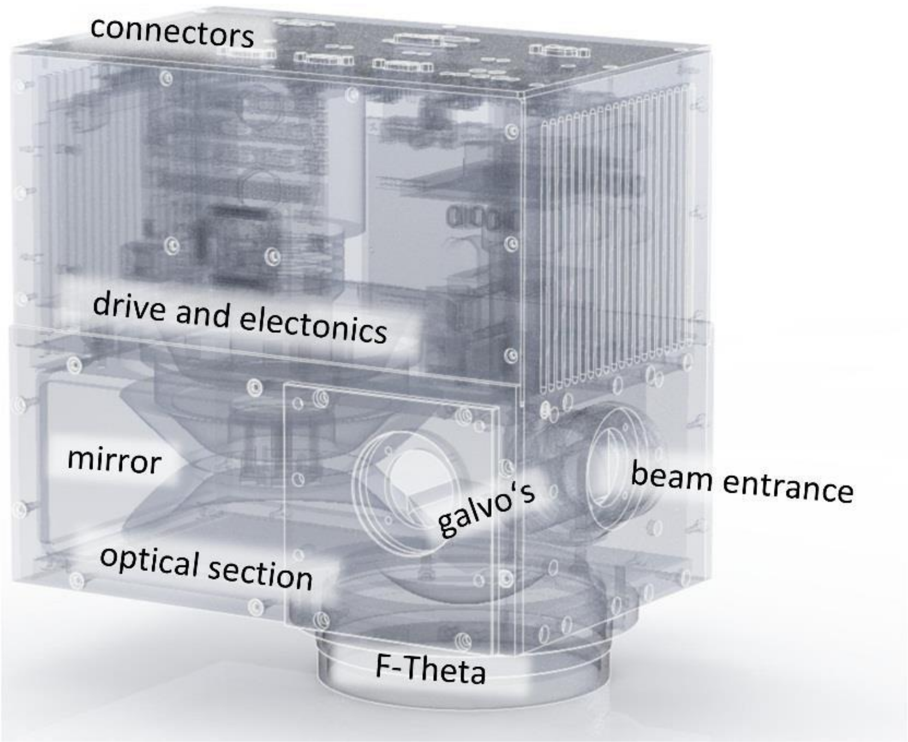


Figure 1: Overview of the 2D polygon mirror scanner.

The beam entrance is located at the side with an aperture of 30 mm, while the beam exit is located at the bottom with an adapter ring for changeable laser objectives. Furthermore, various connectors are available to connect the polygon scanner with a power supply, PC and other electronic units. The patented optical design and the patented FPGA-based real-time data processing provides together with the user software different operation modes for self-sufficient 2D, 2.5D and 3D laser material processes. Additionally, the scanner includes all necessary components for the communication with peripheral hardware such as the laser source, further material handling systems or measuring systems. Thus, the scanners of the PM series perform best, if they control the connected hardware as master in a master-slave relation, since the FPGA is able to calculate the laser switching on and off as well as the laser power for each line in advance. Otherwise it is also possible to configure the scanner fitting in your processing environment following input signals of e.g. an axis system. The

PM series is available in eight different models with different technical specifications and application features, which are addressed in this manual. An overview is presented in section 1.2 on page 6 of this manual.

The manual starts with the basic principles and physical relations inside the optical path. In the following the user software is explained including the different operation modes tailored to common laser processing applications.

The instruction for installation is located in the second half of this manual. It describes the mechanical integration into a laser machine, the electrical connectors and explains the laser beam alignment. At the end, the technical specifications of all models of the PM series are listed.

It is required to read this manual first, to operate the polygon scanner of the PM series properly and safe. Be careful, an improper use of the polygon scanner is a danger for health. The polygon scanners of the PM series are designed for the use with high power visible and invisible laser radiation. Please consider independent from this manual, the local and international regulations and laws for working with laser radiation.

1.2 Models of the PM series

Model	Power	cw	pulsed	Applications	Specials
PM100	> 1 kw	•	• (USP)	Large surface treatment	High power
PM200	< 400 W	•	-	Marking, structuring	Polarized, incl. AOM < 10 MHz
PM300	< 1 kW	•	• (USP)	Marking, LIFT, micro structuring / machining	
PM400	< 1 kW		• (USP)	Drilling, structuring	2nd galvo for phase correction
PM500	Educational version, non-commercial				
PM600	< 1 kW		• (USP)	2.5 D engraving	integrated grayscale processing
PMS700	Internal use only, non-commercial				
PMS800	< 1 kW		• (USP)	Stereolithography, SLM	integrated raeal-time slicer for 3D data
Options					
Synchronization		Synchronization of multiple polygon scanners for working with more than one scanner on a single laser to increase the laser utilization			
Real-time shifter		Synchronization of the scanning process with a fast-moving substrate e.g. Roll-to-Roll system or three axes machining center			

1.3 Optical principle of the PM series polygon mirror scanner

MOEWE's patented optical design allows a low distortion, high precession 2D, 2.5D and 3D laser processing at scanning speeds over 1000 m/s. The essential part of the scanner is the fast-rotating double pyramidal mirror wheel with 16 mirrors in total, which is shown in Figure 2.

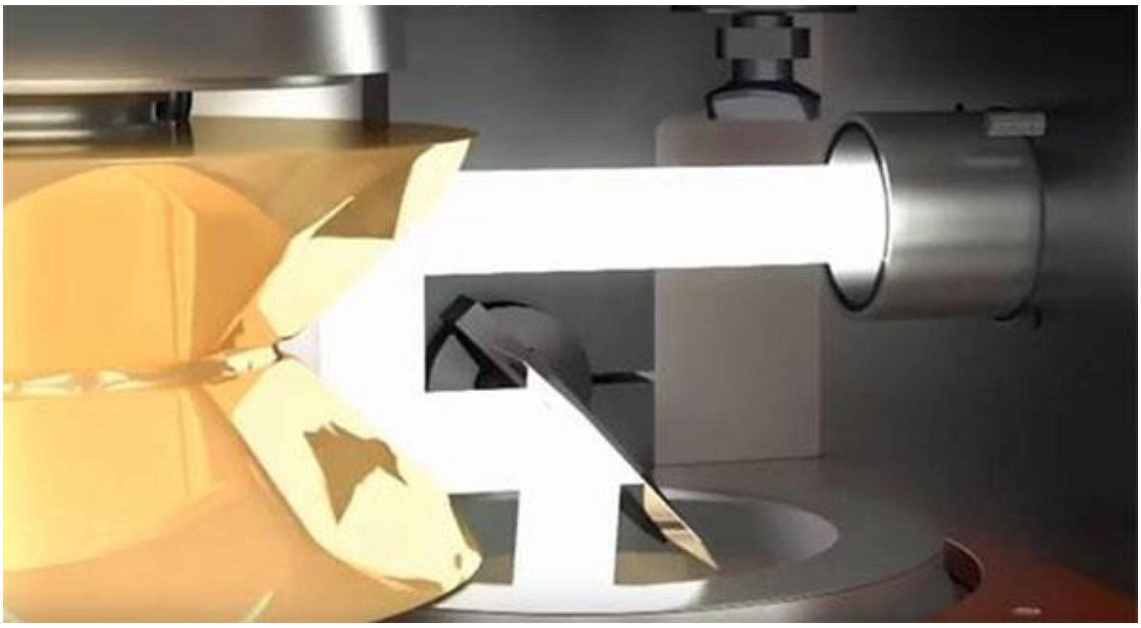


Figure 2: Optical design with laser beam visualization including the double pyramidal mirror (gold), the galvanometer mirror and the f-Θ-Objective

Two of these mirrors forms one of eighth facets on the wheel. The mirrors per facet are perpendicular to each other positioned and have a 45° inclination to the incoming laser beam. Consequently, the beam is reflected twice. As a result of the rotation around the wheel axis, the facet orientation changes continuously and deflects the laser beam with very high speeds. This deflection is used to move the laser beam along a line, the fast axis. For two-dimensional scanning, a galvanometer scanner is positioned in the laser beam after passing the polygon wheel deflecting the beam perpendicular to the fast axis. This scanning is performed with less speed, naming the scanning direction slow axis.

The combination of both mirrors allows the line-by-line scanning of a two-dimensional field. At the transition between two neighbored facets, the laser must be switched off, to avoid arbitrary beam reflections inside the polygon scanner. During this exchange gap, the galvanometer scanner is adjusted to the next line.

The beam propagation on a regular prismatic polygon mirror scanner is described by the deflection angle α of the facet resulting in a doubled deflection (2α) angle of the laser beam as shown in Figure 3a.

The MOEWE mirror deflects the laser beam twice obtaining also an optical reflection angle of 2α. The intermediate "out-of-plane" reflection in the third dimension supports a distortion free working. A flat polygon mirror would create an error, resulting from the shifting of the reflection point during one passage of a facet. This is visualized in Figure 3b.

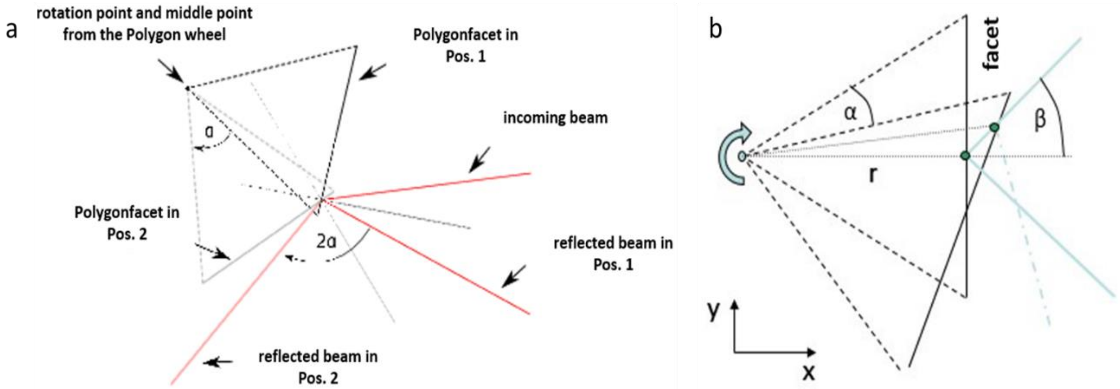

a
rotation point and middle point
from the Polygon wheel
Polygonfacet in
Pos. 1
incoming beam
α
Polygonfacet in
Pos. 2
2α
reflected beam in
Pos. 1
reflected beam in
Pos. 2
b
facet
α
β
r
y
x

Figure 3: (a)Direction of the reflected beam depending on the orientation angle α of the polygon mirror, (b) tangential pivot point error depending on the rotation angle α, the angle of the incoming beam β and the changing radius of the reflection point r.

The shifting results from the facet angles a, the incoming beam angle β as well as the radius r of the deflection point. Especially, the radius of the reflection point changes continuously during the rotation. MOEWE's patented optical setup used in the PM series avoid this shifting error as well as a back reflection due to the double reflection and provides much better scanning behavior than common polygon scanners.

1.4 Scan field

1.4.1 Parameters of the usable scan field

The scan field is the area spanned of between the fast axis Y (polygon deflection) and the slow axis X (galvanometer mirror) and describes the total amount of accessible points. Figure 4 shows the parameters of the two-dimensional scanning field, which are relevant for the laser process.

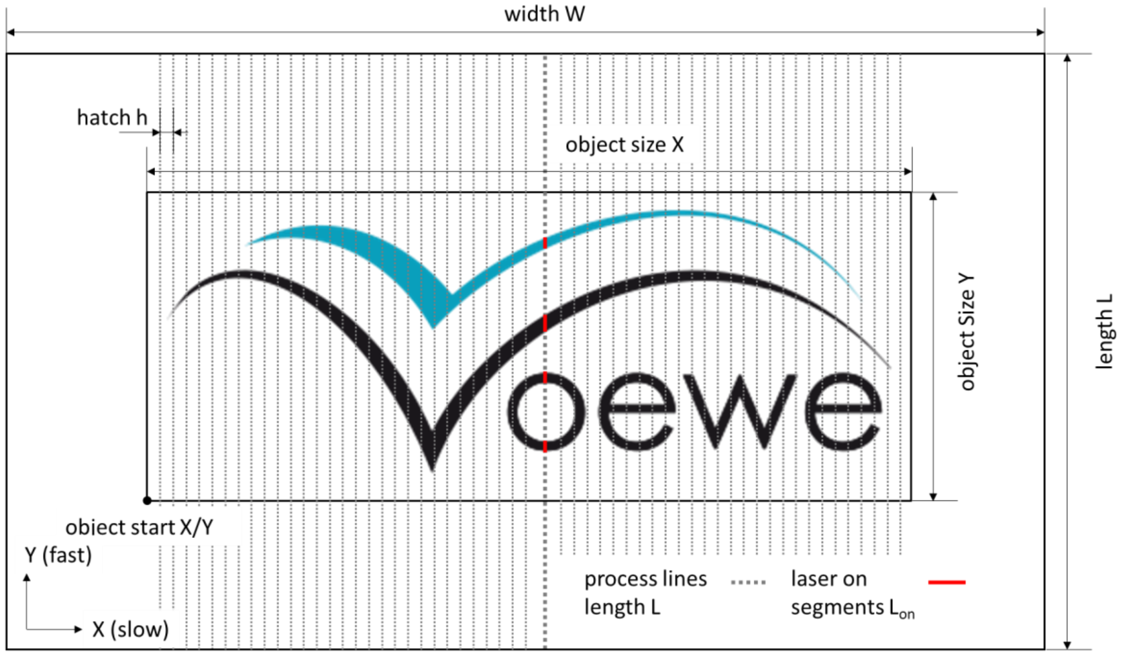

width W
hatch h
object size X
object Size Y
length L
object start X/Y
Y (fast)
X (slow)
process lines length L
laser on segments L_{on}

Figure 4: 2D scan field (L x B) with object (size X x size Y) in bitmap mode with visualized single scan tracks of the polygon mirror (dotted lines) and the laser on (L_{On}) segments (red lines) exemplarily for one line.

The usable size of the scanning field (L x B) is determined by the f-Θ-objective (max. acceptable angle, aperture size, expected position of pivot points) and the maximum deflection angle of the mirrors. Furthermore, the customer’s process can limit the scan field further. The resulting usable working field is scanned line-by-line along the fast axis due to the polygon wheel rotation. The device **scans always the whole range of deflection angle in the fast axis** resulting in a line length determined by the facet dimensions larger or equal to the scan field, even if it is not usable due to restrictions in software or hardware. The lines are separated with the hatch distance h in the slow axis direction.

Additionally, to the scan field, the object can be defined as the surface to be treated. The object can be larger or smaller than the scan field, but only parts inside the scan field can be treated. If it is larger, work piece handling systems are required. If the object is smaller than the scan field, the number of lines in slow axis direction follows the object size X. The lines outside the used working field in slow axis direction are not scanned in any way.

During the process, the lines are divided in segments with laser switched on and segments with laser switched off. The detailed process configuration is described in chapter 2 on page 17. The segments of a line with turned on laser ($L_{on,i}$) are shown red in Figure 4. Since multiple segments per line are possible, the index i is used to differ between them. Accordingly, segments with laser turned off are named $L_{off,\,j}$.

The polygon scanner calculates the target segments for the next line during the exchange gap between two facets, respectively two lines. Consequently, the target laser positions within the scanning field are treated by real-time switching of the laser in each line combined with the hatching of the slow axis.

1.4.2 Distortions of the mirror arrangement

A two-dimensional polygon mirror scanner can build in two types of mirror arrangement. First, the galvanometer mirror is positioned before the polygon mirror. In this case, the lines of the fast axis would be curved all over the whole field. Second, the galvanometer mirror is placed behind the polygon mirror, as visible in Figure 5a. This case has been realized in the MOEWE PM series.

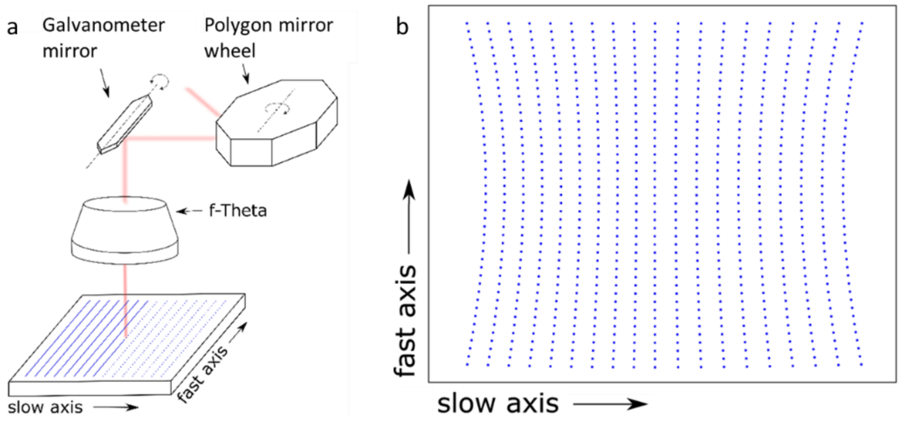


Figure 5: (a) Arrangement of the optical components along the beam propagation with the galvo mirror after the polygon mirror, (b) resulting scan field deformation of these mirror arrangement.

The resulting distortion is visible in Figure 5b. The position error causes a symmetrically concave curvature of the scanned lines along the fast axis. This effect increases with the distance to the center in positive and negative direction of the slow axis. A correction for laterals displacement is already implemented in the software.

1.4.3 Distortions due to focusing f-Θ-objectives

The scanners of the PM series are designed for a usage with focusing f-Θ-objectives, which cause further distortions. An example of a distortion of an objective is shown in Figure 6.

This distortion is symmetrically to the center consisting of concave distortion in the horizontal direction and convex distortion in the vertical direction. Both effects increase with the distance to the center. Hence, this lateral error overlaps with the distortion caused by the mirror arrangement, a correction possible with the same software tools.

Additionally, to the lateral positioning error, a variation of the focal diameter occurs. How this focus variation behaves, must be requested from the optics manufacturer. The example objective from above shows focal diameters variations between 30 and 60 µm, depending on the lateral position.

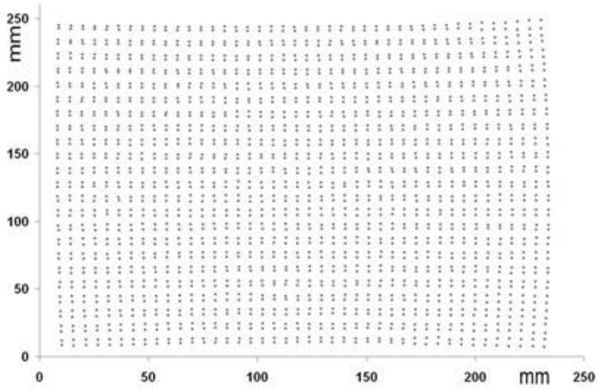


Figure 6: Exemplarily scan field distortion caused by the f-theta objective.

1.4.4 Misalignments due to manufacturing inaccuracies

Further distortions result from fabrication accuracy of all elements in the beam path. Especially, tangential and pyramidal errors of the polygon wheel are addressed. A tangential error of a facet results in a position error along the fast axis as shown in Figure 7a.

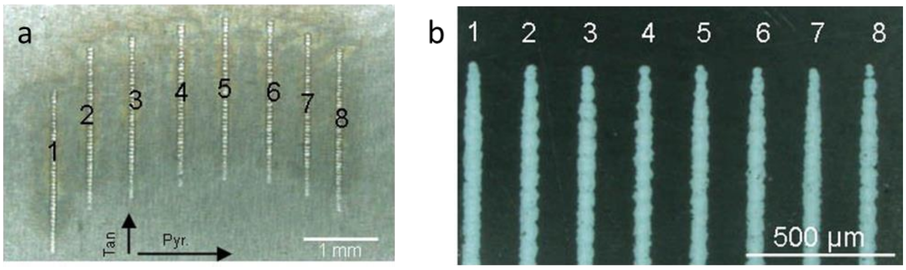


Figure 7: (a) Processes lines on a target material without tangential any pyramidal errors, (b) lines after correction of these error.

It is clearly visible, that the eight lines (1 – 8) processed with the eight facets of the polygon wheel have different starting points. Hence, each facet has their own tangential misalignment. The pyramidal error results in a variable distance between the lines. Both misalignments are measured and can be corrected for each facet. The corrected lines are visible in Figure 7b. Only a corrected scanner can process bitmaps and defined shapes on a material.

1.5 Optical and processing parameters, speed, time and efficiency

1.5.1 Optical relations

The processing speed is a key parameter in the process planning. Since the concept of MOEWE's two-dimensional polygon mirror scanner varies significantly from common galvanometer scanners, this section includes information to the processing speed and the degree of utilization of the scanner.

The line frequency f_L (scanned lines per second) is directly determined by the number of revolutions U of the polygon wheel and the number of facets N_{fac} according to equation (1).

$$\mathrm{f_L} = \mathrm{N_{fac}} \cdot U \quad (1)$$

Typically, the PM series is used with a focusing f-Θ-optic. Consequently, the relation of angle and lateral displacement is known as displayed in Figure 8.

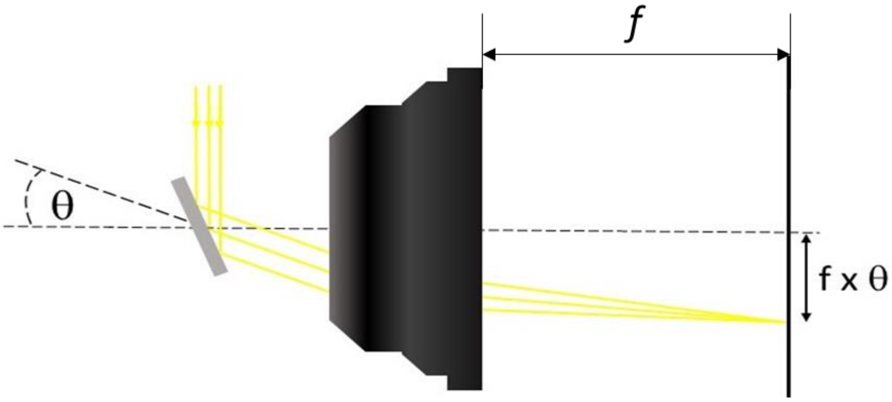


Figure 8: Relation at a f-Θ-objective, that transform an angle of incident Θ on an incoming parallel laser beam into a lateral displacement from the optical axis of the focus position of the laser beam that is the product of the angle and the focal length f of the objective (f x Θ).

In this case, the rotation speed can be transposed into a scanning speed v_f along the fast axis using equation (2), with f as the focal length and U as the numbers of revolutions per unit of time.

$$v_f = 4 \cdot \pi \cdot f \cdot U \quad (2)$$

Thus, the scan speed is constant over the entire scan field and not influenced by the size of the object. The speed cannot be changed from line to line because a change requires an acceleration of the polygon mirror wheel. The scan speed scales with the focal length of the used objective.

In an operation with a pulsed laser source, the pulse separation distance PD depends on the scan speed v_f and the laser pulse repetition rate *PRR* according to equation (3).

$$PD = \frac{v_f}{PRR} \quad (3)$$

From this, the pulse separation distance cannot be predicted. If the spacing is process relevant, the PRR has to adjusted to the target scan speed. Or, if this is not possible, the scan speed has to set according to the given laser PRR.

1.5.2 Process efficiency

The total processing time t_{total} depends on the number N_{LS} of lines in the scanning field and the number of repetitive scans per line, the line count N_{LC} ,as well as the line frequency as calculated in equation (4).

$$t_{total} = \frac{N_{LS} \cdot N_{LC}}{f_L} \tag{4}$$

The number of lines results from the object sizeX along the slow axis and the hatch distance h between the lines.

$$\mathrm{N_{LS}} = \frac{sizeX}{h} + 1 \text{ for } \mathrm{h} > 0\,, \mathrm{sizeX} > \mathrm{h} \tag{5}$$

From equation (5), it is clearly visible, that only the sizeX of the object along the slow axis has an influence on the processing time. Consequently, a maximum utilization of the fast axis is recommended. Rectangular workpieces, for example, should be positioned with the long edge parallel to the fast axis, as illustrated in Figure 9.

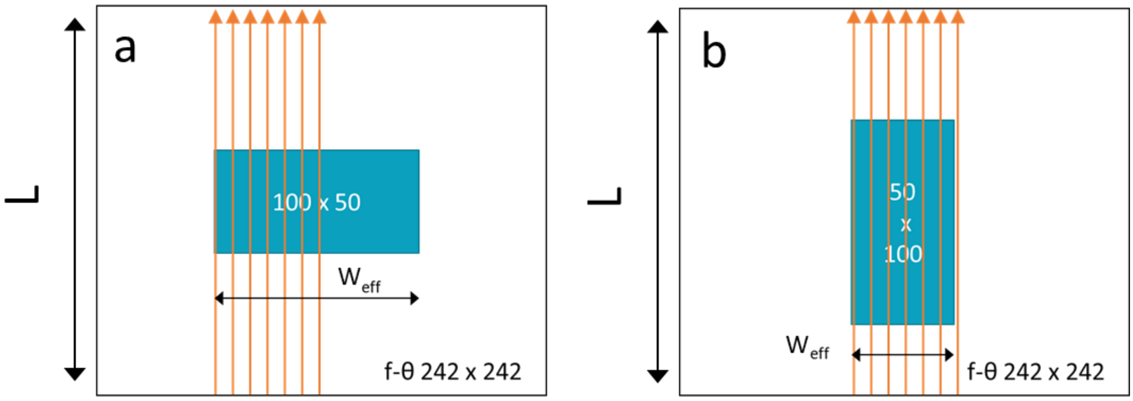


Figure 9: (a) horizontal oriented object with size 100 x 50, and (b) the same object vertically oriented (50 x 100) requiring different number of lines resulting in different process efficiencies.

Besides the processing time, the utilization degree is interesting. Since the laser is turned off during the transition between two facets and the laser is also turned off during the scan of non-treated areas, the system efficiency is reduced by both gaps.

The influence of the machined and non-machined areas is described as the line efficiency η_{line} and can be calculated with the equations (6) to (8). The individual segments with laser on and off are summed up and put in the ratio of segments with laser on to segments with laser off. This calculation can be done for a single line or for the sum of all lines within the scanning field.

$$\mathrm{L_{on}} = \sum_{i=1}^{m} L_{on}, i \tag{6}$$

$$\mathrm{L_{off}} = \sum_{j=1}^{n} L_{off}, j \tag{7}$$

$$\eta_{line} = \frac{L_{on}}{L_{on} + L_{off}} \tag{8}$$

Reducing the scanning of non-machined areas increase the line efficiency. Regarding the example from Figure 9, the line efficiency in case A is 20.7 % and in case B, it is 41.3 %, whether machined area is the same. This results further in a significantly reduced processing time of 50 %.

Another important parameter is the utilization efficiency η_{fac} of the polygon facet, because the whole laser system efficiency is depending on this value and it cannot be increased by process optimization. Figure 10 shows the laser beam with the geometrical diameter $ØD_L$ (energy outside this diameter is cut off, max. 30 mm) on a facet of a polygon with the length L_{fac}.

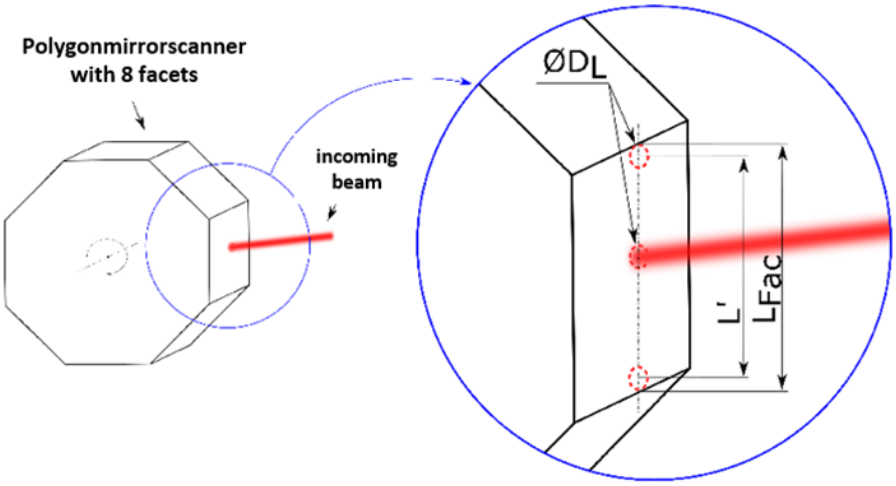


Figure 10: Visualization of the polygon mirror wheel with eight facets with an inset showing the effective usable facet length L′ depending on the geometrical facet length L_{fac} and the geometrical diameter of the laser beam $ØD_L$.

The exchange gap can be calculated from the facet length and the laser beam diameter according to equation (9).

$$\eta_{\mathrm{fac}} = \frac{L_{fac} - ØD_L}{L_{fac}} = 1 - \frac{ØD_L}{L_{fac}} \tag{9}$$

The laser is turned on after the whole beam diameter covers the facet and it is turned off as soon as the beam reaches the facet edge. With increasing beam diameter, the utilization of the faces decreases.

Finally, the duty cycle η_{duty} of the whole polygon mirror scanner process is the product of both values as shown in equation (10).

$$\eta_{duty} = \eta_{fac} \cdot \eta_{line} \tag{10}$$

Finally, an effective scan speed can be calculated with equation (11), correlating the laser on segments (machined tracks) to the processing time.

$$v_{eff} = \frac{L_{on}}{t_{total}} \tag{11}$$

1.5.3 Laser processing at very fast scan speeds

The fast scan speed has influences on the laser process on the target material. Due to the high scan speeds, a deformation of the laser treated area can occur in the direction of the fast axis. Figure 11 shows the comparison of (a) the circular laser-material-interaction spot on during a laser treatment with no or low relative movement of work piece and Gaussian laser beam to (b) the spot of the same laser beam during a high-speed relative movement.

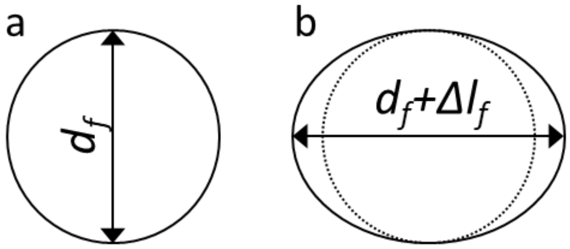


Figure 11: (a) circular laser spot from a treatment with a non-moving Gaussian laser beam, and (b) laser spot from a treatment with the same Gaussian laser beam during ultra-high scanning speeds.

In the direction of the slow axis the laser spot size d_f is not influenced by the scan speed and can be determined following equation (12) as the diameter of a focused Gaussian laser beam.

$$\mathrm{d_f} = \frac{4 \cdot \mathrm{f} \cdot \mathrm{M}^2 \cdot \lambda}{\pi \cdot \mathrm{D_L}} \tag{12}$$

The wavelength of the laser beam is described by λ, while M^2 is the beam quality factor. The beam diameter D_L is used in the ($1/e^2$) definition before the focusing optic.

In the scanning direction, the focused laser beam travels a significant distance Δl in the micrometer range even in short time (nano-second range), that a single pulse appears prolonged by this distance. It can be calculated from the scanning speed and a certain time using equation (13).

$$\Delta l = \mathrm{v_f} \cdot \mathrm{t} \tag{13}$$

This time can be the pulse duration τ_{pulse} for puled lasers or the laser on/off switching time $t_{switsch}$, if for example an acousto-optical modulator is used. The switching time depends on multiple factors, why a certain value must be measured for each system individually. Typical switching frequencies are > 10 MHz (cycle time 100 ns). Consequently, the processing resolution depends directly on the scanning speed.

1.6 Objectives

With an adapter ring a wide range of objectives can be mounted to the polygon scanner of the PM series. For a proper use it is recommended to use only objectives fitting to the optical parameters of the scanner. Especially, the distance of the pivot points of the mirrors in fast and slow axis must fit to the specifications of the objective. Thereby, the position of the pivot points is adjustable with the design of the adapter ring. The minimum values are listed below

Distance **M1** (slow axis):	> 23 mm
Distance **M2** (fast axis):	> 82 mm
Distance from M2 to M1:	59 mm (fix)

In some special cases, the mirror is diving into the objective without mechanical contact. Thus, the minimum distance can be reduced slightly.

The following section includes approximated optical / processing parameters for different objective parameters. Values of tested objectives are marked with a dot. These objectives have focal length of 167 mm, 255 nm and 420 mm respectively. Figure 12 shows scan speeds achievable with f-Θ-objectives of different effective focal length at different rotation speeds of the polygon mirror wheel.

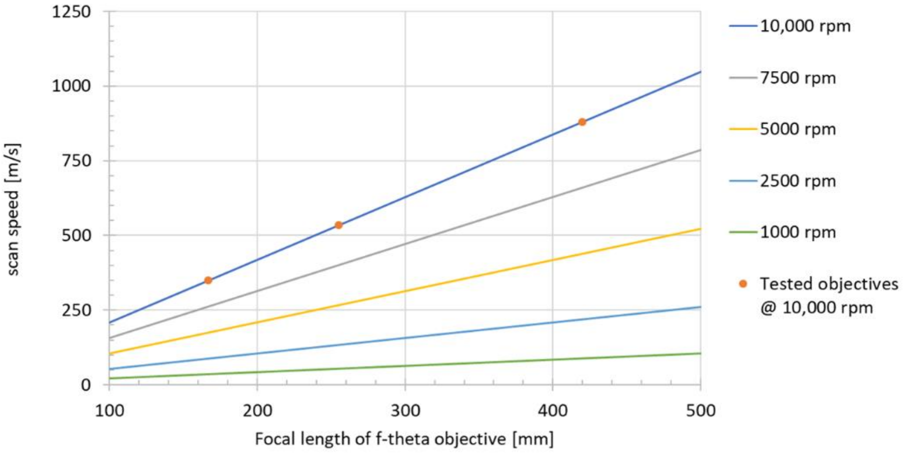


Figure 12: Expected scan speeds depending on the focal length of the objective and the rotation speed of the polygon wheel.

Furthermore, Figure 13 shows some calculated spot diameters, that can be achieved with f-Θ-objectives using different laser wavelength. These values are just approximations and real values can vary significantly, depending on the overall performance of the whole laser system.

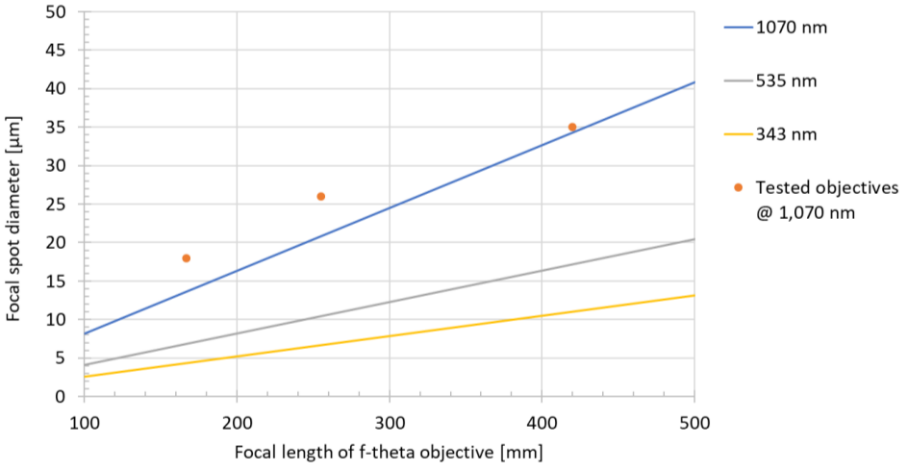


Figure 13: Expected focal spot diameters depending on the focal length if the objective and the wavelength of the laser light.

Estimated values for the diagram are λ = 1070, 535 and 343 nm, D_L = 20 mm, which is the maximum recommended size for the PM series and $M^2 = 1.2$.

1.7 Fully-digital process control

The polygon mirror scanner is a fully digital device with a field programmable gate array (FPGA) as central unit. This FPGA includes a device specific logic core, that calculates all process parameters within a cycle time of 5 ns (200 MHz), which is real-time like. The control unit is capable to calculate process relevant signals, such as polygon motor control signals, galvanometer mirror position or laser switching times, during the facet exchange gap. Thus, parameters for a processed line are calculated always directly before the line scan is performed. Thereby, a couple of input and output signals are utilized. A schematic overview is presented in Figure 14.

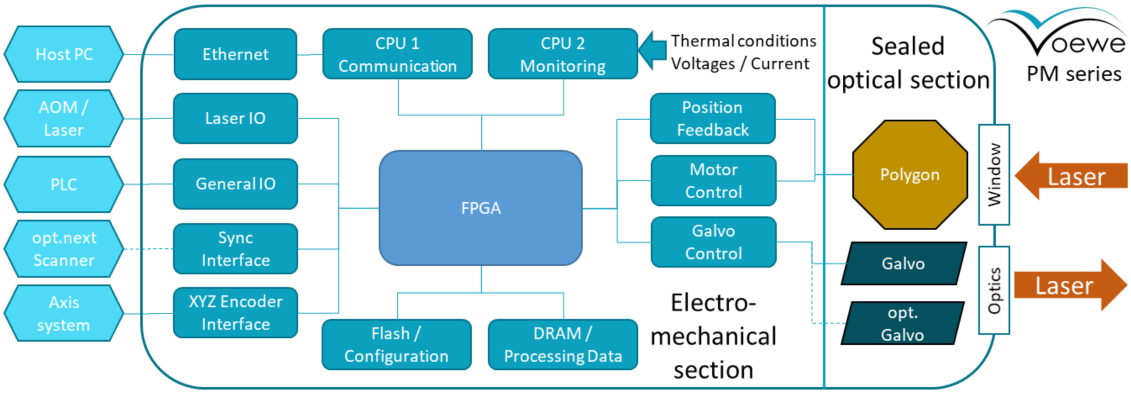

Host PC
AOM / Laser
PLC
opt.next Scanner
Axis system
Ethernet
Laser IO
General IO
Sync Interface
XYZ Encoder Interface
CPU 1 Communication
CPU 2 Monitoring
Thermal conditions Voltages / Current
FPGA
Flash / Configuration
DRAM / Processing Data
Position Feedback
Motor Control
Galvo Control
Electro-mechanical section
Sealed optical section
Polygon
Galvo
opt. Galvo
Window
Optics
Laser
Laser
Moewe
PM series

Figure 14: Block diagram for the scanner control unit with FPGA, electrical connectors and opto-mechanical device connectors for galvanometer and polygon motor.

On the left side, all external devices are listed, which are able to communicate with the polygon mirror scanner. First of all, a host PC is required for running the control software. This PC is connected via ethernet to an internal Processer used for communication. From there, the configurations are set in the FPGA and the related memory. A second internal processor is used to control feedback values from sensors. Once the FPGA is configured, it works self-sufficient controlling optical elements inside the scanner and communicate to the connected peripheral devices. The control of the scanner device includes the polygon motor control, respecting the position feedback from the encoder as well as the galvo mirror control. Consequently, the mirror control is controlling the laser beam during the process.

The most important control of external devices is the laser communication. From the motor position, the FPGA calculates laser on an off time and send the signals to the laser or laser modulator such as AOMs. Furthermore, the FPGA is able to follow a moving substrate, if the axes send an encoder signal to the scanner. The encoder counts are respected, and the current laser position is shifted accordingly.

Scanners with a sync-module are able to synchronize their polygon rotation speed in a master-slave principle. Therfore, the master scanner sends its motor position signal to the slave, which is matching its spin speed to this signal. The slave can send its motor signal again to a further slave building a sync-chain.

Additionally, customizable input and outputs are available at the GPIO port.

2 Operating the PM series with *PolyControl* Interface

The scanner is turned on as soon as the power supply applies a voltage.

Before the first start, read the installation guide in chapter 3 of this manual.

2.1 Operation modes

The polygon scanner is ready to work in various application fields. Since every laser application has certain requirements to the process management, the polygon scanner is able to operate in different modes, tailored to certain processing strategies. In the following the various possible modes are described in detail.

The **2D modes** are design to manage the laser on and off switching in the scanning field.

In the **line mode**, lines along the fast scanned within the defined scanning field (L x W). The hatch distance can be defined in the software. Also, the number of scans can be managed. A sub-hatch is also possible, where the scanning field is treated with the hatch between the lines, but the next over scan of the field is shifted by the sub-hatch. Thus, the entire area can be treated with a small line-distance, but a better heat distribution during the process.

In the **Bitmap mode**, the laser switching is following a binary image.

The **2.5D mode** can be used for **engraving**. An 8-bit greyscale image is used to ablate material with multiple over scans. Thus, a depth profile is generated due to the greyscale. This mode is not able to fabricate undercuts.

The **3D treatment** is only useable with the 3D real-time slicer (optional for models PM S600, PM S800)

2.2 Software settings

Start the software by clicking on the “PolyControl Interface.exe”. After the start, the drop down menu in the lower right corner of the window shows all available scanners. Select the one, you want to configure.

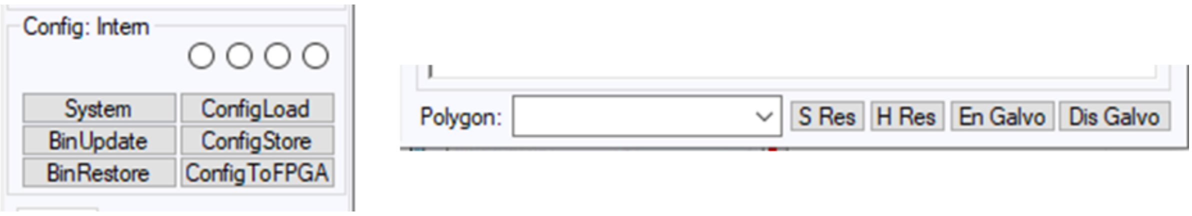


Figure 15: Config panel, with the four internal memories, update, load and storage buttons, and polygon selection menu.

Afterwards the IP is shown in this window and a message confirms the connection.

Now the current scanner configuration is displayed. Inside the control unit four different configurations can be stored. The selection is done with the four option boxes in *Config* panel. Changes in any field of the window have to be applied with Enter on the keyboard. Afterwards the changes will be used in the scanner but gets lost without storage. The whole configuration can be stored internally in the current selected memory place using the **Config to FPGA** button. Thereby the current values are saved in the selected memory. A transfer to another internal memory is not possible. Alternatively, a configuration can be stored externally on the PC using the **Config Store** button. A windows dialog will open, to choose the place and name of the config-file. A configuration can be load from the PC using the **Config Load** button following the windows dialog. Also, another configuration of the internal memories can be used by selecting another option box. A done switch will be responded with a message in the *message* panel. Store changes before switching to another internal memory. In the *Config* panel, further system settings can be done. The **System** button will open a window with system information and version numbers. An update of the controlling binary file can be done with the **BinUpdate**. A windows dialog opens, where the new "boot.bin" file can be selected. The update will be performed, while the last used bin file is still kept in the scanner. Only one version of old bin files is stored. After updating, a message requests a restart of the system. The **BinRestore** button, loads the previous bin file from the internal memory. This option should be used, if any error appears after updating-

There are two ways to restart the scanner. A soft reset is performed with the **S Res** button next to the polygon selection. Thereby, the software is restarted. A hard reset **HRes** also reboots the whole system.

Furthermore, it is possible to enable and disable the galvo controller, with the **En Galvo** and **Dis Galvo** buttons respectively.

2.3 Configuration of software and scanner

All scanners are delivered with a preset configuration including the zero position (X_shift, Y_shift), the µ/bit definition and a facet correction in X any Y direction for all facets. Furthermore, standard values for the galvo tolerance (G_Hyst), the rotation synchronization tolerance (Sync), the galvo reaction times (G_Math, G_Jump) and the delay (On Delay) are preset. Nevertheless, the following section declares how to configure the scanner and software. Start *PolyControl* Interface on a PC with windows 7 or later. The window offers different panels for the scanner configuration and process control as shown in Figure 16.

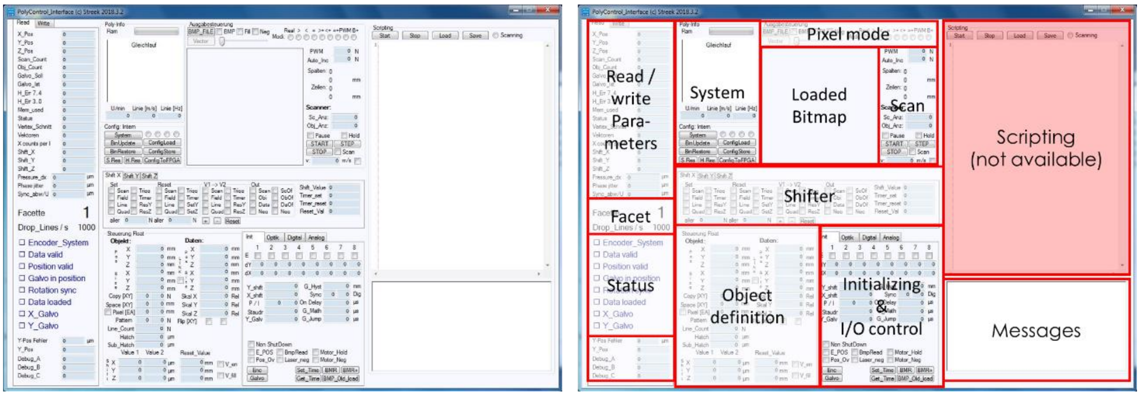
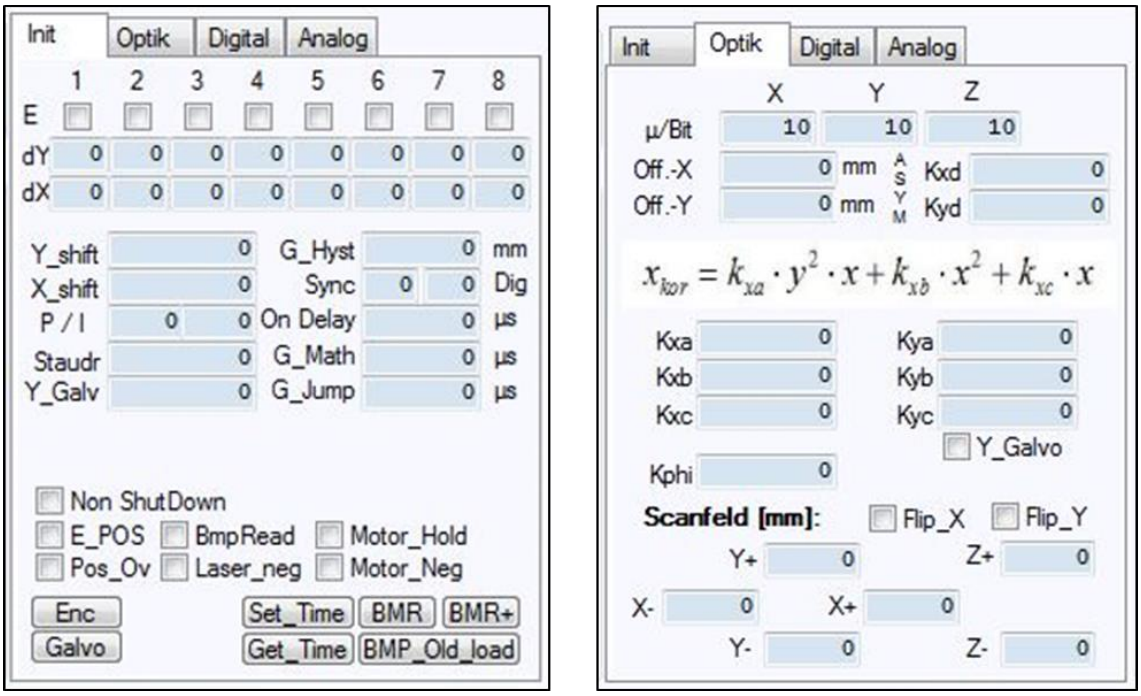


Figure 16: PolyControl interface and the location of the panels.

The configuration starts in the *Init* panel, shown in Figure 17 . Eight checkboxes (**E**) in the top of the *Init* panel enable the facets (1-8) for processing. Unchecked facets are skipped during the process, which is helpful for e.g. configuration. Below a table contains the facet correction values of each facet in fast and slow axis (**dY** and **dX**) as well as an angular correction **dP**. The values represent bitwise shift of the processing position ranging from -128 to 127. A single bit correlates to 1/16 of the µ/bit value in the *Optik* panel. How to get the values is described in the installation chapter of this manual in section 3.3.3 on page 39.

The **Y_shift** and **X_shift** moves the initial position of the laser beam. Here a hexadecimal value of eight digits (0-F) is used. The process is described in the installation chapter of this manual in section 3.3.2 on page 38.

The **G_Hyst** value contains the error of the galvo mirror in [mm]. A line is processed only, if the current galvo position is inside this range around the target position value. The checkbox galvo in position is enabled in the *status* panel.



	1	2	3	4	5	6	7	8
E	☐	☐	☐	☐	☐	☐	☐	☐
dY	0	0	0	0	0	0	0	0
dX	0	0	0	0	0	0	0	0

Y_shift 0
X_shift 0
P / I 0 0
Staudr 0
Y_Galv 0
G_Hyst 0 mm
Sync 0 0 Dig
On Delay 0 µs
G_Math 0 µs
G_Jump 0 µs

☐ Non ShutDown
☐ E_POS ☐ BmpRead ☐ Motor_Hold
☐ Pos_Ov ☐ Laser_neg ☐ Motor_Neg

	X	Y	Z
µ/Bit	10	10	10

Off.-X 0 mm
Off.-Y 0 mm
ASYM Kxd 0
Kyd 0

$$x_{kor} = k_{xa} \cdot y^2 \cdot x + k_{xb} \cdot x^2 + k_{xc} \cdot x$$

Kxa 0
Kxb 0
Kxc 0
Kya 0
Kyb 0
Kyc 0
☐ Y_Galvo
Kphi 0

Scanfeld [mm]: ☐ Flip_X ☐ Flip_Y
Y+ 0
Z+ 0
X- 0
X+ 0
Y- 0
Z- 0

Figure 17: "Init" and "Optik" panel of PolyControl Interface

The **Sync** has two values, which describe the tolerance of rotation speed fluctuations. The left one, indicates the tolerance of rotation speed fluctuations in short time, while the right one is long term value. If a steady rotation speed is achieved, the rotation sync checkbox is enabled on the *status* panel.

G_Math and **G_Jump** contains controller values of the galvanometer controller.

At the bottom a couple of checkboxes are visible. Most of them are used for debugging and will not be used during processing. **Laser_neg** will invert the laser signals and **Motor_neg** inverts the polygon rotation direction. The last button should be used only if the wheel is turned off to avoid motor damage.

The *Optik* panel contains the configurations changing with the objective. The **µ/bit** correlates the internally digital positions of the controlling unit to externally lengths [µm]. These values have to be evaluated in an experiment. How to get the values is described in the installation chapter of this manual in section 3.3.2 on page 38. The following values are used to correct the scan field distortions and will be performed due to a galvo movement along a line scan. The x-position can be corrected with the given function. The parameters have to be evaluated from the user. Similar corrections can be performed with the Y-galvo (optional) (**Kya, Kyb, Kyc**) if the checkbox is enabled. **Kphi** corrects the angular orientation of the scan field.

The **scan field** has to be limited to real achievable values in X and Y directions and for 3D processing also in Z.

The **Flip_X** and **Flip_Y** inverts the sign along the axis.

2.4 Inputs output control

The scanner has three digital and two analog high-speed outputs and one input. The input is at the moment not available in this software.

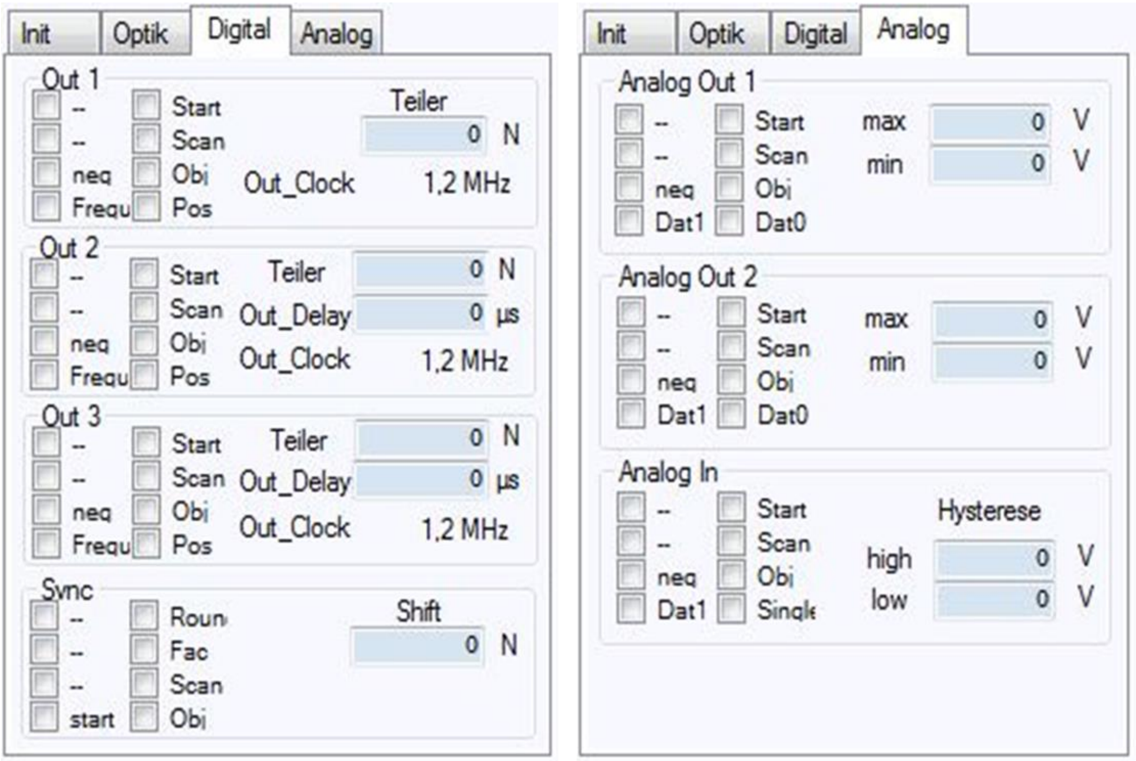

Init
Optik
Digital
Analog
Out 1
☐ --
☐ --
☐ neq
☐ Frequ
☐ Start
☐ Scan
☐ Obi
☐ Pos
Teiler
0 N
Out_Clock
1,2 MHz
Out 2
Teiler
0 N
Out_Delay
0 µs
Out_Clock
1,2 MHz
Out 3
Teiler
0 N
Out_Delay
0 µs
Out_Clock
1,2 MHz
Sync
☐ start
☐ Roun
☐ Fac
☐ Scan
☐ Obi
Shift
0 N
Analog Out 1
☐ Dat1
☐ Dat0
max 0 V
min 0 V
Analog Out 2
max 0 V
min 0 V
Analog In
☐ Single
Hysterese
high 0 V
low 0 V

Figure 18: "Digital" and "Analog" output control panel

In the digital panel three digital outputs can be configured in the same way. Each of them can give a TTL signal multiplexed from six different sources signals. These sources are enabled as output by enabling the checkbox. Typically, only one signal is sent out of one output. If more than one source is enabled, the out is HIGH if all sources are HIGH. A short description of the sources is given in TABLE XXX

Source signal	Digital	Analog	Description
Neg	•	•	Switches HIGH and LOW at the output
Freq	•		Signal switching with a frequency of Out_Clock
Start	•	•	HIGH during the scan process is running
Scan	•	•	HIGH during the current position is within the scan field
Obj	•	•	HIGH during the current position is within the object
Pos	•		Position dependent signal switching with a frequency of Out_Clock
Dat0		•	DA-converter of the bitmap using the most significant bits (16-32)
Dat1		•	DA-converter of the bitmap using the least significant bits (0-15)

If the current position is inside the defined object, **Obj** is HIGH. If the object is coupled to a bitmap, the signal is HIGH if the bitmap conditions are true. More about bitmap conditions in section 2.5.

Freq is giving a fix frequency of 200 MHz divided by the **Teiler** (hexadecimal value), while **Pos** is giving a frequency depending on scan speed (distance of positions / scan speed), respecting speed fluctuations. For out 2 and 3, an additional signal delay (**Out_delay**) can be adjusted.

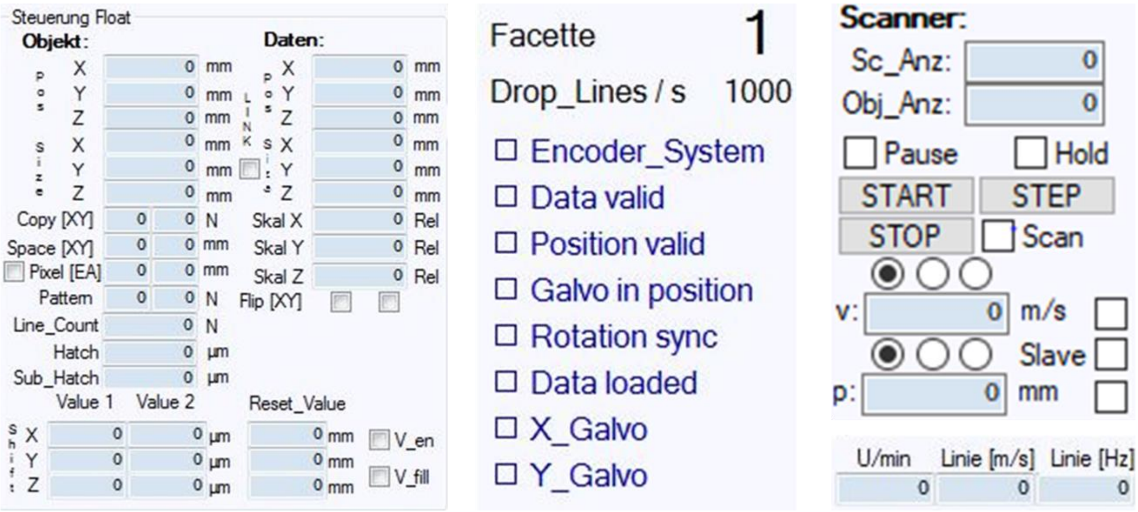
The analog outputs have four signals in common. Here, the high value is substituted with the maximum voltage and the low value with the minimum voltage. Instead of the frequency signals **Dat0** and **Dat1** are available, where a 32-bit value of the bitmap data is transferred to an analog signal between the min. and max. voltage. Dat0 is using the most significant bits (16-32) of the 32-bit data and Dat1 is using the least significant bits (0-15).

In the *Digital* panel, there is the sync area. Here, a couple of events can be used to reset the output signal. That can be useful for the position depending frequency signals. The possible events are **start** resetting with the beginning of the process, **Round** resetting once per full turn of the mirror wheel, **Fac** resetting with the beginning of each facet, **Scan** resetting with the beginning of the scan field and **Obj** resetting with the beginning of the object. Also, a combination is possible.

2.5 Processing

2.5.1 Line mode

The line mode enables the scanning of a line or an arrangement of lines. It is the easiest way to utilize the scanner. First of all, the object must be defined. Therefore, the *Object* panel is used.



Pos X 0 mm
Pos Y 0 mm
Pos Z 0 mm
Size X 0 mm
Size Y 0 mm
Size Z 0 mm
Copy [XY] 0 0 N
Space [XY] 0 0 mm
☐ Pixel [EA] 0 0 mm
Pattern 0 0 N
Line_Count 0 N
Hatch 0 µm
Sub_Hatch 0 µm
Shift X 0 0 µm 0 mm
Shift Y 0 0 µm 0 mm
Shift Z 0 0 µm 0 mm
☐ V_en
☐ V_fill
☐ LINK
Daten: Pos X 0 mm
Pos Y 0 mm
Pos Z 0 mm
Size X 0 mm
Size Y 0 mm
Size Z 0 mm
Skal X 0 Rel
Skal Y 0 Rel
Skal Z 0 Rel
Flip [XY] ☐ ☐

Facette 1
Drop_Lines / s 1000
☐ Encoder_System
☐ Data valid
☐ Position valid
☐ Galvo in position
☐ Rotation sync
☐ Data loaded
☐ X_Galvo
☐ Y_Galvo

Sc_Anz: 0
Obj_Anz: 0
☐ Pause
☐ Hold
☐ Scan
● ○ ○
v: 0 m/s ☐
● ○ ○
Slave ☐
p: 0 mm ☐
U/min 0
Linie [m/s] 0
Linie [Hz] 0

Figure 19: Object panel for defining the processing area, Status panel and Scanner panel with speed control and process start and stop conditions.

The object represents the area to be treated with the laser and is defined by a starting point **start_X** and **start_Y** and its dimensions **size_X** and **size_Y** (towards positive axis directions) in the coordinate system of the scanner in [mm]. An illustration of the parameters is presented in Figure 4 on page 8. It is possible to use negative values. If size_X is 0, only a single line defined. If the size_X is > 0, a hatch distance has to be defined.

The **hatch** is the spacing of scanned lines in x direction. A hatch of 0 results in a single line process. After each scanned line, the hatch is added to the x position until it is leaving the defined object size_X. Then the process will start again at the start_X position. Furthermore, a **sub_hatch** can be defined, which is added as offset in x with each restart of the object. The object is finished if the sub_hatch offset becomes equal or larger than the hatch.

The **line_Count** defines the number of repetitions of a line before moving to the next line. A zero value is used to process a line once.

It is possible to process multiple objects. At the same time. The **copy [XY]** function defines the copies along the X and Y axis. A zero value means no copies. If both values are > 0, an array of copy [X] x copy[Y] is generated. The **Space [XY]** defines the distance between the end of an object to the beginning of the next object. The total treated area is *copy* times larger than the size_X and size_Y value.

After the object definition, the scan speed and number of repetitions has to be set in the *Scanner* panel. The Scanner can run infinity processes if the following counts are set to 0 or ends if a limit is reached. **Sc_Anz** is a limit for number of scan fields. The scan count is increased every time the x positions is reaching its maximum and is reset to the start. Processing with sub_hatch requires a well-defined number of Sc_Anz to avoid early finishing. **Obj_Anz** considers the whole object definition and the is increase after the object is treated completely. In this case the sub_hatch is respected.

Behind the **v:** the scan speed can be set. Three options are available: speed [m/s], rotations speed in in revolutions per minute [RPM], or line frequency [Hz]. The checkbox behind enables the motor. The current speed is visible in the *Poly-Info* panel above the *Object* panel. Also, the current facet is shown as well as the number of processed and skipped facets. Working with pulsed laser systems will lead to a pulse to pulse separation following equation (3) as the ratio of scan speed to pulse repetition rate.

If the rotation speed is reached and constant, the *Rotation_sync* is enabled in the *Status* panel. There is also visible, if the necessary devices are working correctly and if the data are correct.

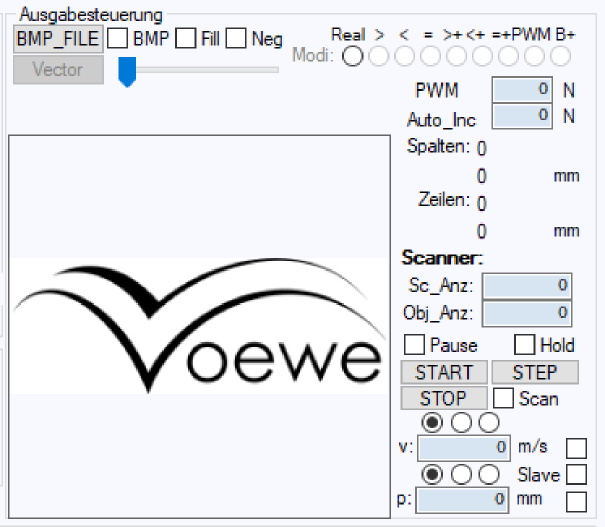
The scan process is started by clicking the **start** button above the scan speed selection. It is stoppable with the **stop** button or finishes by reaching a limit defined before. Make sure, that the **laser outputs** are set, otherwise the process runs without laser. Use the Obj output for treating full lines within the object definition respecting the resulting pulse to pulse distance. Working with pulse synchronization requires additional Freq or Pos signals, described under 2.7 on page 27.

The **pause** checkbox interrupts the scan process after finishing the current line until the box is disabled. Then the process continues. During a break, the **hold** checkbox activates a line scan of the current line. The **step** button let the paused process skip to the next line.

2.5.2 Bitmap mode

The PM series is made to process bitmaps (*.bmp) of 1-bit, 8-bit, 16-bit,24-bit and 32-bit. Other formats are not supported. To process an image, it must be load to the scanner using the **BMP_FILE** button in the *Ausgabesteuerung*. A windows dialog opens, where a bitmap can be selected from the explorer. After pressing the open button in this dialog, the image is loaded in the scanner. After loading the image, it is shown in the software. Additionally, a message confirms the reception of the image in the massage window including the number of bits per pixel.

In the *Object* panel, values occur in the data column with, which is structured similar to the object definition (declared in 2.5.1). These values show the size and position of the image. The **Skal** represents the relative scaling factor in X Y Z dimension. Changing the absolute **Size** or the relative Skal refreshes always both values. The **Flip [XY]** mirrors the image. The **LINK** checkbox between object and data column couples the size of the data to the size of the object by overwriting the object start and size with the data values. During the linked state, changes of any value in one column changes also the value in the other column. If the data are not linked to the object, only the part of the data inside the object definition are respected. If the data are smaller the residual object area is not treated.



PWM 0 N
Auto_Inc 0 N
Spalten: 0
0 mm
Zeilen: 0
0 mm
Sc_Anz: 0
Obj_Anz: 0
v: 0 m/s
p: 0 mm

Figure 20: Bitmap panel with loaded bitmap and bit-comparator options.

After defining the object and data size, the modulation of the lines following the bitmap data must be activated using the **BMP** checkbox next to the BMP_FILE button. If the BMP checkbox is disabled, the scanner processes a line mode and does not respect the image. If the **bitmap mode is enabled**, the object output signal is HIGH if the current position is inside the object and the bitmap condition is TRUE.

Depending on the depth of the bitmap, different comparations are possible to set a TRUE bitmap comparation. For **1-bit** images, the **Real** mode is used, setting the pixel value TRUE if it is white. This option is useful for marking and similar processes.

For images with **8, 16, 24 or 32 bit,** more options are available. The **Real** mode is used for the modulation of the analog outputs using the Dat0 and Dat1 signal. This option can be used with a laser power modulation to treat different areas with different laser powers.

The mathematical comparations **>,<,=** compare the pixel value with a fix value adjustable with the slider setting a TRUE if the comparison is true. Using the plus comparators **>+,<+ =+**, a scan is performed using the comparison of the pixel value to the given compare value, but the compare value is increased after each scan by the **Auto_Inc** value. These options are useful for engraving since the number of repetitions in a certain area can be coded in the image grey scale resulting in a variable depth.

The **PWM** mode generates a pulse width modulation, which is useful for digital outputs together with grey scale images.

The **B+** encodes a multibit image layer by layer setting a TRUE if the current bit is 1 increasing the current compare bit with every scan. Using this option, up to 32 layers can be encoded including up to 32 different 1-bit images. This option enables moved images with color lasers for visual purposes.

2.5.3 Engraving

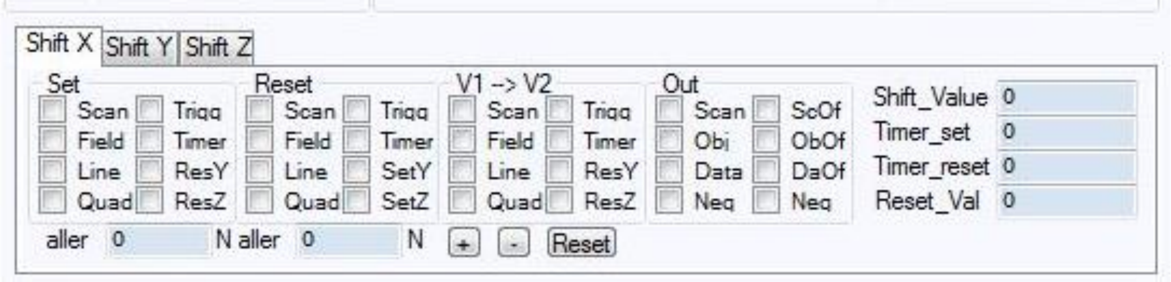
The engraving mode is a 2.5D processing mode, where a greyscale image (up to 32 bit) is used to irradiate the surface in multiple steps. This can be done with variable laser intensity within a scan using the analog outputs or with a variation of the treated areas per step / depth (Z-direction) using the digital outputs.

The image is loaded as same as described in the bitmap mode. Working with variable intensity requires a laser that supports the power modulation. Then the object is defined similar to the 2D bitmap case. The analog output has to be set to **Dat0** for 8-bit images. The **Obj_Anz** defines the number of repetitions of this image, while the image greyscale controls the position depending laser power.

Using the digital outputs, the **comparator plus** option can be used. In an 8-bit image up to 255 layers can be included, where the layer count is increased after each scan following the **Auto_Inc** value. Thus, areas with low ablation are treated only once with a 1/255 layer and the deepest ablation is obtained from 255 / 255 layers ablation. Each layer itself is then just digital (ON/OFF).

2.6 Shifter

The shifter function varies a value of Out about a set shifter value after a trigger event from set happens. This function can be used to move the treated area over the substrate or follow a moving substrate with the laser process.



aller 0 N aller 0 N

Shift_Value 0
Timer_set 0
Timer_reset 0
Reset_Val 0

Figure 21: Shifter panel in X axis with the sub fields Set, Reset, V1→V2 and Out and the current shifter values.

The shifter function is available for three Axis XYZ, each configuration panels are built similarly. On the left side, the trigger event is selected. Below the N value defines the how much of the trigger events must happen until the shift is done. The following table declares the trigger events for the X shifter. The events in Y and Z are similarly.

Trigger event	Set	Reset	Description
Scan	•	•	Shifter activated with the start of the scan process (single event)
Field	•		Shifting / resetting after N scan fields (reset x to start value)
Line	•	•	Shifting / resetting after N lines
Quad	•	•	Shifting / resetting after N signals from the axis quadrature encoder
Trigg	•	•	Shifting / resetting after N signals from an external trigger event (GPIO)
Timer	•	•	Shifting / resetting after N durations of timer_set /timer_reset values
ResY	•		Shifting X after resetting of Y shifter
ResZ	•		Shifting X after resetting of Z shifter
SetY		•	Resetting X after shifter event in Y shifter
SetZ		•	Resetting X after shifter event in Z shifter

The Reset panel has similar trigger events, which defines when the shifted value is reset to its start value or to the defined reset value. Here, also a N counter can be set. For a proper work the reset counter must be larger than the set counter. **In both panels, N respects the 0 as the first counted event.** The cross correlation of the shifters is possible with the Set / Reset X Y Z events. After choosing the trigger event and the event counter, the value to be shifted must be selected. The possible values are presented in the next table. A shifting in X or Y or Z direction must be defined separately. Thereby, the selected output is shifted by the shift value, which has to be defined in the *Objekt* panel for each direction. It is also possible to set a second shift value, that can be activated in the **V1->V2**. If a trigger event is selected in this panel, the second shift value is used for this trigger. For unselected trigger events, the first shifting value is used. In the case of a reset, the current position is set to the Start XYZ + Reset XYZ.

Out	Description
Scan	Shifter activated with the start of the scan process (single event)
Obj	Shifts the object start position in the corresponding axis
Data	Shifts the data start position in the corresponding axis
Neg	Negates the shift value
ScOf	Applies an offset to the Scan
ObOfr	Applies an offset to the object
DaOf	Applies an offset to the data
Neg	Shift value is negated

Now some examples of shifting are shown in Figure 22, including macroscopic shifting, shifting for micro texturing and shifting to follow a moving substrate. Firstly, a shift of the object in a diagonal direction is performed on a stationary workpiece, visible in Figure 22a. Producing simple copies of the object in an array or along the X or Y axis can be achieved easier using the copy function. A movement in diagonal direction or coupled to a certain trigger signal is not possible with the copy function.

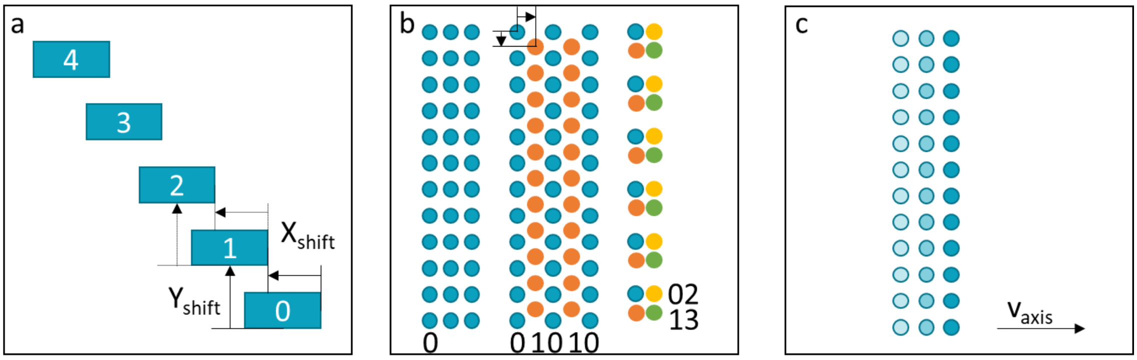


Figure 22: (a) macroscopic shifting, (b) micro shifting and (c) shifting following a moving substrate.

Therefore, the Field trigger is selected in Set of the X-shifter. The set N is selected to 0 (shift after each field). As out, the obj is selected shifting the object in x direction. The shift value can be set in the object definition panel as well as the reset value. Now, after each field the object is shifted in X about a given shift value. To shift it diagonally, the Y-shifter must be used too. Here the set and out values are selected similarly to field and obj. The y shift value is also defined in the object panel. After configuring both shifters the scan process can be started. To process only 5 fields the scan count must be set to 5. Otherwise it is possible to repeat the process.

Then, the reset value in X and Y is also coupled to field and the counter is set to 4 (5 times of the set value, respecting 0 as first count).

In Figure 22b, shifting for micro texturing is presented in two different ways. This type of shifting is only possible in pulse synchronous processing. The left side (blue only) shows pulse synchronous treatments without shifting. The laser spots are arranged rectangularly with a certain distance in fast axis (scan speed / pulse frequency) and the selected hatch between the lines. To obtain hexagonally arranged spots, the shifter must be used. In this case the hatch distance is doubled, so that every second line is processed first. Keep attention, that the line spacing in hexagonally arranged patterns is smaller than in rectangular ones. After processing all blue spots, the shifter is used with the **Field** trigger respecting the number of repetitions in N. The shifter must be activated in **X and Y direction**, while X the X shift value is a line spacing and the Y shift value is half of the pulse separation distance coupled to the Out **Obj**. As reset also the field can be used with N twice the set N. Thus, after the shift the missing orange spots are processed. After finishing the shifter is reset and starts again or the process is finished using the **Obj_Anz** or **Sc_Anz** counters.

The second type of micro shifting leads to an arrangement of 2x2 spots in a group, repeated over the whole object. Here the separation distance of the groups is the separation distance of the set spots. First of all, the blue spots are processed with the distance in fast axis depending on scan speed and pulse frequency and in slow axis defined by the hatch distance. The distance between the spots within a group is controlled with the shifter. The Y-shifter is set to Field again with N(set) respecting the number of pulses per position. As Out the **Obj** is selected and the shift value Y is set to the spacing of spots within a group along the fast axis. Consequently, the orange spots are processed after the first shift event. The X-shifter is set with an N twice the Y-shifter. Thus, the X shifting event is activated after processing the orange spots. At the same time the Y-shifter needs to be reset. This can be done using the Field reset in Y-shifter with an N twice the set (equals the set N of X-shifter). Alternatively, the Y shifter can be reset with the **SetX** trigger, that resets Y always, when X-shifter is activated. The yellow spots will be treated next, then again, the Y shifter is activated by the field count and the green spots will be processed.

The number of elements in such a group (a x b) can be determined ratio of N(set) in the first shifting direction (Y in this example) and the (a x N_Y) as N_X(set) in the second direction (here X). The reset value of Y must be the same or using the SetX as reset function. The number of Elements in the second direction is controlled with the Obj_Anz or Sc_Anz respecting the (a x b x pulses per position).

The third case is the laser treatment of moving substrates, as shown in Figure 22c. The lateral movement of the substrate must be detected with an incremental encoder with A, B and index signal feed into the scanner using the Axis IO port. The displacement length per encoder step must be set as shift value. This information can be provided from the axis manufacturer. The Set event is selected to **Quad.** The object is in this case larger than the scan field and moves with the axis through the scan field. And the scanner knows during the process which line has already been treated. Up to three axes XYZ can be followed in this way using the three shifter functions.

2.7 Pulse synchronization

Pulse synchronization means, that laser pulses of neighbored lines can be placed without displacement in fast axis direction. In Figure 23a, laser processing without pulse synchronization is shown. The target positions in fast axis direction are displayed with a black line, the real treated positions differ from this position without any system. This is a consequence of difference between the frequencies of the polygon mirror rotation and the pulse repetition rate. The first one defines, the scan position at a certain time, while the second frequency defines the time, when a pulse is emitted from the laser source. Still small deviations sum up to visible displacements after a couple of rotations.

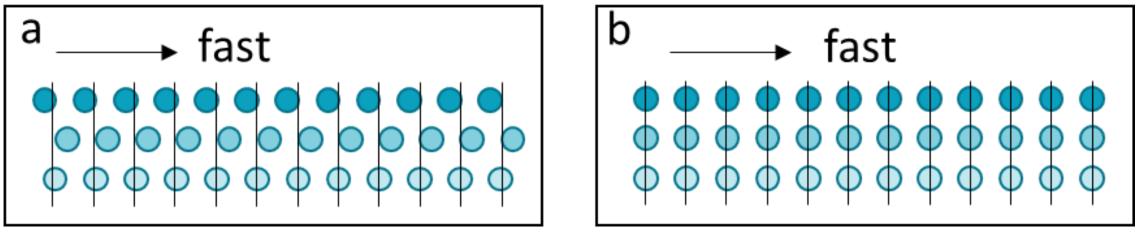
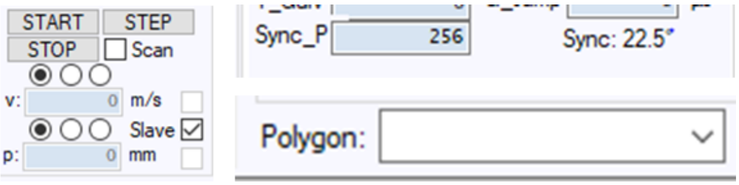


Figure 23: (a) line processing with a fix frequency laser resulting in constant pulse-to-pulse distance but displacements between the lines. (b) Pulse synchronized laser processing with position depending laser frequency resulting in well-arranged pulses in all lines.

Figure 23b shows well-arranged pulses achieved with pulse synchronization. Two ways of pulse synchronization are possible. The utilization of a laser with pulse on demand is the first option. The second option requires a laser with adjustable pulse frequency. That allows also pulse synchronization, but no single pulse treatment, only synchronized segments. In both cases, a digital output must be used with the **Pos** signal multiplexed with the **Obj** resulting in a position depending signal only inside the object. The intrinsic position signal frequency must be reduced to the target distance following equation (3). Therefor the **Teiler** value must be used with a hexadecimal number. The out frequency is the intrinsic frequency divided by Teiler and written a line below the Teiler field. Do not use the Freq signal, because it follows the clock of the scanner and do not recognize the scan speed. Furthermore, in the digital signal has to be synchronized *Sync* to **Fac** (below the 3 digital outputs) resetting the out signal with every facet, respectively every scanned line.

2.8 Scanner synchronization

Scanners that are connected at their sync-modules can work with synchronized rotation of the polygon wheels or independent from each other. It is recommended to activate the master's polygon wheel first choosing a scan speed and enable the motor checkbox. To activate the synchronization, select the slave device in the *Polygon* drop down menu in the lower left corner.



v: 0 m/s ☐
Slave ☑
p: 0 mm ☐
Sync_P 256
Sync: 22.5°

Figure 24: Activate the slave mode by enabling the slave checkbox of the selected polygon scanner. A offset between the synced devices is possible with Sync_P.

The activation of the **slave checkbox** below the motor enable checkbox will define de device as a slave. At the same time, the motor enable button will disabled, because the slave is following the master's rotation signal now. The slave scanner will start a polygon rotation right now, if the master device is still running in a *rotation sync* state. If the slave's polygon wheel has the same rotation speed achieved, the *Slave_sync* box on the left side is enabled. In the *Init* panel, the **Sync_P** value defines the offset between the facets of the polygon wheels. Values from 0 to 511 are possible, and correspond to angular offsets from 0° to 45°. A single step is (360/4096 degree). Following this, a value of 256 respectively 22.5° is optimal for two scanners, using one facet, when the synchronized scanner is in the facet exchange gap.

The residual configurations are done separately for both scanners and allow independent processing. It is also possible, to work with synchronized scanners on the same process. Nevertheless, the process start button has to be enabled for both scanners.

2.9 Communication to peripheral hardware

The communication to peripheral hardware offers very customized solutions. The scanner is equipped with up to two auxiliary IOs a axis IO and a GPIO. At the moment, the axis synchronized treatment is implemented using the encoder signals, as described in the shifter chapter. The GPIOs can also be used for customized solutions. The standard GPIO includes 8 digital inputs to trigger events in the scanner with external signals. The following table shows, how the 8 input pins are influencing the scanner control.

Input #	Description
0	Start the process if LOW → HIGH
1	Stop the process if LOW → HIGH
2	Trigger_in if LOW → HIGH
3	Motor enable if LOW → HIGH
4	Use Config 1 if LOW → HIGH
5	Use Config 2 if LOW → HIGH
6	Use Config 3 if LOW → HIGH
7	Use Config 4 if LOW → HIGH

3 Installation

3.1 Mechanical installation

Before starting check, if the laser beam is aligned to the entrance aperture (see p. 37).

The scanner contains sensible optics. Avoid any contact with hands and tools to the aperture window, the focusing optic or optics inside the housing. Handle with gloves.

The installation starts with the mechanical mounting of the polygon mirror scanner. The devise has a mass of 13 kg. It is recommended to mount the scanner with two persons. One is holding the scanner, while the second drive the screws. In Figure 25, the overall and connecting dimensions are shown.

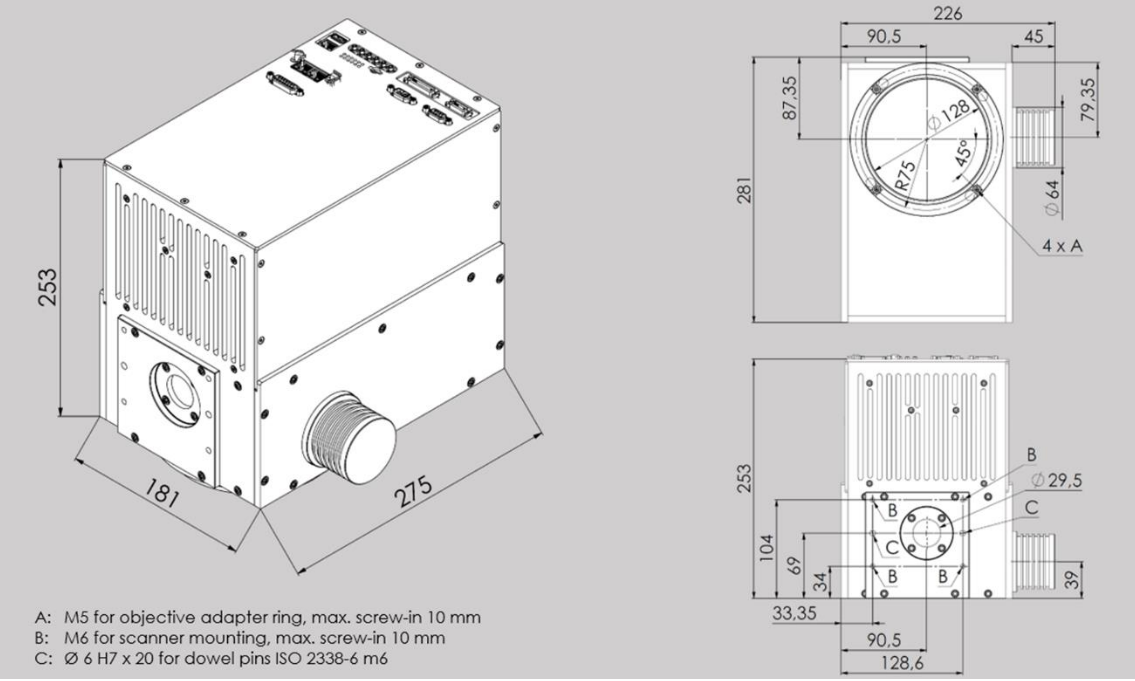

253
181
275
226
90,5
45
87,35
79,35
∅128
R75
45°
∅64
4 x A
281
253
B
∅29,5
C
B
C
B
B
104
69
34
39
33,35
90,5
128,6
A: M5 for objective adapter ring, max. screw-in 10 mm
B: M6 for scanner mounting, max. screw-in 10 mm
C: Ø 6 H7 x 20 for dowel pins ISO 2338-6 m6

Figure 25: Connection and overall dimensions of the scanner device. Mounting points are A, B and C

Firstly, put the **two dowel pins in the holes (C).** The length depends of the thickness of the mounting plate in your facility. Secondly, bring the scanner slowly in the right position and insert the dowel pins in the counterpart. The bottom side includes the beam exit with the diameter of 128 mm, the mounting plate includes the aperture for the beam entrance. Do **not touch the optics and the aperture glass**. Screw the four **M6 screws in the threads (B)**. The mounting plate of the scanner and the threads are made from steel. The length of the screws depends of the thickness of the mounting plate in your facility, too. The scanner is mounted, now.

At the bottom side, four **M5 screws (A)** with a length of 16 mm hold the standard brass ring. This is already installed before delivery. In any case you change the ring, **avoid screwing in more than 10 mm the base plate**. Each objective requires its own ring with the fitting thread for the objective. Unmount the ring to install the objective. Re-mount the ring with the objective inside.

3.2 Electrical installation

The electrical connectors of the scanner are located on the top side as shown in Figure 26. A detailed description of these connectors is given in the electrical specifications on page 43.

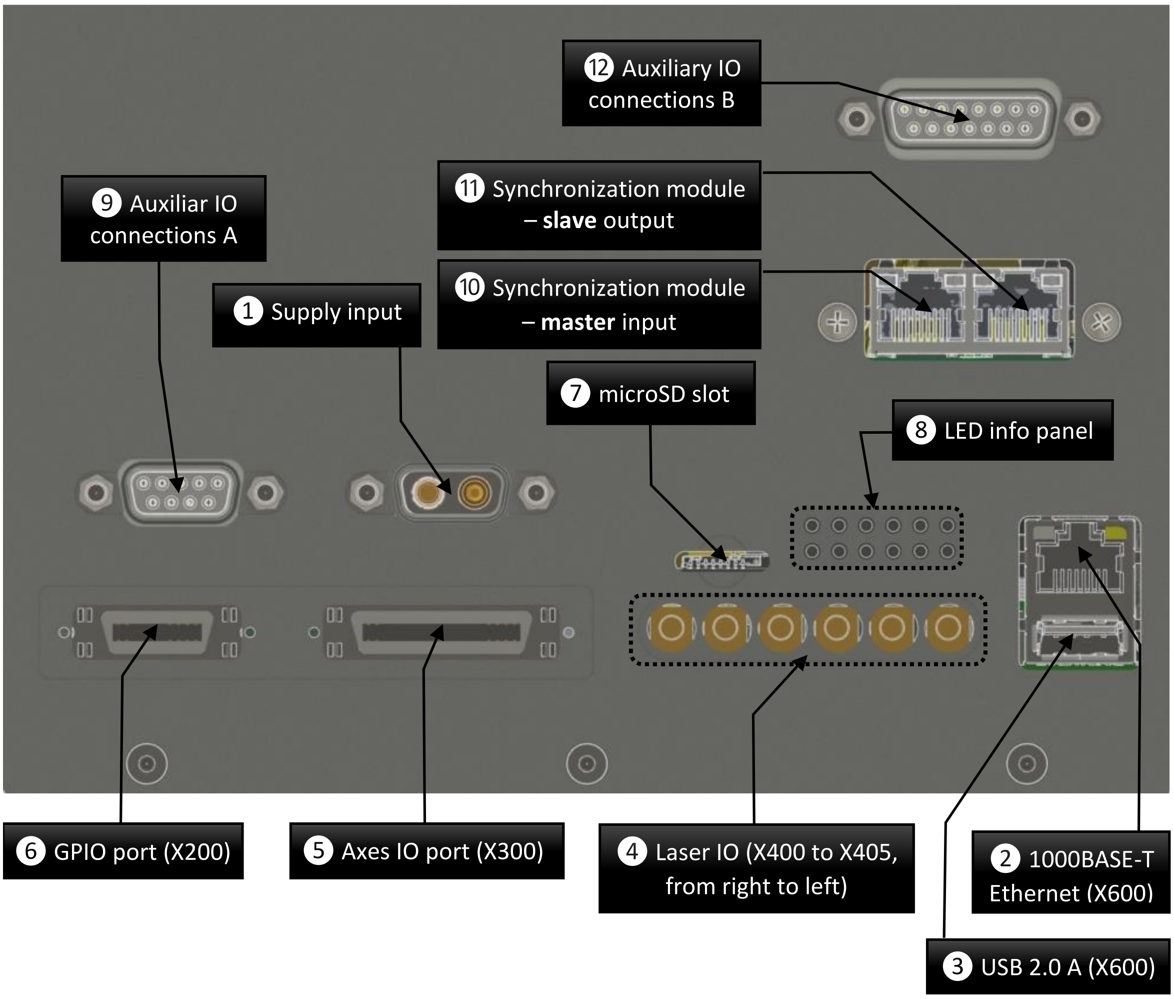

⑫ Auxiliary IO connections B
⑪ Synchronization module – **slave** output
⑨ Auxiliar IO connections A
⑩ Synchronization module – **master** input
① Supply input
⑦ microSD slot
⑧ LED info panel
⑥ GPIO port (X200)
⑤ Axes IO port (X300)
④ Laser IO (X400 to X405, from right to left)
② 1000BASE-T Ethernet (X600)
③ USB 2.0 A (X600)

Figure 26: Electrical connectors on the top side.

In the following, three standard applications are described with the corresponding electrical connections. The communication to the laser and laser related devices is described in detail in 3.2.2 afterwards.

3.2.1 Usual applications

Case A – Stand alone:

The first set up describes the stand alone use of the PM series polygon mirror scanner. An overview is shown in Figure 27.

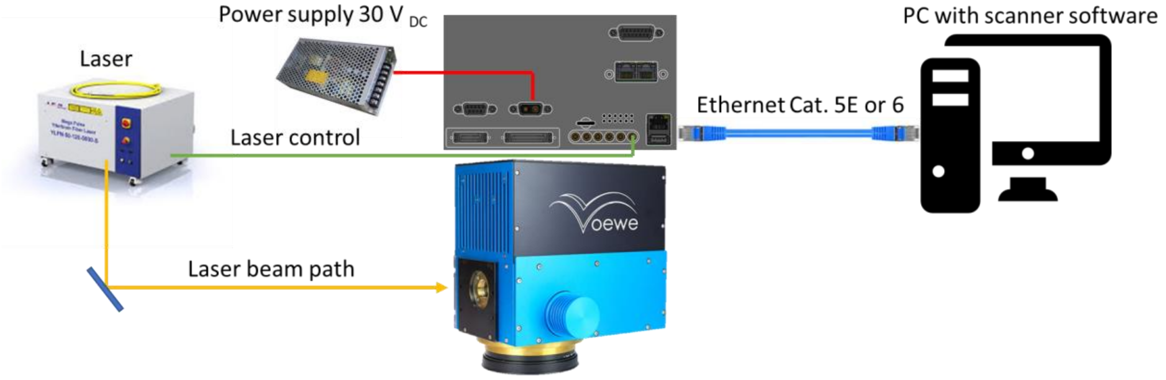


Figure 27: Stand-alone use of the polygon scanner.

This set up can be used for ultra-fast laser processing of flat materials, that are positioned manually or using an independent working handling system (not shown in the image). Nevertheless, the user has to ensure the correct position of the workpiece before starting the process.

1. The scanner is connected to a PC with an ethernet Cat. 5E or 6 cable **(connector No. 2)**. The PC is used to run the scanner software which requires Windows 7 or later.
2. The scanner communicates with the laser using the high speed I/O **(No. 4)** with shielded coaxial cables and SMB connectors at the scanner side. Different possible laser communication scenarios are described at section 3.2.2 at page 36.
3. The scanner requires a power supply with + 30 ± 2 V_{DC} with at least 15 A **(No. 1)**. Use a D-SUB socket (2W2C, female) with high current contacts. The positive V+ has to be applied to connector A1 and ground to A2. For more details look at the electrical specifications on page 43. The scanner device is turned on, if a voltage is applied.
4. Adjust the laser beam to the entrance aperture. A guide is provided at chapter 3.2.3 at page 37.

Danger! Avoid direct and scattered laser radiation of eye or skin.

5. Configure the processing parameters in the scanner software. A description of the software is given in chapter 2on page 17.

Case B – Scanner with external work piece handling system

This set up describes the use of the PM series polygon mirror scanner with an external handling system. Encoder signals of the handling system are used to calculate in real-time the position of the work piece in the scanning field and follow the moving substrate with the laser process. An overview of the used devices and their connections in the case of a single axis is shown in Figure 28.

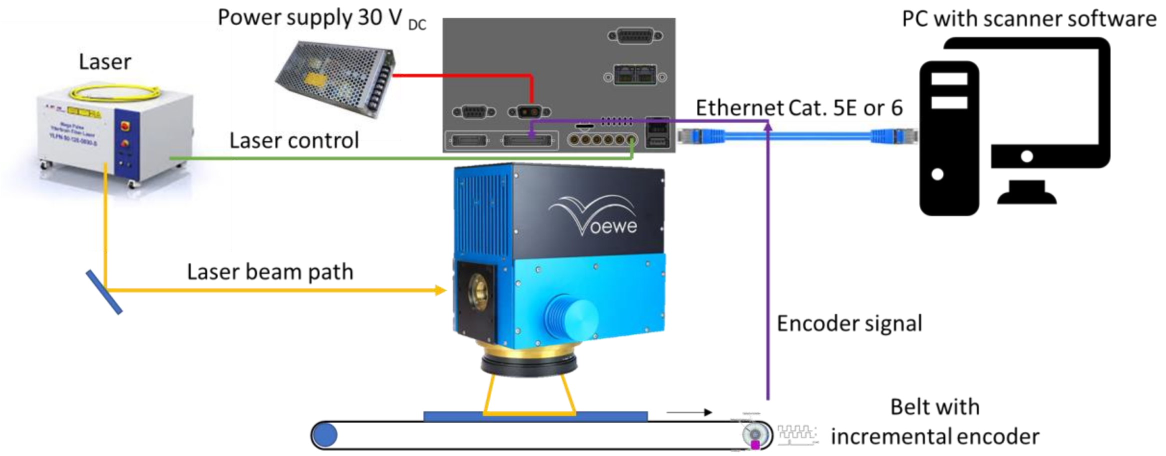


Figure 28: The polygon scanner is working on a moving substrate calculating the current processing line in real time from the incremental encoder signals of the axis system or transportation belt.

The connection to the power supply, laser, and PC is done analogously to case A. Additionally, the incremental encoder signal of the axis, belt, roll-to-roll machine or similar is feed into the polygon scanner using the inverted and noninverted signals of the A and B phase as well as the index signal (6 signals in total). The current position to be processed on the moving work piece is calculated in real time within the scanner device and the laser is switched on and off accordingly. The steering of the axis is done by a separate software and controlling hardware.

1. Connect the PC, power supply and laser as in the case A Step 1 to 3
2. Connect the encoder signals to the Axis I/O **(No. 5)**. The connector assignment is described in the electrical specifications on page 43.
3. Adjust the laser beam to the entrance aperture. A guide is provided at chapter 3.2.3 at page 37.

Danger! Avoid direct and scattered laser radiation of eye or skin.

4. Configure the processing parameters in the scanner software. The correct interpretation of the encoder signal requires the use of the shifter function with the value of traveling distance per encoder step. A description of the software is given in chapter 2on page 17.

Case B2 - Scanner with up to three axes:

This set up describes the use of the PM series polygon mirror scanner with an external handling system. Encoder signals of the handling system are used to calculate in real-time the position of the work piece in the scanning field and follow the moving substrate with the laser process. An overview of the used devices and their connections in the case of xyz- axes is shown in Figure 29.

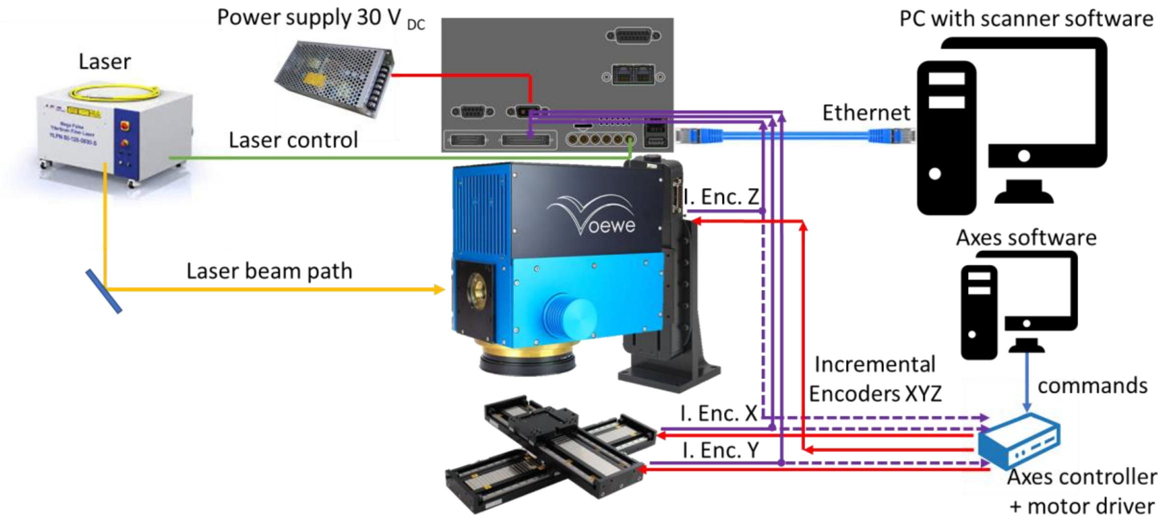


Figure 29: The polygon scanner is working on a substrate with up to three axes handling e.g. XYZ-moving.

The connection to the power supply, laser, and PC is done analogously to case A. Additionally, up to three incremental encoder signals of the axis or similar are feed into the polygon scanner using the inverted and noninverted signals of the A and B phase as well as the index signal of each axis (18 signals in total). The current position to be processed on the moving work piece is calculated in real time within the scanner device and the laser is switched on and off accordingly. The steering of the axes is done by a separate software and controlling hardware.

1. Connect the PC, power supply and laser as in the case A Step 1 to 3
2. Connect the encoder signals to the Axis I/O **(No. 5)**. The connector assignment is described in the electrical specifications on page 43.
3. Adjust the laser beam to the entrance aperture. A guide is provided at chapter 3.2.3 at page 37.

Danger! Avoid direct and scattered laser radiation of eye or skin.

4. Configure the processing parameters in the scanner software. The correct interpretation of the encoder signal requires the use of the shifter function for each axis e.g. x-, y- and z-shifter with the value of traveling distance per encoder step for each direction. A description of the software is given in chapter 2 on page 17.
5. The movement of the material has to controlled externally, using the software and hardware recommended by the manufacturer/provider of the handling system.

Case B2' – Scanner is moving

This set up can be used for large work pieces, which are not movable. The scanner is moved instead. Figure 30 displays the operation principle.

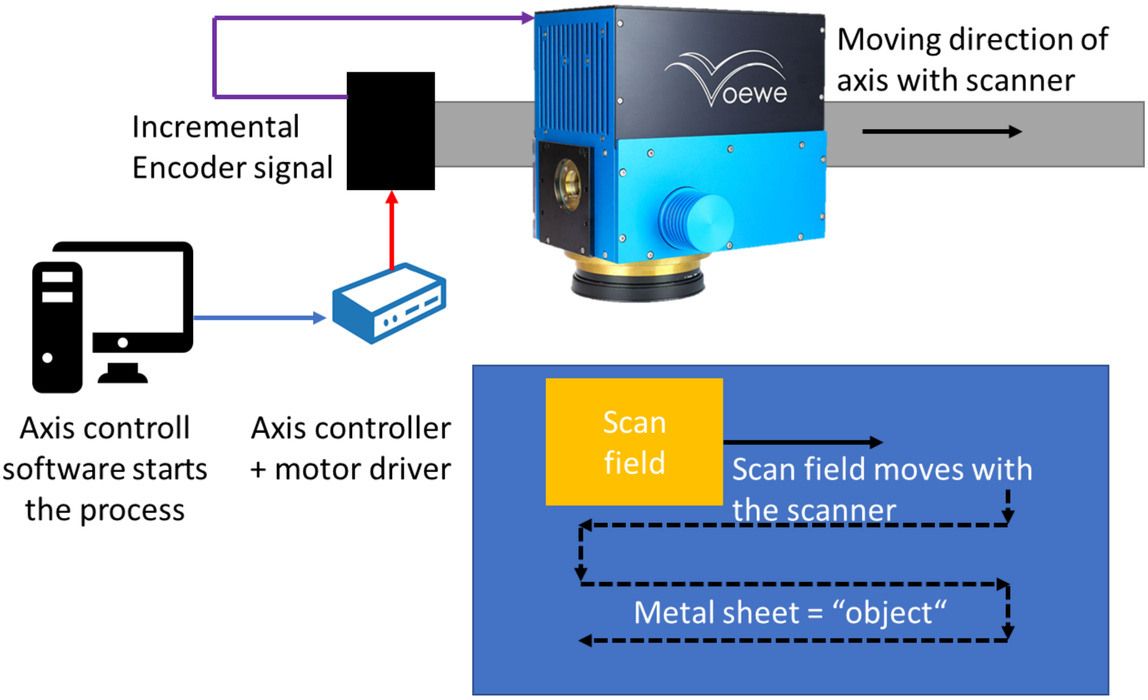

Moving direction of axis with scanner
Incremental Encoder signal
oewe
Axis controll software starts the process
Axis controller + motor driver
Scan field
Scan field moves with the scanner
Metal sheet = "object"

Figure 30: The scanner is mounted on the axes and moves over the object.

The axes are controlled by a PC with a controlling software and an axis controller hardware provided or recommended by the manufacturer of these axes system. The scanner is connected similar to the previous case B2 to the power supply, PC with scanner software and laser. Furthermore, the incremental encoder signals of the axes are feed into the scanner. From these signals the scanner calculates the position of the scan field on the work piece, the object.

Due to the high rotation speeds of the polygon mirror wheel inside the scanner, it is important to accelerate and decelerate the scanner slightly.

It is recommended to move the scanner with a continuous speed instead of a step-by-step processing. The real-time calculation will follow this movement with the laser.

The processing parameters can be configured in the software, as described in chapter 2on page 17.

Case C – the scanner follows axes and can control the axes movement

FUTURE OPTION, CURRENTLY NOT IMPLEMENTED

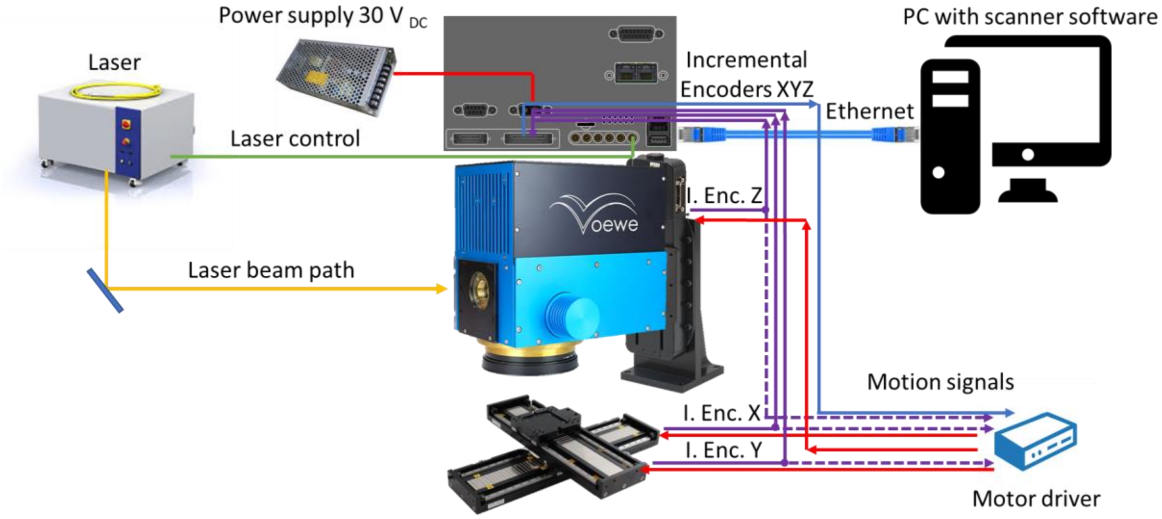

Power supply 30 V DC
Laser
Incremental Encoders XYZ
PC with scanner software
Ethernet
Laser control
I. Enc. Z
Laser beam path
Motion signals
I. Enc. X
I. Enc. Y
Motor driver

Figure 31: Additional to case B, the set-up is extended with the communication from the scanner to the motor driver and allows the steering of the axes.

3.2.2 Communication to the laser

The high speed I/O **(No. 4)** is recommended for communication between the laser and scanner using shielded coaxial cables. These are realized as six SMB connectors offering three digital outputs X400 – X402 (5 V TTL @ 100 MHz) two analog outputs X404 and X405 (configurable 0-2 V or 0-10 V @ > 1 MHz) and an input with configurable trigger X403. The details are described in the electrical specifications on page 43. For a proper transmission of signals with longer cable lengths (pulses and analog signals), double-shielded low-loss coaxial cables, e.g. CLF-100 or MULTIFLEX 86, should be used. For short cables, RG174 is also sufficient.

Attention!

Communication to the laser can enable laser emission.

Danger! Avoid direct and scattered laser radiation of eye or skin.

Depending on the available controlling options of the used laser system, variable laser communication scenarios are possible. The most relevant cases are presented below in Figure 32 to Figure.

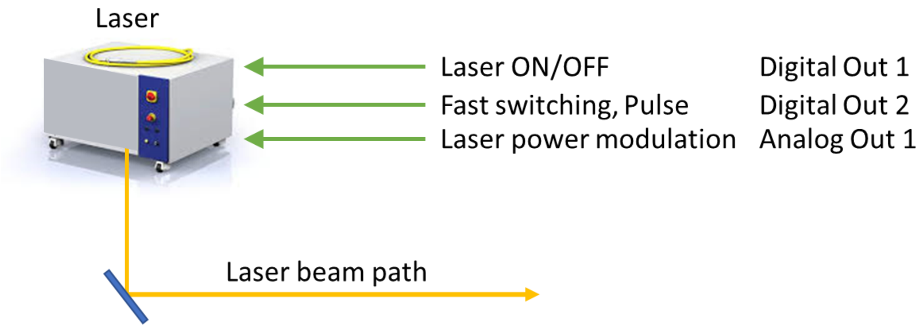

Laser
Laser ON/OFF
Digital Out 1
Fast switching, Pulse
Digital Out 2
Laser power modulation
Analog Out 1
Laser beam path

Figure 32: High speed communication used for fast laser switching and power modulation.

If required, the laser enable signal can be set using a digital output. The process relevant switching of the laser can be realized using a digital output, that can be configured in the software. If the laser allows fast switching, the digital switching signal is going directly into the laser controlling unit. A power modulation can be realized using an analog output, see also Figure 32.

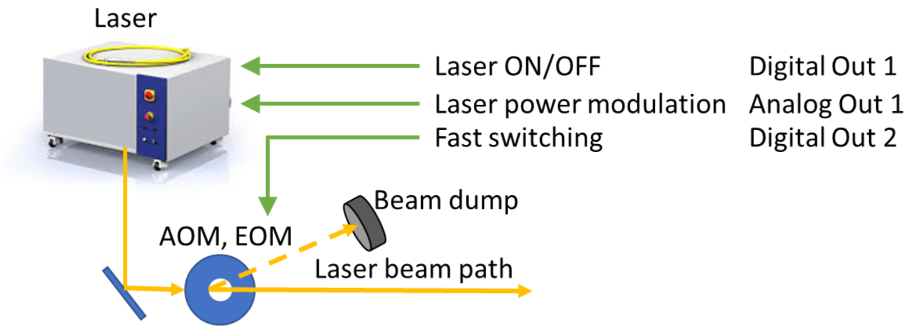

Laser
Laser ON/OFF
Digital Out 1
Laser power modulation
Analog Out 1
Fast switching
Digital Out 2
Beam dump
AOM, EOM
Laser beam path

Figure 33: Fast laser switching is realized with an external modulator controlled by the laser high speed I/O.

If the fast laser switching is realized outside the laser device e.g. with an acousto- or electro-optical modulator (AOM or EOM), the switching signal is sent to this device using the digital output as shown in Figure 33. Further signals such as laser enable or power modulation can be sent additionally to the laser, using the other outputs.

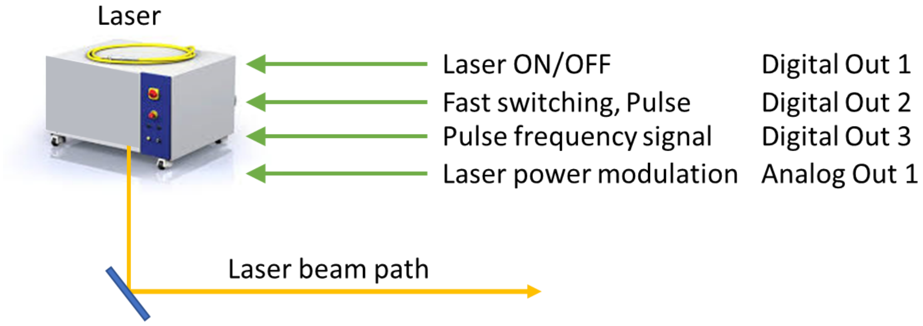

Laser
Laser ON/OFF
Digital Out 1
Fast switching, Pulse
Digital Out 2
Pulse frequency signal
Digital Out 3
Laser power modulation
Analog Out 1
Laser beam path

Figure 34: Fast laser switching and pulse synchronization realized with the high speed I/O of the scanner.

Position synchronized laser processing requires a synchronization of the laser pulse repetition rate (PRR) and the position frequency, which correlates to the rotation speed polygon mirror wheel. To realize this kind of processing, the scanner generates a position synchronized frequency signal, that the laser PRR has to follow. This signal is transferred using digital output as visible in Figure 34. Additionally, the switching signal and power modulation can be transferred.

3.2.3 Scanner synchronization

Scanner synchronization works in a master slave principle with multiple levels. Starting with two scanners, an ethernet cable connects the sync-modules (No. 11) of both scanners. Each sync-module has two plugs. The right one (as in Figure 26) is for out (master) and the left one is in (slave). Connect masters' out to slave's in as shown in Figure 35. The slave will be able to follow the master's polygon wheel rotation, if configured in the software, see also section 2.8 on page 27. A further scanner can now be connected from the 1st slave's out to 2nd slave's in to follow the rotation of the 1st slave. Thus, a chain of many scanners is possible.

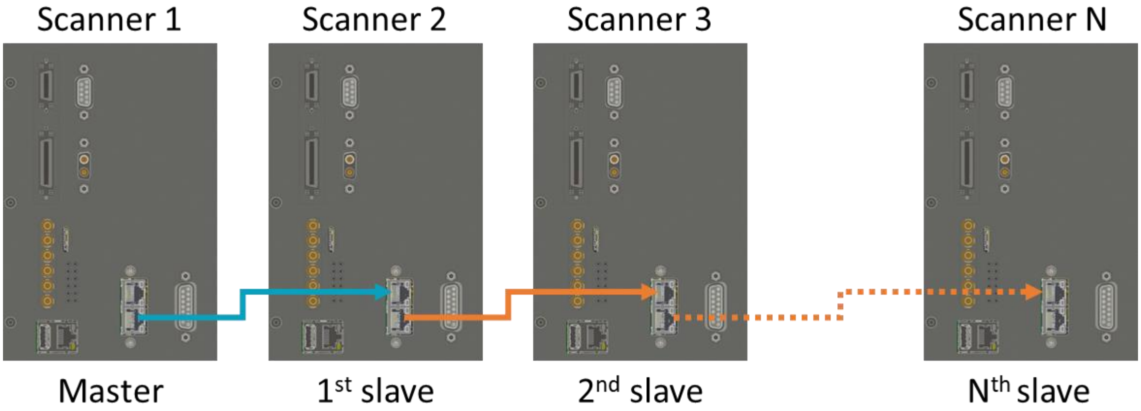

Scanner 1
Scanner 2
Scanner 3
Scanner N
Master
1st slave
2nd slave
Nth slave

Figure 35: Connection of a master to a slave device using the right plug as master's out and the left plug as slave's in (blue connection). More than two devices can be linked in a multi-level hierarchy using slave's out for the synchronization of a further scanner "2nd slave".

3.3 Optical Integration

3.3.1 Laser beam alignment

Firstly, the laser beam has to be aligned to the entrance aperture. That has to be done before mounting the scanner and requires, that the machine-side mounting plate is already implemented. It is useful, to have a circular aperture of the same size as in the scanner device in this mounting plate.

Danger! Avoid direct and scattered laser radiation of eye or skin.

The laser beam has to entrance the scanner centered through the aperture window. The beam must be parallel to the optical axis. To reach this alignment, the use of cross-hairs is recommended. They are not part of the delivery. A pair of cross hairs should be mounted at the beginning and end of a tube as shown in Figure 36. In a first step, this tube has to be mounted on the machine-side mounting plate without the scanner.

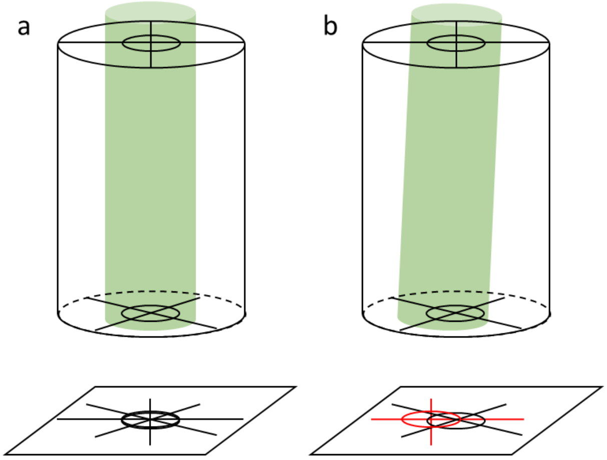


Figure 36: Using cross-hairs in a tube to align the beam. (a) well-aligned beam with overlapping shadows of the cross-hairs and (b) tilted beam causing two shadows of cross-hairs.

A well aligned beam shows overlapping shadows of both cross-hairs. If the beam is tilted, the shadows are mismatching on the screen. Furthermore, the parallel beam matches the center of the aperture, if the cross-hairs divide the beam in four equal quarters.

After aligning the beam and unmounting the cross-hairs, the scanner can be mounted as described in section 3.1on page 29.

3.3.2 Optical configuration

The scanner is configured before the delivery. This configuration includes zero positioning of the beam, correction of faced deviations and objective depending digital analog conversion bit / µm. Nevertheless, a reconfiguration can be required if the beam is re-aligned (= mounting in another place!) or the objective is changed.

The configuration starts with the adjustment of zero position. For this process, cross hairs are required that can be adapted to the beam exit aperture of the scanner. In the scanner software, the INIT-page includes the two relevant values “X_Shift” (slow axis) and “Y_Shift” (fast axis). These values are offset values in hexadecimal format added to the commanded value from the object definition. To adjust the beam properly, the object size should be equal in x and y and symmetrically to the zero position e.g. start X/Y at -1/-1 [mm] and size X/Y of 2/2 [mm]. The laser switching has to be coupled to the object. The beam can now be shifted with the X and Y shift until four equal quarters are visible through the cross hairs with overlapping shadows. Shift values can be written in the window or changed using the courser keys (UP and DOWN) to increase the shift value in the box. Curser only shifts 1 digit up or down, curser + SHIFT 10 digits, curser + CTRL 100 digits and curser + ALT 1000 digits.

After aligning the zero position, the objective can be mounted using the adapter ring and four M5 screws of 16 mm length. The value "µ/bit" in the page OPTIK must be checked. Therefore, a test substrate has to be processed using only one facet. Uncheck 7 of 8 facets in the INIT page of the software. The measured distance must be the same as defined distance in the object definition. If not, the µ/bit values must be changed according the following equation (14).

$$\mu/bit(new) \;= \mu/bit(old)\,\cdot \frac{target\ distance\ (e.g.100\ \mu m)}{measured\ distance\ \ (e.g.107\ \mu m)} \tag{14}$$

Thereby, the relevant distance in the X-direction (slow) is the hatch distance between two lines, while the relevant distance in the Y-direction (fast) is the pulse-to-pulse separation in a single pulse ablation process (line count and object count = 1). The last step is the facet correction, that is not affected by the two previous steps and has not to be reconfigured. It is only required, if the old configuration gets lost or a pulse-synchronized laser system is used. The tangential and pyramidal error of the polygon facets are corrected using the correction table in the INIT-page. Values from -128 to +127 (bit) can be used to shift the value in X and Y direction. Each digit has a value of 1/16 of the corresponding µ/bit value in the OPTIC page.

3.3.3 Facet correction

As in the previous case, a test process has to be performed. Following steps can be used:

Select only facet 1 in the INIT page. Set the hatch to 800 µm, set the object width to a multiple of 800 µm (e.g. 4 mm), set the object start X to 0.0 mm, set the object count to 1. Process the object. For better visibility of the lines, the line count can be larger than 1. Switch the active facet to facet 2, set the start to 0.1 mm, repeat the process. Increase the facet and start position (0.1 mm steps) after each run until every facet was used. The resulting image looks similar to Figure 37

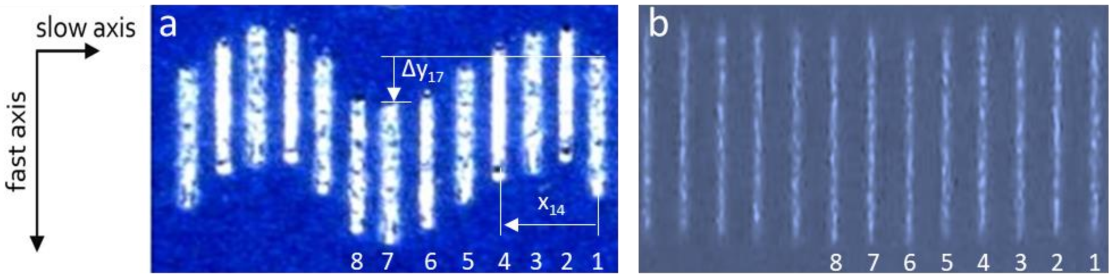


Figure 37: Structured lines before (a) and after (b) facet correction.

Starting from the facet 1 line (most right line), the distance to the other facet's lines can be measured and compared to the target position (for example 100 µm steps). For the correction in y direction, the distance between the line beginning is measured, starting with facet 1 in zero position. The measure difference in both directions (Δx,y) can be used to calculate the correction value in bit according to the following equation (15).

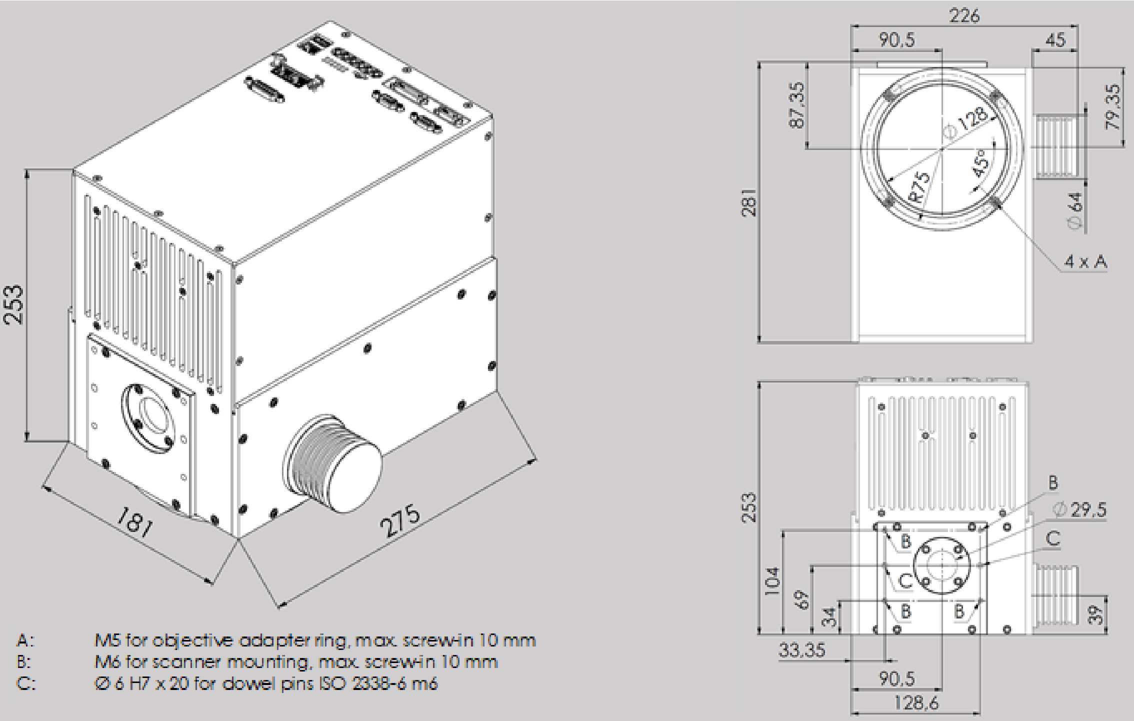
$$Corr = \frac{\Delta\mathrm{x},\mathrm{y}}{\frac{1}{16}\ (\mu/bit)} \tag{15}$$

If a correction value exceeds the given range, any offset can be added to all eight values to shift them as block to lower / higher values.

4 Specifications

4.1 General specifications

The PM series is designed for ultra-fast high-power laser processing. The system is realized as two-dimensional beam deflection unit available for 2D, 2.5D and 3D processing. It stands out with a patented low-distortion double polygon mirror and is able to handle high laser power 5 kW cw / 2 kW pulsed. Ultra-fast scan speeds are achieved on the entire scanning field (no acceleration loss). The high-end PM scanners stands out with a with a free aperture of 30 mm and a real-time on-board data processing (FPGA-based) allowing highest accuracy for macro and micro processing on never seen throughputs.
The bitmap mode supports laser image processing in the 2D and 2.5D using 1, 8, 16 or 32-bit bitmaps (*.bmp). Furthermore, the optional slicer engine can process 2.5D and 3D vector graphics or STL-files, for a real three-dimensional laser processing.
The communication with other machine parts enable two-dimensional beam deflection as sand-alone utilization or machine integration (axis, roll-to-roll) as well as processing of moving substrates. Multiple digital and analog I/O connectors, Ethernet for communication, encoding, process control support the full digital process control and fast, position-depending laser switching.
The device can be equipped with changeable objectives (standard or customized).



A: M5 for objective adapter ring, max. screw-in 10 mm
B: M6 for scanner mounting, max. screw-in 10 mm
C: Ø 6 H7 x 20 for dowel pins ISO 2338-6 m6

Figure 38: Dimensions of the PM series scanner and positions of the mounting points.

General specifications		
Power supply	Voltage	+(30±2) VDC, GND
	Current	max. 15 A
	Ripple/Noise	max.200 mVpp
Wight		13 kg
Size (LxWxH)		281 x 226 x 253
Input aperture		29.5 mm
Beam displacement		0 mm
Operating temperature		+18…+30°C
Humidity		20…90 % rel.H.
Data processing and communication specification		
Data transfer	1x	Ethernet
Digital Out	3x	5 V @ 120 MHz
Analog Out	2x	0…5 V @ 3 MHz
Analog In	1x	0…5 V
Axis I/O	36 pin	D-Sub-Micro-D
Sync I/O	Master/slave	Ethernet
GPIO I/O	20 pin	D-Sub-Micro-D
Aux. I/O	9 and 15 pin	D-Sub
USB 2.0 A		5 V, max. 0.5 A
On-board memory		1 GByte
Scanning field		90,000 x 90,000 pixel
FPGA frequency		200 MHz (5 ns)
Image formaz		BMP (1-bit, 8-bit, 16-bit, 32-bit))
Vector-graphics		DXF,
3D real-time-slicer		STL, VRML
Optical specifications		
	Polygon mirror	**Galvo mirror**
	Primary axis	Secondary axis
Max. deflection	± 0.454 rad	± 0.698 rad
Resolution	<2 µrad (24-bit)	< 4 µrad (20 bit)
Repeatability		< 1 µrad (RMS)
Temp. Drift		< 5 µrad/K
Max. Lines / s		1,333 Hz @ 10,000 rpm
Max. scan speed		> 800 m/s @ 10,000 rpm, 420 mm f-θ
Wavelenght		NIR >1,000 nm (Au)

4.2 Electrical specifications

4.2.1 Connector panel

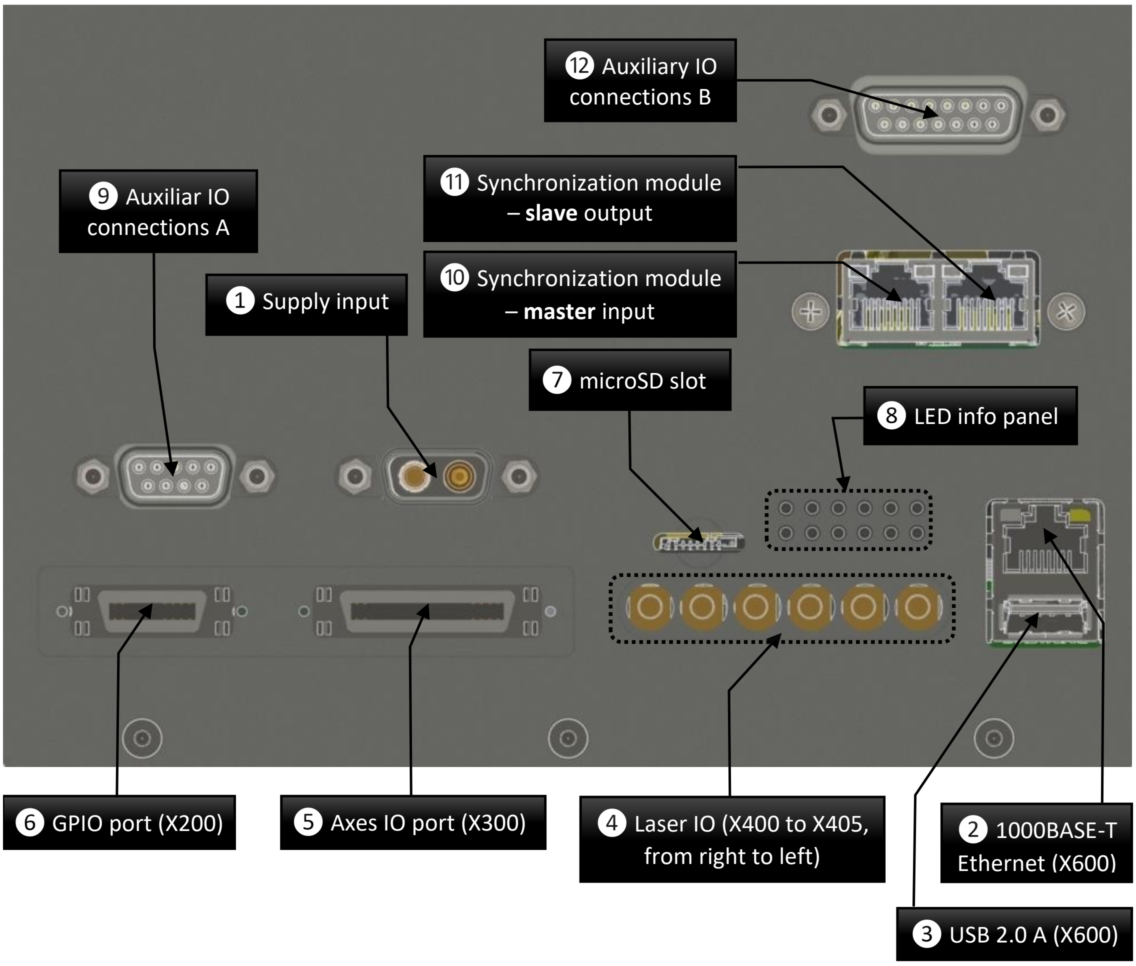

⑫ Auxiliary IO connections B
⑨ Auxiliar IO connections A
⑪ Synchronization module – **slave** output
① Supply input
⑩ Synchronization module – **master** input
⑦ microSD slot
⑧ LED info panel
⑥ GPIO port (X200)
⑤ Axes IO port (X300)
④ Laser IO (X400 to X405, from right to left)
② 1000BASE-T Ethernet (X600)
③ USB 2.0 A (X600)

Figure 39: Connector panel of the polygon mirror scanner with all possible connector, including optional equipment of the device.

4.2.2 Power supply input

The polygon mirror scanner is powered by a combination D-SUB socket (2W2C, female) with high current contacts. The positive supply voltage must be applied to contact A1 (plug) and the corresponding ground to contact A2 (socket). A suitable plug would be e.g. the FMK1G-2W2PC-5934 from FCT Electronics (Molex). The supply line and the power supply should be dimensioned for 30V and at least 15A. For a length of less than 10m a wire diameter of 1.5mm² is sufficient, for longer lengths it should be at least 2.5mm². The use of a shielded cable is recommended. The shield should be connected to the housing of the connector and should be connected to the machine's protective earth. The scanner was tested with a Meanwell HRP-600-36 power supply which was set to 30V output voltage.

① Power supply input		
	A1	+30V$_{DC}$ ±2V @15A
	A2	Ground
	Housing	Screen

4.2.3 Ethernet Port

The ethernet interface is the primary communication interface of the polygon mirror scanner and is designed as 1000BASE-T (Gigabit-Ethernet). A shielded twisted pair Category 5E or Category 6 cable should be used to connect to a computer or network switch.

4.2.4 USB 2.0A port

The USB 2.0A connector is designed as a host port and provides a maximum of 500mA at 5V for external devices. The port is currently unused and without function.

4.2.5 Laser Input and Output Port (High-Speed IO)

The Laser IO provides three fast digital and two fast analog outputs, as well as a fast trigger input. For all signals 50 Ω SMB jacks are used. For the proper transmission of signals with longer cable lengths (pulses and analog signals), double-shielded low-loss coaxial cables, e.g. CLF-100 or MULTIFLEX 86, should be used. For short cables, RG174 is also sufficient.

The reference ground is the same for all laser signals, but galvanically decoupled from the power supply ground of the scanner. However, this galvanic decoupling is only functional in order to ensure the clean coupling of different devices over longer lines. The maximum potential difference of the ground should not exceed 50 V.

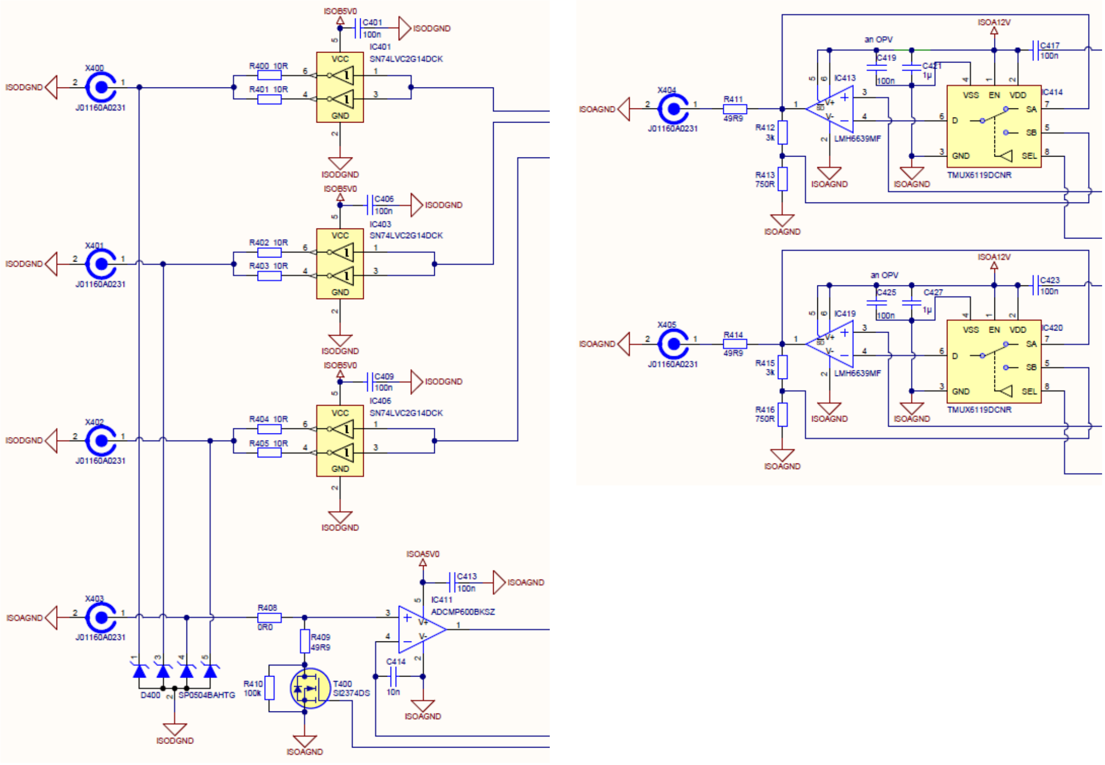
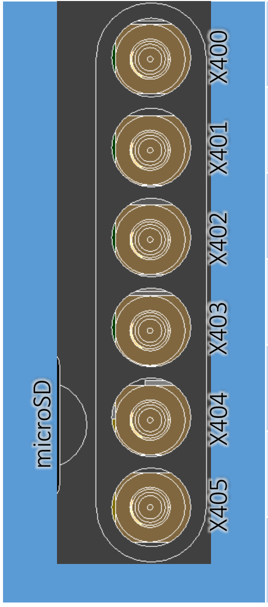

ISOB5V0
C401 100n
ISODGND
IC401 SN74LVC2G14DCK
VCC
GND
X400
J01160A0231
R400 10R
R401 10R
C406 100n
IC403 SN74LVC2G14DCK
X401
R402 10R
R403 10R
C409 100n
IC405 SN74LVC2G14DCK
X402
R404 10R
R405 10R
ISOA5V0
C413 100n
ISOAGND
IC411 ADCMP600BKSZ
X403
R408 0R0
R409 49R9
R410 100k
T400 SI2374DS
C414 10n
D400 SP0504BAHTG
ISOA12V
an OPV
C417 100n
C419 100n
C421 1µ
IC413 LMH6639MF
X404
R411 49R9
R412 3k
R413 750R
VSS EN VDD
D
SA
SB
SEL
IC414 TMUX6119DCNR
C423 100n
C425 100n
C427 1µ
IC419 LMH6639MF
X405
R414 49R9
R415 3k
R416 750R
IC420 TMUX6119DCNR

Figure 40: Schematic of digital outputs (X400 to X402) and trigger input (X403) as well as analog outputs (X404 and X405)

The digital outputs (X400 to X402) are primarily used for fast switching laser signals, electro-optical modulators or acousto-optical modulators. The signal level is unloaded 5 V and can be loaded with a maximum of 100 mA. The maximum output frequency is more than 120 MHz, with a rise time of less than 3 ns. For the low-noise and low-reflection transmission of fast signals, a 50 Ω terminating of the line is recommended. If low impedance inputs such as optocouplers are connected, no termination is required.

The trigger input (X403) is designed for signals up to 5 V and can be terminated to ground with 50 Ω via configuration software. The trigger level can also be set between 0 V and 5 V with the configuration software. *[The feature is not yet implemented in the software.]*

The X405 and X406 analog outputs, for example, can be used to quickly modulate laser power. The analog outputs have an update rate of 3 MHz and a resolution of 16 bit. The maximum output level is either 2 V or 10 V at an unloaded output, depending on the setting with the configuration software. Due to the output impedance of 50 Ω the signal levels are halved when using a 50 Ω termination, the maximum output levels are then 1 V or 5 V. *[The feature is not yet implemented in the software.]*

④ Laser IO port			
	X400	digital output “OUT 1”	0 V / 5 V digital output, max. 100 mA
	X401	digital output “OUT 2”	0 V / 5 V digital output, max. 100 mA
	X402	digital output “OUT 3”	0 V / 5 V digital output, max. 100 mA
	X403	Trigger input “Analog TRIG IN”	0-5 V analog comparator input, **≈ 100 kΩ or 50 Ω input impedance**
	X404	Analog output “Analog OUT 1”	0-2 V / 0-10 V analog output, **≈ 50 Ω output impedance,** max. 100 mA
	X405	Analog output “Analog OUT 2”	0-2 V / 0-10 V analog output, **≈ 50 Ω output impedance,** max. 100 mA
	Housing of all SMB jacks		isolated reference ground of all laser signals

4.2.6 Axes IO port

The axes IO port provides inputs for incremental encoder signals and fast inputs and outputs for controlling motor drivers of stepper motors or BLDC motors. Depending on the software configuration, these inputs and outputs can also be used for customized signals. The encoder signals are received as differential signals with RS-485/RS-422 levels up to 30 MHz and are terminated with 150 Ω. The other control signals are digital output or read in signals with 5V level.

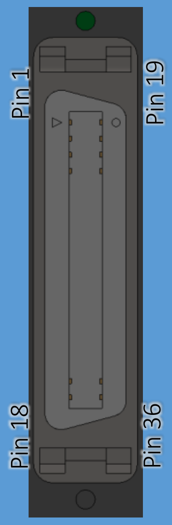
The jack is a shielded .050" Mini D Ribbon (MDR) connector with 36 contacts (3M N10236-5212PC). For cable lengths up to 10m it is recommended to use a pre-assembled cable e.g. 3M 4120-4120-XX-B series. For larger cables or special lengths, a shielded cable with 18 twisted pairs should be used. The shielded 3M .050" Solder Plug Connector Series 101 (10136 - 3000PX) can be used for this purpose. The twisted pairs are soldered to the opposite pins of the connector (pair 1: Δ1-ο19, pair 2: Δ2-ο20; ...).

Up to three quadrature encoder inputs, the digital input and three outputs for axis control are grouped by axes (X-axis, Y-axis, Z-axis).

In addition, four general input and/or output signals are available, which can be configured via the software. ***[The feature is not yet implemented in the software.]***

A +5V supply is provided as reference voltage or as power supply for the encoder. The power supply and signal ground are galvanically isolated from the scanner supply and is at the same potential as the laser signal ground. However, this galvanic decoupling is only functional in order to ensure the clean coupling of different devices over longer lines. The maximum potential difference of the ground should not exceed 50 V.

⑤ Axes IO port



1 ENCX_A- 6 ENCY_A- 11 ENCZ_A-	Inverted input of phase A of the quadrature encoder	Input Voltage Range (A-B) ≥ +0.2V to ≤ +13.2V and ≤ -0.2V to ≥- 10V, with 150 Ω term., max. 30 MHz
19 ENCX_A+ 24 ENCY_A+ 29 ENCZ_A+	Noninverted input of phase A of the quadrature encoder	Input Voltage Range ≥ +0.2V to ≤ +13.2V and ≤ -0.2V to ≥- 10V, with 150 Ω term., max. 30 MHz
2 ENCX_B- 7 ENCY_B- 12 ENCZ_B-	Inverted input of phase B of the quadrature encoder	Input Voltage Range ≥ +0.2V to ≤ +13.2V and ≤ -0.2V to ≥- 10V, with 150 Ω term., max. 30 MHz
20 ENCX_B+ 25 ENCY_B+ 30 ENCZ_B+	Noninverted input of phase B of the quadrature encoder	Input Voltage Range ≥ +0.2V to ≤ +13.2V and ≤ -0.2V to ≥- 10V, with 150 Ω term., max. 30 MHz
3 ENCX_I- 8 ENCY_I- 13 ENCZ_I-	Inverted input of the index of the quadrature encoder	Input Voltage Range ≥ +0.2V to ≤ +13.2V and ≤ -0.2V to ≥- 10V, with 150 Ω term., max. 30 MHz
21 ENCX_I+ 26 ENCY_I+ 31 ENCZ_I+	Noninverted input of the index of the quadrature encoder	Input Voltage Range ≥ +0.2V to ≤ +13.2V and ≤ -0.2V to ≥- 10V, with 150 Ω term., max. 30 MHz
4 MOTX_EN 9 MOTY_EN 14 MOTZ_EN	Motor enable output or general output	5V digital output, ≈ 50 Ω output impedance, rise/fall time max. 5 ns, max. ±10 mA, max. 50 MHz[1]
22 MOTX_DR 27 MOTX_DR 32 MOTX_DR	Motor direction output or general output	5V digital output, ≈ 50 Ω output impedance, rise/fall time max. 5 ns, max. ±10 mA, max. 50 MHz[1]
5 MOTX_ST 10 MOTY_ST 15 MOTZ_ST	Motor step output or pwm output or general output	5V digital output, ≈ 50 Ω output impedance, rise/fall time max. 5 ns, max. ±10 mA, max. 50 MHz[1]
23 MOTX_LS 28 MOTY_LS 33 MOTZ_LS	Axis limit switch input or general input	5V digital input, 2.2 kΩ pull-up resistor against 5V, max. 50 MHz[1]
16 AXIS_IO0 34 AXIS_IO1 17 AXIS_IO2 35 AXIS_IO3	general purpose inputs or outputs	5V digital input or output, 10 kΩ pull-down resistor against GND, max. ±20 mA, min. 10 ms pulse width
18 GND	Ground reference for all signals and return of the +5V supply	maximum current for this pin is 1A
36 +5V	+5V reference voltage, encoder power supply	maximum current for this pin is 1A, fused with 1.1 A PTC fuse
Housing	Shield	coupled to GND via 1 MΩ || 100nF

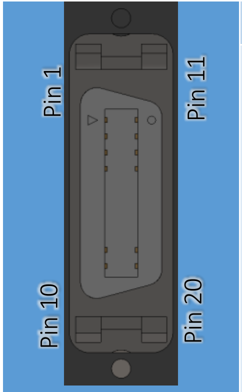
[1] depending on cable length and cable type and signal termination

4.2.7 GPIO port

The general-purpose IO port provides 8 inputs and 8 outputs. The signals can be customized to the user's specification. At the moment, a standard functionality is only provided for the inputs *[The feature is not yet implemented in the software.]* Furthermore, a galvanically isolated RS-485 interface is available at this port for general communication or for fieldbuses.

The inputs are polarity independent optocouplers with a common return line. They can be operated with a voltage of ±3.3V to ±24V. The outputs are polarity independent photomos relays with a common return line. They can switch a maximum voltage of ±60V.

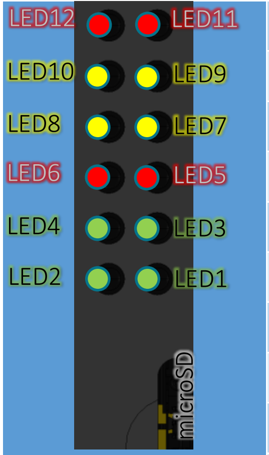
The jack is a shielded .050" Mini D Ribbon (MDR) connector with 20 contacts (3M N10220-5212PC). The cable can be an unshielded or shielded cable with 20 wires, at least 1 twisted pair for the RS-485 should be available. The shielded 3M .050" Solder Plug Connector Series 101 (10120 - 3000PX) can be used for this purpose. The twisted pair are soldered to the opposite pins of the connector (pair: Δ10-○20).

⑥ GPIO port			
 	1 GPIO_IN_COM	Return of all inputs	maximum current for this pin is 1A
	2 GPIO_IN0	Optocoupler inputs (Broadcom ACPL-214 with R_{FWD}=3.3kΩ in line) ±3.3 V to ±24 V input voltage for active state, max. ±8 mA input current, min. pulse width 250 µs	Start process if 0 → 1
	3 GPIO_IN1		Stop process if 0 → 1
	4 GPIO_IN2		Trigger for single step if 0 → 1
	5 GPIO_IN3		Motor enable if 0 → 1
	6 GPIO_IN4		Switch to config 1 if 0 → 1
	7 GPIO_IN5		Switch to config 2 if 0 → 1
	8 GPIO_IN6		Switch to config 3 if 0 → 1
	9 GPIO_IN7		Switch to config 4 if 0 → 1
	11 GPIO_OUT_COM	Return of all outputs	maximum current for this pin is 1A
	12 GPIO_OUT0	Photomos relay outputs (Panasonic AQY212S) Max. 60V output voltage, max. 500 mA output current, on resistance max. 2.5 Ω, min. pulse width min. 1 ms	No standard function
	13 GPIO_OUT1		
	14 GPIO_OUT2		
	15 GPIO_OUT3		
	16 GPIO_OUT4		
	17 GPIO_OUT5		
	18 GPIO_OUT6		
	19 GPIO_OUT7		
	10 RS485_B	Inverted input of RS-485 interface	RS-485-Level, ≈ 120 Ω term., max. 16 Mbps
	20 RS485_A	Noninverted input of RS-485 interface	RS-485-Level, ≈ 120 Ω term., max. 16 Mbps
	Housing	Shield	coupled to internal isolated Ground of the RS-485 via 1 MΩ || 100nF

4.2.8 MicroSD slot

The micro SD slot carries the micro SD card with the binary files, which is delivered with the scanner. Usually, it needs no change. If the SD card is broken a XXXX card is required, which contains original software from MOEWE.

4.2.9 LED info panel

⑧ LED info panel		
 LED12 LED11 LED10 LED9 LED8 LED7 LED6 LED5 LED4 LED3 LED2 LED1 microSD	LED1 green	ON – internal 3.3V power supply ready
	LED2 green	ON – internal 5.0V power supply ready
	LED3 green	ON – external power, motor and galvanometer supply o.k.[1]
	LED4 green	ON – isolated IO power supply o.k.[1]
	LED5 red	no definition yet
	LED6 red	no definition yet
	LED7 yellow	no definition yet
	LED8 yellow	no definition yet
	LED9 yellow	no definition yet
	LED10 yellow	no definition yet
	LED11 red	no definition yet
	LED12 red	no definition yet

[1] currently not implemented

Detailed description will be given soon …

4.2.10 Auxiliar IO connector A

Connector panel for special extensions with male or female D-sub connector with size DE. The description of the interface is supplied with the extension. *[Currently equipped with a serial interface for configuration purposes. Do not use!]*

4.2.11 Synchronization module

The "SYNCHRONIZATION MODULE" is used to exchange time and position signals for synchronizing the polygon wheels between the master scanner and the slave scanner. The master input of the master scanner must be connected to the slave output of the slave scanner via a twisted pair Category 5E or Category 6 patch cable (1:1).

Detailed description will be given soon …

4.2.12 Auxiliary IO connector B

Connector panel for special extensions with male or female D-sub connector with size DA. The description of the interface is supplied with the extension. *[Currently not equipped]*

4.3 Software functions overview

Configuration Files			
Label	Unit	Field type	Description
System	–	Button	Displays the version used and other system data
Pushbuttons	–	Checkbox	Quick selection of saved internal configurations (preassignable)
Bin Update	–	Button	Update bin-file version
Bin Restore	–	Button	Reset to previous version bin-file
Config load	–	Button	Loading a previously saved configuration from host PC
Config store	–	Button	Save current configuration as file on host PC
Config to FPGA	–	Button	Save current configuration to current internal polygon memory (FPGA)
SRes	–	Button	Software-Reset
HRes	–	Button	Hardware-Reset

Poly-Info			
Label	Unit	Field type	Description
Ram	–	Display	Utilization of polygon memory (filled bar)
Window	–	Display	Dynamic display of polygon synchronization
U/min	rpm	Display	Current rotation speed of the polygon
Scan	m/s	Display	Trajectory speed in focus
Line	Hz	Display	Resulting line frequency (scanned lines per second)

Init			
Label	Unit	Field type	Description
E (1-8)	–	Checkbox	Selection of the active individual polygon facets (e.g. in case of damage to the individual facets or for test purposes)
dX/dY (1-8)	Digit	Checkbox	Horizontal (X, slow axis) and vertical (Y, fast axis) correction values for the facet 1-8. Values from -128 to + 127 as relative position changes in 1/16 steps of µ/bit (optic)
Motor Hold	–	Checkbox	hold the polygon motor in one position
Laser_neg	–	Checkbox	Is Laser-ON at Low Level
Motor_neg	–	Checkbox	Reversing the direction of rotation of the polygon wheel

Optic			
Label	**Unit**	**Field type**	**Description**
µ/Bit X/Y/Z	µm/Bit	Input	Conversion factor (bits in micrometer) for X-/Y-/Z-directions
Off.-X/-Y	mm	Input	Correction of the beam position for X- and Y-directions
Kxd/Kyd	-	Input	Asymmetric correction factors for scan field correction
Kxa/Kxb/Kxc	-	Input	Correction values (constants) for equalization in X-direction
Kya/Kyb/Kyc	-	Input	Correction values (constants) for equalization in Y-direction
Kphi	-	Input	Correction value (constant) to compensate the scan field rotation
Y-Galvo	-	Checkbox	Realize correction via Y-galvo (optional equipment)
Scannfield			
Flip_X/Flip_Y	-	Checkbox	Mirroring of the scan field around X-/Y-axis
+ /- X	mm	Input	Limitation of the scan field in negative and positive X (slow axis)
+/- Y	mm	Input	Limitation of the scan field in negative and positive Y (fast axis)
+ /- Z	mm	Input	Limitation of the scan field in negative and positive Z-direction

Digital			
Label	**Unit**	**Field type**	**Description**
-	-	Checkbox	Unused
-	-	Checkbox	Unused
neg	-	Checkbox	Negate signal
Freq	-	Checkbox	Outputs a frequency signal based on the internal clock
Start	-	Checkbox	Output HIGH, when pressing Start (Scanner section) set output to HIGH until Stop is pressed or limit is reached
Scan	-	Checkbox	Signal becomes 1 if the current position is within the scan field
Obj	-	Checkbox	Signal becomes 1 if the current position lies within the object
Pos	-	Checkbox	Output of a position-related frequency signal
Teiler	-	Input	Divider base of the output frequency for Freq and Pos
Out Delay	µs	Input	Time delay of the digital output (delayed)
Sync			
Start	-	Checkbox	Single reset of the signal at the start of the process
Round	-	Checkbox	Reset the signal at each full lap of the polygon wheel
Fac	-	Checkbox	Reset of the signal at each new facet
Scan	-	Checkbox	Reset of the signal with each new scan
Obj.	-	Checkbox	Reset of the signal with each new object
Shift	-	Input	Counting base for modelling the signal to be output

Analog			
Label	**Unit**	**Field type**	**Description**
Analog 1 und 2			
neg	-	Checkbox	Negate signal
Dat1	-	Checkbox	Digital analog converter 16 bit to analog signal from min. V to max. V (Conversion of the most significant bits 16-32 of a bitmap)
Start	-	Checkbox	Signal output during process is running (Start/Stop button)
Scan	-	Checkbox	Signal output if the current position is within the scan field
Obj	-	Checkbox	Signal output if the current position lies within the object
Dat0	-	Checkbox	Digital analog converter 16 bit to analog signal from min.V to max. V (Conversion of the least significant bits 0-15 of a bitmap)
Min	V	Eingabe	Signal voltage minimum
Max	V	Eingabe	Signal voltage maximum
Analog In			
Single	-	Checkbox	
high	V	Eingabe	Two-point trigger value HIGH
low	V	Eingabe	Two-point trigger value LOW

Scanner			
Label	**Unit**	**Field type**	**Description**
Sc_Anz:	–	Input	Number of exposures from scan field until process ends If reached, process stopped independent from other limits.
Obj_Anz:	–	Input	Number of exposures from loaded object until process end If reached, process stopped independent from other limits.
Pause	–	Checkbox	Stopping after a galvo jump (*slow axis*)
Hold	–	Checkbox	Permanent exposure of a line for test purposes (only in combination with Step Mode)
Start	–	Button	Starting the program
Stop	–	Button	Cancel the running program
Step	–	Button	Execution of a program step (e.g. in combination with Step Mode)
v	m/s rpm Hz	Input Selection	Target process speed, selectable as: Scan speed in focus Rotation speed of the polygon wheel Line frequency
Motor Enable	–	Checkbox	Switching on the polygon motor (indispensable for dynamic beam deflection along the fast axis)

Control Float: object control [0,0 in the upper left object corner]

Label	Unit	Field type	Description
Pos X/Y/Z	mm	Input	X-/Y-/Z-Coordination start position of the object on the workpiece
Size X/Y	mm	Input	Size of the object on the workpiece
Skal [XY]	–	Input	Scaling factor in X & Y direction (*slow* & *fast axis*)
Copy [XY]	–	Input	Number of objects duplicated in X & Y direction
Space [XY]	mm	Input	Distance between the duplicated objects
Pixel [EA]	–	Checkbox & Input	Selection and properties in pixel mode (dashed line). The first value [E] describes the length of the individual dashes, the second value [A] the distance between them along the fast axis
Pattern	–	Input	Selection and properties in Pattern mode. The left value describes the number…, the right value describes the number…
Line_Count	–	Input	Number of repeated exposures for each line (fast axis)
Shift X/Y/Z	µm	Input	Shift value of the individual X-/Y-/Z-axes used for shifter function
Hatch	µm	Input	Line distance X direction (slow axis)
Sub-Hatch	µm	Input	Hatch offset after each scan in X-direction (slow axis)

Controll Float: data control [0,0 in the upper left object corner]

Label	Unit	Field type	Description
Pos X/Y/Z	mm	Input	X-/Y-/Z-Coordination of the loaded 2D image on the workpiece
Size X/Y	mm	Input	Size of the loaded image on the workpiece
Skal X/Y/Z	–	Input	Scaling facktor
Flip [XY]	–	Checkbox	Mirroring around X/Y axis
LINK	–	Checkbox	Link the data to the object

Systemstatus (read only)

Label	Unit	Field type	Description
X_Pos	mm	Display	Current X-position (galvo mirror position, slow axis)
Y_Pos	mm	Display	Current Y-position (*fast axis*)
Z_Pos	mm	Display	Current Z-position (depth, along the beam propagation axis)
Scan Count	–	Display	Current number of exposures/scans
Obj. Count	–	Display	Current number of the object-counter
Shift_X/Y/Z	mm	Display	Current position of the shifter in the directions

Output control			
Label	Unit	Field type	Description
BMP_File	–	Button	Selection of the bitmap file (*.bmp)
BMP	–	Checkbox	Activates bitmap mode (otherwise the rectangle in the object size will be fully exposed)
Fill	–	Checkbox	The scanning field is filled with bitmap duplications Incomplete duplications possible
Neg	–	Checkbox	Invert bitmap values e.g. 0/1 or 255/0
Window	–	Display	Displays loaded image
PWM	–	Input	Pulse width modulation following the greyscale of the image
Auto_Inc	–	Input	Determining the increment value for + operations
Spalten	Pixel, mm	Display	number of columns of the loaded bitmap in pixels and mm
Zeilen	Pixel, mm	Display	number of lines of loaded bitmap in pixels and mm
Real	–	Checkbox	Analog modulation of the loaded BMP file (gray values)
><	–	Checkbox	Comparison with an external value (adjustable by means of slider) e.g. greater than slider values are exposed
=	–	Checkbox	Comparison with an external value (adjustable by slide control) only identical values are exposed
<+;>+;=+	–	Checkbox	Comparison with slider-value, increased with every scan about the auto inc value
B+	–	Checkbox	Encode different bitmap layers (up to 32) as 1-bit imager per layer

Shift control X,Y,Z			
Label	Unit	Field type	Description
Set (Trigger event)			
Scan	–	Checkbox	Event count at start of the scan process (single event)
Field	–	Checkbox	Event count after each scan fields (reset x to start value)
Line	–	Checkbox	Event count after each line
Quad	–	Checkbox	Event count after 4 signals flank from the axis encoder
Trigg	–	Checkbox	Event count from an external trigger event (GPIO option)
Timer	–	Checkbox	Event count after durations of timer_set
ResY	–	Checkbox	Event in X after resetting of Y shifter (other axes respectively)
ResZ	–	Checkbox	Event in X after resetting of Z shifter (other axes respectively)
N(set)	–	Input	Number of event counts until shifting (counts from 0)

Reset (Event)			
Scan	–	Checkbox	Reset count after process start (single event)
Field	–	Checkbox	Reset count after each scan fields (reset x to start value)
Line	–	Checkbox	Reset count after each line
Quad	–	Checkbox	Reset count after 4 signals flank from the axis encoder
Trigg	–	Checkbox	Reset count from an external trigger event (GPIO option)
Timer	–	Checkbox	Reset count after durations of timer reset
SetY	–	Checkbox	Reset count in X after shifting in Y (other axes respectively)
SetZ	–	Checkbox	Reset count in X after shifting in Z (other axes respectively)
N(reset)	–	Input	Number of event counts until resetting (counts from 0)
V1 → V2			
Same trigger as “Set”	–	Checkbox	If selected, the corresponding set event is related to shift value 2 If unselected, shift value 1 is used
Out			
Scan	–	Checkbox	Shift is applied to scan field
Obj.	–	Checkbox	Shift is applied to object
Data	–	Checkbox	Shift is applied to Data
neg	–	Checkbox	Shift value is negated
ScOf	–	Checkbox	Offset (Applied to scan field)
ObOf	–	Checkbox	Offset (Applied to object)
DaOf	–	Checkbox	Offset (Applied to data)
Neg	–	Checkbox	Shift value is negated (increase or decrease from Size possible)

Scripting			
Label	Unit	Field type	Description
Start	–	Button	Starting your own program from the scripting window
Stop	–	Button	Cancel your own program from the scripting window
Load	–	Button	Loading a program into the scripting window
Save	–	Button	Save program from scripting window
Scanning	–	Checkbox	Do you also want to scan with a polygon mirror scanner?
Upper window	–	Input	Input and editing window of own scripts
Lower Window	–	Display	Display window with system information, such as polygon scanner with the designation XY found, the polygon IP, etc.

4.4 Selected specifications of tested equipment

4.4.1 Objectives

Property	SILL S4LFT1920/328 *	SILL S4LFT0910/328*	SILL S4LFT0420/126*
Effective focal length	1,920 mm	910 mm	420 mm
Working Distance	2,000 mm	1,050 mm	480 mm
Scan field	1,000 x 1,000 mm²	500 x 500 mm²	240 x 240 mm²
Wavelength	1,064 nm	1,064 nm	1,064 nm
Pulse duration	fs, ps, ns, cw	fs, ps, ns, cw	fs, ps, ns, cw
Spotsize (focus)	> 170 µm	> 67 µm	> 40 µm

Property	Sill special development	JENar™ 255-1030...1080-239*	Sill S4LFT0221/126
Effective focal length	270 mm	255 mm	207 mm
Working Distance	300 mm	290 mm	273 mm
Scan field	160 x 160 mm²	100 x 80 mm²	106 x 106 mm²
Wavelength	1,064 (1,030 – 1,090) nm	1,030 – 1,080 nm	1,064 nm
Pulse duration	fs, ps, ns, cw	fs, ps, ns, cw	fs, ps, ns, cw
Spotsize (focus)	> 26 µm	> 24 µm	> 30 µm

Property	Linos Ronar 4401-513-000-26*	Sill S4LFT5365/126	Sill S4LFT6125/126*
Effective focal length	167 mm	163 mm	100 mm
Working Distance	215 mm	198 mm	115 mm
Scan field	50 x 50 mm²	70 x 70 mm²	25 x 25 mm²
Wavelength	1,064 nm	1,064 nm	1,064 nm
Pulse duration	fs, ps, ns, cw	fs, ps, ns, cw	fs, ps, ns, cw
Spotsize (focus)	> 16 µm	> 16 µm	> 8 µm

* tested