Beam Alignment System
"Compact"

User Manual

Contents

1. General

The *Compact* laser beam stabilisation compensates for vibrations, shocks, thermal drift, or other undesired fluctuations of the laser beam direction. The system should be applied whenever laser fluctuations or movements of optical components occur but a high precision and stability of the beam direction is required.

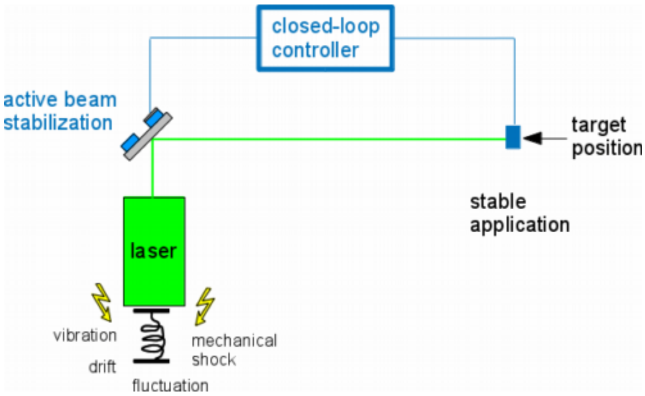

Figure 1: Principle of laser beam stabilisation

The desired position of the laser beam is defined by a 4-quadrant-diode (4-QD) or a PSD. For that purpose a small portion of laser power transmitted through a high-reflective deflection mirror is sufficient.

The closed-loop controller continuously determines the deviation of the laser beam from the desired position and drives the fast actuators in that way that the steering mirrors stabilise the laser beam in the desired position.

The system is available in two different models. The 2-axes system comprises one detector and one steering mirror and controls the laser beam in two axes. Thus, the laser beam is fixed in one position but the beam direction can change. The 4-axes system combines two detectors and two steering mirrors in order to detect the laser beam at two distant positions. Thereby both, position and direction are fixed.

2. System components

The laser beam stabilisation utilizes optoelectronic components (steering mirrors, detectors) as well as electronic modules. We offer different types of actuators and detectors. For more details please check the specification in section 3 and the photos in section 6.

Figures 2, 3, and 4 (from left to right): Steering mirror with Piezo drive (version PSH), detector with position display (horizontal orientation), detector (vertical orientation)

The system electronics (controller, amplifiers, power supplies) is fully integrated into a single compact housing. It is powered by a standard 12V wall power supply.

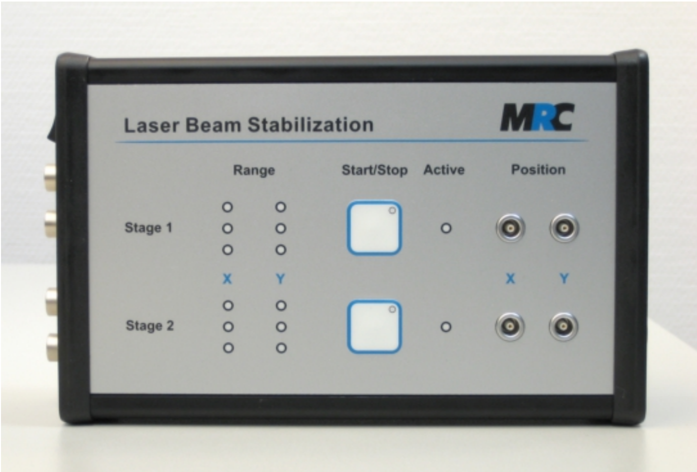

Figure 5: Keyboard and connectors on top panel

Figure 6: Power input and output connectors on left side

Figure 7: Input connectors and switches on right side

3. Specification

Optical parameters	
Wavelength	320 to 1100 nm, UV and IR detectors are available on request
Repetition rate	any rate or cw For repetition rates < 100 Hz we integrate an adaptation for low repetition rates. For single pulses and operations with laser off-times we offer an additional sample & hold circuit, see also note 1
Laser beam diameter	< 6 mm ($1/e^2$), see also note 2
Height of laser beam	45 mm for PKS actuators, 39.5 mm for PSH actuators (Please ask for adapters if you need other heights.)
Mirror diameter	1" (standard), other beam diameters on request
Mirror thickness	1/4" or 1/8" (recommended)

Controller housing dimensions	
w x h x d	166 x 106 x 56 mm³
Steering mirror mounts	
Type 1: PKS (K-700-31)	
Actuator type	Piezo electric elements
Bandwidth	< 700 Hz (measured with 1" mirrors, thickness: 0.125")
Maximum tilt	< 1 mrad (± 0.5 mrad)
Type 2: PSH (K-102-10)	
Actuator type	Piezo electric elements
Bandwidth	< 840 Hz (measured with 1" mirrors, thickness: 0.125")
Maximum tilt	< 2 mrad (± 1 mrad)
Position detector	
Detector type	Si 4-quadrant diode (for standard wavelengths), see also note 3
Bandwidth	< 10 kHz
Detection area	10 x 10 mm² (for standard wavelengths), see also note 3
Mechanical dimensions	49 x 40 x 20 mm³
Optical filter	11.9 x 11.9 mm²
Control features	
Power level display	LED bar with 10 elements on the backside of the detector unit
Position display	LED cross on the backside of the detector unit
Variable intensity gain	Continuous, adjustable with potentiometer (1:6)
Low power switch-off	Power level falls below 10% of saturation power
Switch on activity delay	300 ms
Connectors at controller unit	
Actuator	LEMO 0S series
Detector input	LEMO 0B series
Controller status signal (Interlock)	LEMO 00 series
x, y position output	LEMO 00 series
Power supply	12 V / DC pin-and-socket connector
Connectors at detectors	
x, y, intensity outputs	MCX
Power	12 V / DC pin-and-socket connector
Cable lengths	
Detector → Controller (2 cables)	4 m (other lengths on request)
Actuator → Controller (2 cables)	PKS: 1.5 m (directly mounted to Piezo element) PSH: 1.2 m (directly mounted to Piezo element)
Actuator → Controller (Elongation)	10 m (one pair of cables for one actuator is included in delivery, additional or other cables on request)
x-y-position cable (2 cables)	2 m (other lengths on request)

Notes:

(1) A description of the sample & hold circuit is given in a separate appendix "Additional sample & hold circuit to fix the laser beam position during laser-off times".

(2) In case the beam diameter is larger than 6-8 mm, a lens in front of the detector can be used. For larger beam diameters adapters for 1.5", 2" or other mirrors are available (on request, see also figure 13b in section 6.2).

(3) UV and IR detectors are available on request. They may have differing dimensions and detection areas. As an alternative to the 4-QDs we also offer PSDs. These can have different dimensions and sensitive areas, too.

3.1. Positioning accuracy

The positioning accuracy depends on several parameters:

- Optical distance between steering mirror and detector: The accuracy is higher for larger distances. Therefore a large distance should be chosen. The first steering mirror should be placed close to the fluctuation source.
- Beam diameter: Having the same absolute change of laser beam position, a smaller diameter leads to stronger power differences on the quadrants and therefore a steeper control signal. That is why laser beams with smaller diameter can be positioned with higher accuracy.
- Intensity: The resolution of the detectors further depends on the intensity hitting the sensitive area. This can be varied by an appropriate choice of optical filters and optimised electronically (see also section 5.2).
- Repetition rate and pulse duration: The controller bandwidth can be optimised for different laser parameters. Higher bandwidths lead to a faster reaction and therefore higher accuracy in case of fast fluctuations.

In figure 8 the typical resolutions of the detectors are displayed. The example shows that a resolution of better than 100 nm on the detectors can be achieved with an appropriate choice of parameters. The angular resolution can be determined from these data with respect to the respective arm lengths.

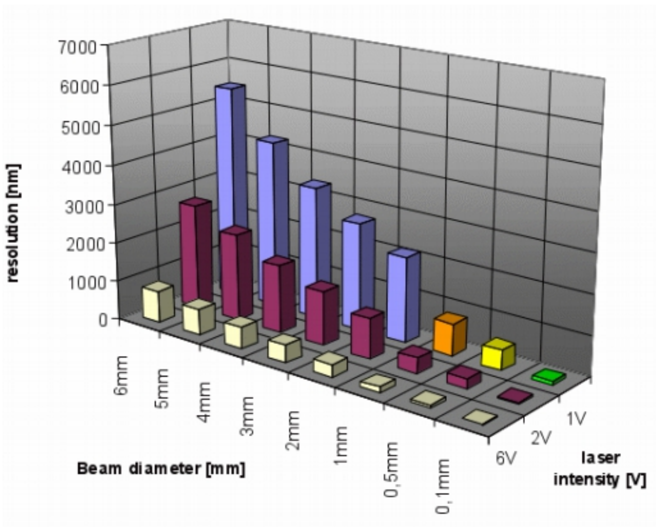

Figure 8: Resolution of a 4-quadrant-diode irradiated by a red He-Ne laser with different beam diameters and laser intensities

The actuators are controlled with an analog signal so that the positioning is not restricted in separate steps. The positioning accuracy of the Piezo elements are specified as < 2nrad (*PKS*) and 4 nrad (*PSH*).

4. Installation and operation

4.1. Brief “step-by-step” instruction

The following steps shall assist you during the first startup of the beam stabilisation. The following section will then explain the single steps more comprehensively.

1) Robust set-up of optical components (steering mirrors and detectors): The centres of the detectors define the beam position. The detectors can be placed directly behind mirrors. Alternatively, a small portion of the beam can be deflected to the detectors by means of a beam splitter.
2) Cable connection: First mirror with output *Actuator 1*, second mirror with *Actuator 2*. First detector with input *4QD1*, second detector with input *4QD2*.
3) Switch on power supply (switch on left side of housing): Thereupon the four green *Range* LEDs will shine at the controller box.
4) Adjustment of intensity on detectors (by means of the potentiometer and if necessary exchange of optical filters): In the best case 9 LEDs should be shining.
5) Pre-adjustment (with non-activated control stages): Adjustment of the laser beam onto the detectors. After this step no red LEDs of the position display (LED cross) should shine.
6) Direction coding: Activation of control stage 1. If red LEDs are shining on the controller box the switch position for x and y direction should be changed (see section 4.6).
7) Direction coding according to step 6, now for stage 2.
8) Fine-tuning for control stage 1: Deactivate both control stages ("Active" LEDs do not shine). Then follow the description in section 4.7 until the x and y position outputs are close to 0V.
9) Fine-tuning for control stage 2: Activate stage 1 (stage 2 is still deactivated). Then proceed according to section 4.7.
10) For the stabilised operation of 4 axes activate both stages.

4.2. Introduction

The system operation can be described best with reference to figures 5 to 7. The top panel in figure 5 shows the keyboard and the position signal outputs for two pairs of detectors and actuators (“stage 1” and “stage 2”). Each stage can be switched on and off independently by pressing the *Start/Stop* button. If the stage is started the small LED in the top right corner of the button is shining. The *Range* display shows whether or not the steering mirrors are within the available capture range. The *Active* LED is shining whenever the control stage is active. This is the case whenever the *Start/Stop* button has been pressed and the laser power on the detectors has the right level.

The *Position* outputs on the top panel can be used to read out the current position of the laser beam on each 4-quadrant diode (x and y).

Notes:

(1) Whenever the *Start/Stop* button is pressed (and the *Active* LED is on) the actuators start to move from the zero position and then respond to the controller input.
(2) If a *Range* LED is shining red, this does not automatically mean that the beam is not stable. But it indicates that no further tilt of the respective steering mirror is possible although it might be necessary.
(3) If the power on the detectors is too low the actuators are driven to the zero position (and the *Active* LED is off). This is due to the low power switch off that was implemented for safety reasons (see section 5.3).

Figures 6 and 7 show both sides of the controller box with all input and output connectors and the switches for the *Directions* and the *Bandwidth* selection. The cables going to the actuators are connected on the left side. The cables coming from the 4-quadrant diodes are connected on the right side.

The direction switches enable a coding of the x and y directions of each controller stage. They are connected with 4QD-1 and 4QD-2, respectively. The performance is further described in section 4.6.. The function of the bandwidth limitation switch is explained in section 5.6.

The *Status* signal output can be used as an interlock or to drive a shutter (see section 5.5).

Note: The Piezo elements have large electrical capacity. That is why the cables should not be disconnected as long as the Piezo elements are charged. I.e. you should always switch off the power of the stabilisation system on the left side of the panel and then wait for a few seconds before you disconnect the actuator cables.

4.3. Set-up of optical components

The optical components (steering mirrors and detectors) can be configured in variable arrangements for different applications.

The detectors can be placed behind high-reflection mirrors. They are very sensitive and can work with the leakage behind the mirrors. This has the advantage, that no additional components are required in the beam path. Alternatively, it is possible to use the reflection of a glass plate or beam splitter in the beam path. The latter can be necessary for lasers with larger beam sizes where the actuator would constrain the transmission.

In any case, the centres of the 4-QDs are positioned in that way, that they define the desired laser beam direction. The first actuator should be placed close to the laser or the last source of interference. The last detector should be placed close to the target.

Note: Take care for a robust mechanical mounting of the optical components. If possible the delivered components should be directly tightened to an optical table without further positioning equipment (like height adjustment). If there are oscillating components with resonance frequencies within the control bandwidth in the set-up, such resonances can provoke oscillations of the system at that frequency.

The following figures 9a-e show a selection of possible arrangements. These examples are demonstrated with the 4-axes system with two 4QDs. However, they can be applied in similar configurations for the 2-axes system with only one actuator and one detector.

- Figure 9a shows a typical 4-axes set-up of the system where the laser beam hits the optical components in the following sequence: steering mirror, combination of steering mirror and detector, mirror with detector.

- Figure 9b shows a similar set-up where additional lenses are placed in front of the detectors. Further, a beam splitter is integrated in the beam path. This set-up might be better for lasers with large beam diameters.

- In figure 9c a lens is placed in front of detector 2 in order to improve the angular resolution. In this case, the distance between lens and detector should be the focal length of the lens. The focal length itself should be chosen in that way – depending on the beam diameter – that the focal spot is not too small. The beam should still have a diameter on the sensor area of > 50 µm, so that it hits all quadrants of the diode. (The gap between the quadrants of our standard 4QD measures 30 µm.)

- Figure 9d shows a variation of 9c where both detectors are placed behind the same mirror. A lens is placed in front of one of the detectors in order to measure both, the beam position and the direction at the same point.

- Figure 9e finally shows a different arrangement where the 4-axes system is used as two 2-axes systems, i.e. the two stages of the controller are used to separately stabilise two independent beam lines.

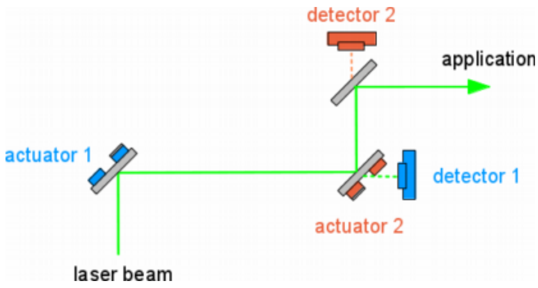

Figure 9a: Typical sequence of components for the 4-axes stabilisation: Detector 1 stabilises the beam position on actuator 2. Detector 2 then defines the beam position at a separate point and hence the direction.

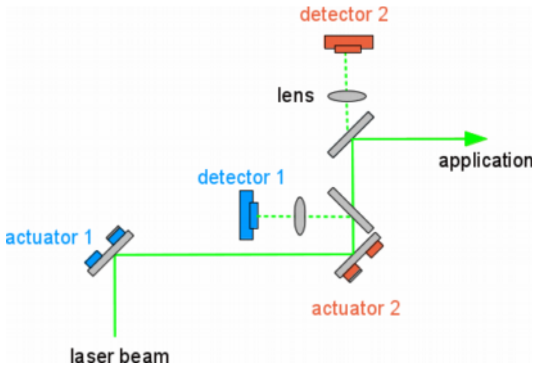

Figure 9b: Set-up as in 9a, with an additional beam splitter and a lens in front of detector 1 and an additional lens in front of detector 2 (Often used for lasers with larger beam diameters)

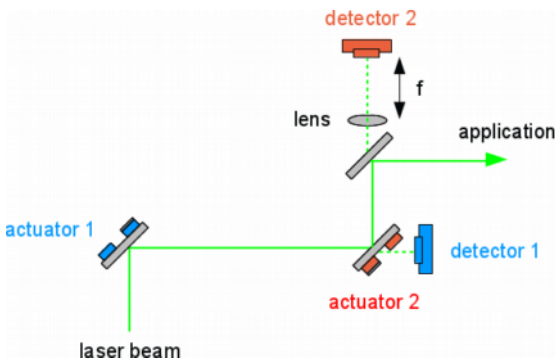

Figure 9c: Set-up as in 9a, but a lens is used to discriminate the angle by means of detector 2. This can be of advantage in case of restricted space with small distances between the optical components. Detector 2 must be placed in the focal plane of the lens.

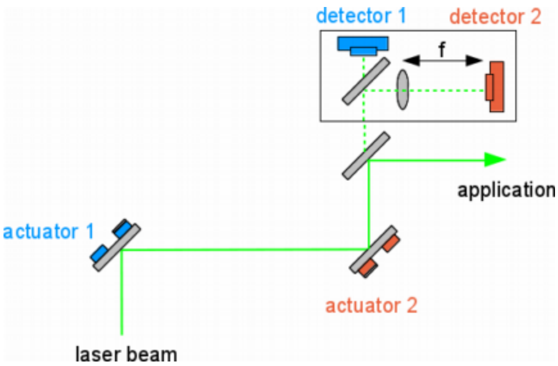

Figure 9d: In this set-up both detectors are placed behind the same mirror. Here, the beam position and the direction are stabilised in close distance to the application. Again, as in figure 9c detector 2 is used to discriminate the angle.

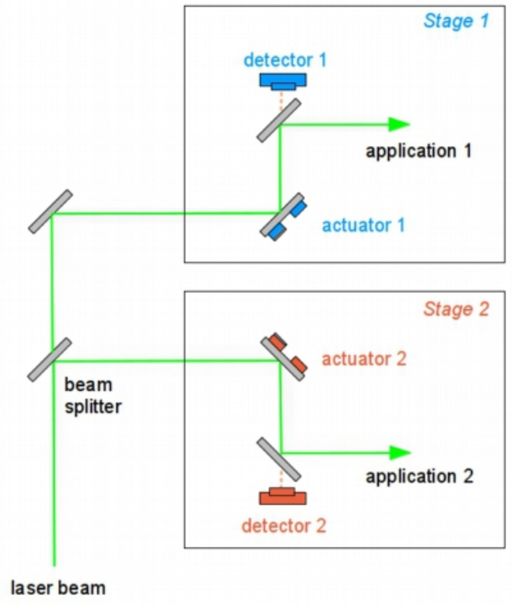

Figure 9e: Set-up of a 4-axes system used as two 2-axes systems. With this set-up the position of two independent lasers can be stabilised with one controller.

4.4. Inputs and outputs

The first steering mirror (figure 2) is connected to the *Actuator 1* output. The second steering mirror is connected to *Actuator 2*.

The connection of the detectors to the controller unit is made by a LEMO cable with a length of 4m and an adapter cable that splits the LEMO cable into four separate cables. These cables are connected to the detectors according to the following rules: The x and y lines have to be connected in accordance to the orientation of the detector housing. If the detector is oriented in vertical orientation as shown in figure 4, the x line has to be connected to the x output and the y line to the y output. If the detector is turned by 90° to a horizontal orientation as shown in figure 3, the x line has to be connected to the y output and the y line to the x output. At the other end, the LEMO cables of the detectors are connected to the respective *4QD* inputs at the controller module.

Notes:

- The *PKS* steering mirror mounts can be mounted in two orthogonal orientations. In the standard factory installation they are mounted and labelled in that way that the x axis drives the horizontal tilt and the y axis drives the vertical tilt. If you change the orientation please take care that always the horizontal tilt must be connected to the x input and the vertical tilt must be connected to the y input of the controller box.
- In case of the 2-axes system you can either use the first or the second stage for stabilisation.

4.5. Intensity adjustment

To make sure that the detectors operate in the linear range, the power level can be adjusted by tuning the potentiometer for intensity variation (see figure 10). For that purpose, switch on the system (Power on) and inactivate the closed-loop control (*Stop* button switched OFF, green *Active*-LED and LED on button off). Then adjust the laser beam onto the detectors in that way that at least 3 but not more than 9 elements of the power level display are shining. The amplification increases by counter-clockwise rotation.

If you do not find an appropriate adjustment you have to exchange the optical filters in front of the 4-QDs. If the required filters are not available please contact the manufacturer or distributor.

Notes:

- In a standard delivery we integrate two optical filters in front of the sensor area. These are a filters with a high and a low density for coarse and fine adjustment, respectively. Usually the filter which is the first to be reached is the low density one.
- Please be aware that the sensor area is quite sensitive. If you want to clean it you should do this carefully with a dry cloth.

If you want to exchange the filters you can detach the plastic screws which fix the filters in the housing. With a tilt of the detector housing it should be possible to release the filters. Once you put in new filters please be careful so that you do not damage the detector. Finally you can fix them with the plastic screws.

Figure 10: 4-quadrant-diode. The arrow points to the potentiometer for intensity variation (Please use a screwdriver)

4.6. Direction coding detector outputs

For any deviation of the laser beam position on a 4-QD the respective steering mirror is tilted in that way that it adjusts the laser beam back to the desired position. Each control stage makes use of a steering mirror and a 4-QD as described in sections 4.2 and 4.3. The components that are working together are identically coloured in figures 9. The direction in which the steering mirror must be tilted depends on the arrangement of 4-QD and steering mirror. It can be changed during the pre-adjustment process described in section 4.7 in the following way:

There are four switches on the right side of the controller module (see figure 7). These switches stand for the x- and y- directions of the control stages Stage 1 and Stage 2. To turn them into the correct position just switch on the respective stage. If the laser beam is then deflected into an extreme x (horizontal) and/or y (vertical) position instead of the centre of the 4-QD, you have to toggle the belonging switch.

4.7. Optimization of laser beam position on detectors

i. Pre-adjustment (Obtaining linear range of steering mirrors)

Activate the controller module (*Start* button switched ON, green *Active*-LED and LED on button shining) and adjust the laser beam onto the detectors by means of manually tilting the steering mirrors until the four *Range* signals on the Piezo amplifiers are shining green. Now the steering mirrors are operating in their linear range.

ii. Fine-adjustment (Obtaining zero position and full range of Piezo drives)

Inactivate the controller module (Piezo drives are in zero position, green *Active*-LEDs are dark) and adjust the laser beam by means of manually tilting the steering mirrors in that way, that it hits the centres of the 4-QDs. This can be done by reading out the x and y position outputs of the controller module or by observing the position display on the backside of the detector module. The position outputs deliver a signal that is directly proportional to the deviation from the desired position. You can easily display these signals on an oscilloscope. The better the correlation of desired position and zero position, the smaller the position shift after activating the closed-loop control.

After these adjustments the system should show no fluctuations of laser beam position after the last mirror with detector when the controller is activated.

5. Operation and safety features

5.1. Power level and position display

The total power on each connected 4-QD (measured as the sum power on all quadrants) is displayed by means of a LED bar on the backside of the detector module. Furthermore, a LED cross on the detector module displays the current laser beam position. If the laser beam hits the centre of the 4-QD only the green LED of the position display will shine. In other cases also yellow and red LEDs will shine according to the examples in figure 11.

a) b) c) d)

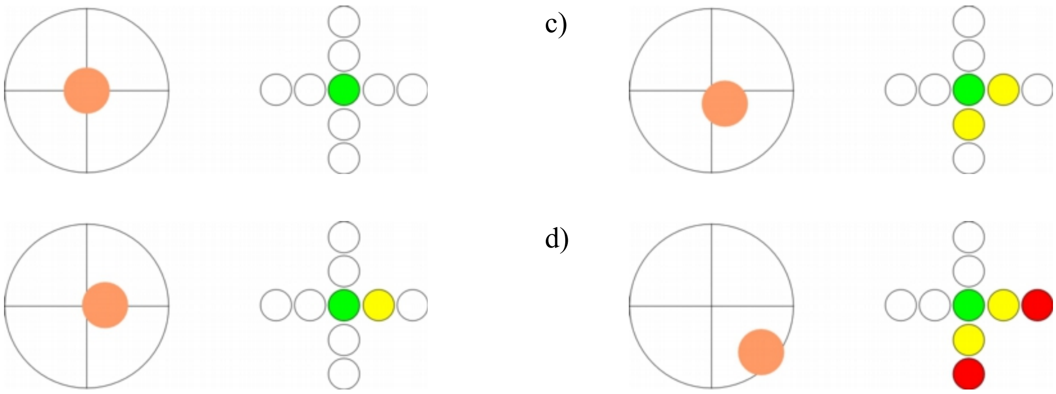

Figure 11: Examples for laser beams hitting the 4-QD (orange spots) and the corresponding position display. The left pictures are shown in a view from the rear side of the housing to the sensor area.

If only green and yellow LEDs are shining the sensor electronics is in the linear range where a direct correlation between measured signal and position exists. If a red LED is shining too, the correlation is no more possible due to the principle of 4-QDs.

5.2. Variable intensity gain control

For an easy adjustment of the signal intensity the stepless potentiometer on the side of the detector unit can be used. This enables the optimization of the power level in case of intensity changes without an exchange of optical filters. The gain can be changed by a factor of 6 between the lowest and the highest value.

5.3. Low power switch-off

If the total power falls below 10% of the saturation power (and only one LED of the power level display is on) the controller module automatically drives the mirrors into zero position. This leads to the advantage that the closed-loop control can start from the zero position even if the laser was switched off or blocked.

5.4. Switch-on activity delay

The integrated switch-on activity delay starts the controller module not before a short time has passed and the steering mirrors have reached the zero position. The *Active*-LED will not shine during this delay.

5.5. Controller status signal

If the system is completely switched off (power-off), the Piezo actuators tilt the steering mirror into an extreme position. This is about 0.5 mrad (*PKS* mount) or 1.0 mrad (*PSH* mount) from the zero position. However, the system is equipped with a TTL output that can be used to block or electronically switch off the laser in order to avoid damage by the misaligned beam. The level is HIGH whenever the controller module is active and the steering mirrors are in the correct range or in zero position. It is LOW if the module is active and one of the actuators is out of range. (If the controller module is not active, the level is always HIGH.)

5.6. Bandwidth limitation switch

The controller bandwidth directly influences the quality of the stabilisation. The system can be operated with two different controller bandwidths. The default setting is the high bandwidth. However, especially in case of unstable mechanical set-ups or if a mutual interference of the control stages occurs it can be of advantage to choose the low bandwidth. Therefore a bandwidth limitation switch is integrated in the controller module (*Bandwidth*, see figure 7, H = high, L = low bandwidth). The bandwidth can be chosen independently for both stages.

Note: The system uses the intensity centre of the transversal laser beam profile. It does not reduce fluctuations of the laser beam profile itself.

6. Optical components

6.1. Steering mirror PKS

The mirror mount *PKS* has a tilting range of ± 0.5 mrad which is smaller then the range of the *PSH* mount. In comparison, it offers a wider free space behind the mirror. The mount can be adjusted manually for coarse adjustment. Figure 12 shows a photo of this mount.

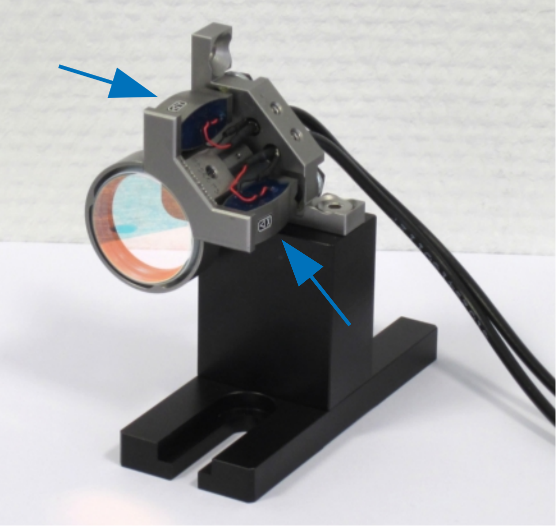

Figure 12: Steering mirror mount PKS with 1" mirror. The blue arrows point to the x and y labels

6.2. Steering mirror PSH

The mirror mount *PSH* has a wider tilting range of ± 1 mrad. It can also be adjusted manually for pre-adjustment to the zero-position. The mirror mount is optimized for low torque by means of reinforced springs and a balancing weight. The standard mount is used with 1" mirrors. But it can be equipped with adapters for bigger mirror sizes.

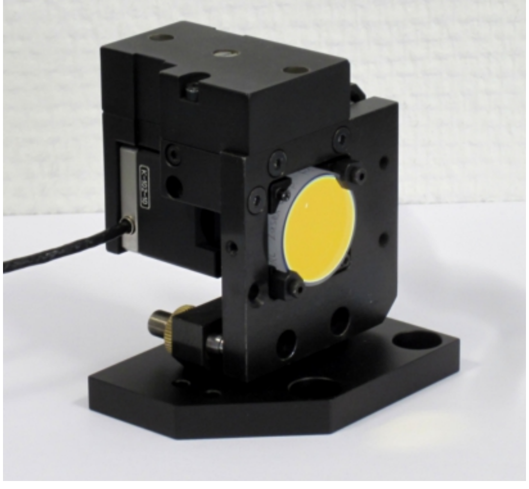

Figure 13a: Steering mirror mount PSH with 1" mirror

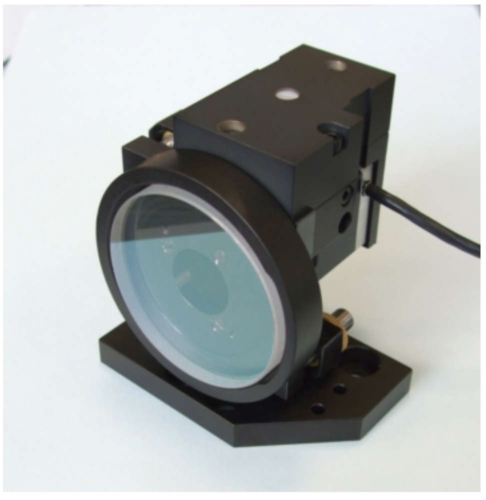

Figure 13b: Steering mirror mount PSH with adapter for 2" mirrors

Notes:

- The movable plate of the Piezo elements is sensitive to mechanical forces. Please avoid the impact of strong forces or torsional moments on this plate. The Piezo stack is directly attached to this plate.
- If you intend to remove the 1.5" or 2" adapter you should be especially careful. We can provide a specific instruction and a tool for this purpose.

6.3. Detectors (4-quadrant diodes)

Figure 14a shows the front side with the detection area of the standard 4-quadrant diode. The outer dimensions of the PSD housing are identical. Figure 14b shows the same side for the UV detector which is available on request.

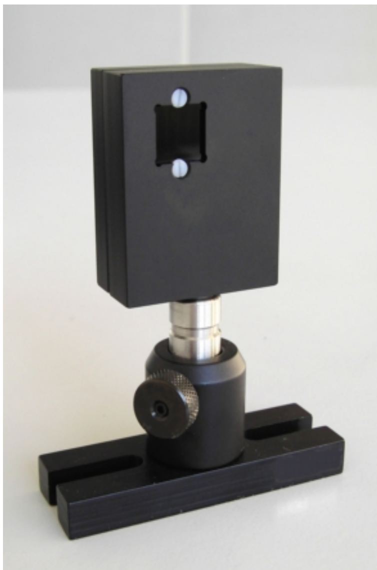

Figure 14a: Standard detector (4 quadrant-diode with sensitive area of 10x10 mm^2)

Figure 14b: UV detector (4 quadrant-diode with sensitive area of 3x3 mm^2)

7. Drawings

7.1. Mirror mount PKS

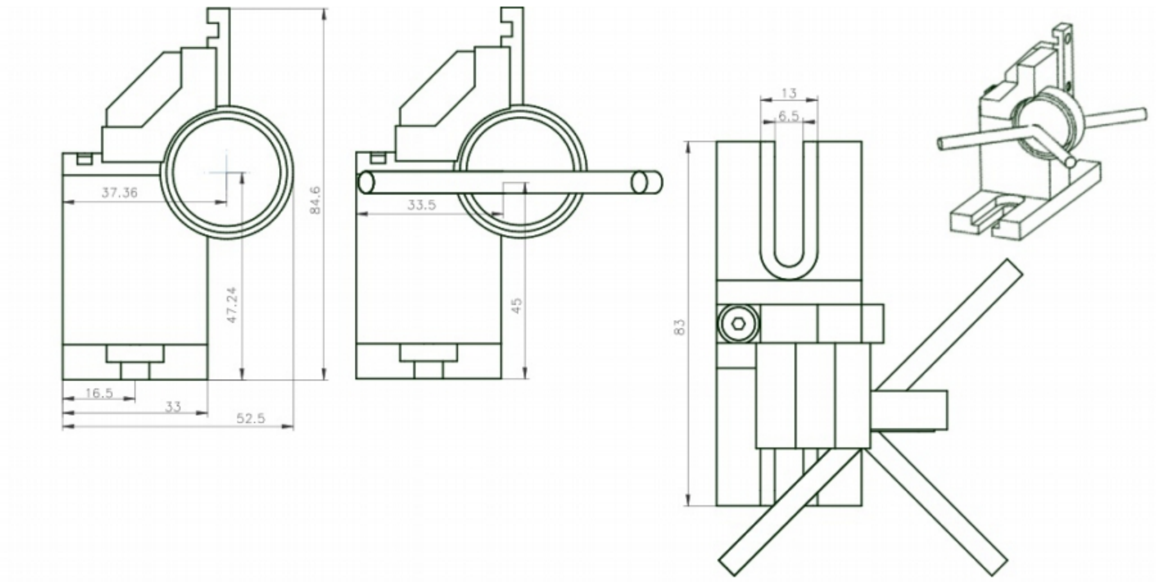

Figure 15: Mirror mount PKS. For a better overview a typical path of a laser beam is displayed.

7.2. Mirror mount PSH

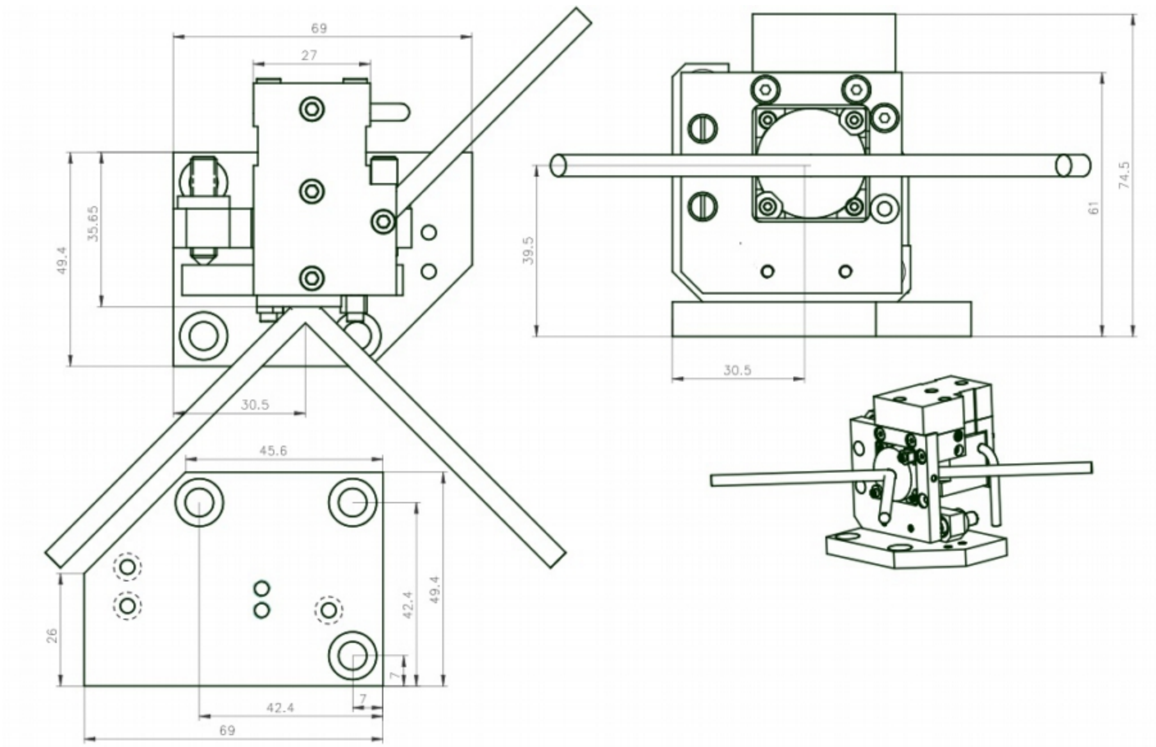

Figure 16: Mirror mount PSH. For a better overview a typical path of a laser beam is displayed.

7.3. Detector housing

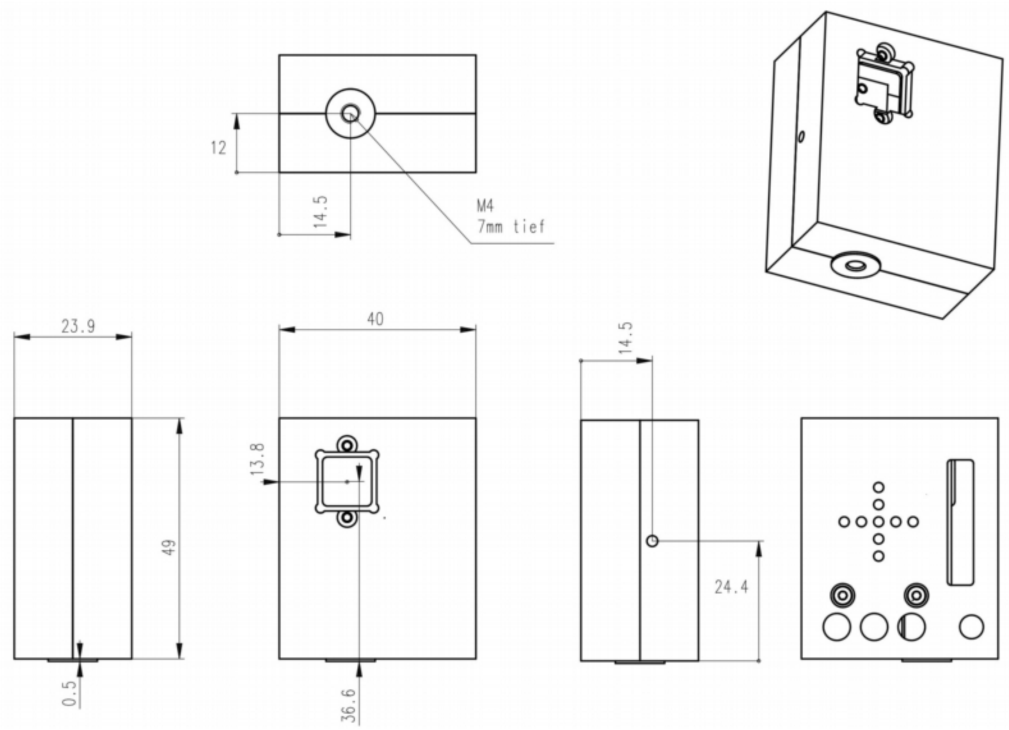

Figure 17: Standard detector housing

8. Troubleshooting

8.1. No signals on display

Please check if the power line chord is connected to a conducting power plug and if the power switch at the controller unit is activated. If everything is okay with the power line, please contact the manufacturer or distributor.

8.2. No signals on detector

Please follow the instructions in section 4.5 and check if an aperture or edge is blocking the laser. If the laser beam hits the sensitive area of the detector another reason can be that the chosen filters are too strong. In that case the filters should be exchanged.

8.3. The laser beam is not correctly positioned

Please check the following issues:

i. Are all LEMO plugs (x and y) of each steering mirror correctly connected to the controller electronics?
ii. Is the laser power in the allowed range?
iii. If the red *Range*-LED is on:
   a. Are all cables connected as described in section 4.4?
   b. Is the initial position of the laser beam in an acceptable position? If the initial position has changed strongly the closed-loop control does not work in the linear range any more. Please refer then to section 4.6.
   c. Is the direction coding correct?

8.4. The steering mirrors make exceptional noise

Please **immediately** switch off the system. Irreparable damage to the steering mirrors can occur. Then check the laser power on the detectors and adjust it as described in section 4.5. Make sure that the initial laser beam has not changed strongly and that it hits the 4-QDs. Take care that the beam is not blocked by an aperture or an edge anywhere in the beam path. This could be the case at the cut-out of the Piezo actuator. If the red *Range*-LED is on, the closed-loop control does not work in the linear range any more. Please refer to section 4.5 then.

8.5. Laser position is not stable

If the automated stabilisation of the laser beam does not work although the controller is active this might be due to a wrong direction coding of the 4-QD inputs (see section 4.6). Please check the direction coding.

Another reason might be an unstable mechanical set-up leading to oscillations of the system. Usually this phenomenon is accompanied by an exceptional humming noise. E.g. high positions of components (especially of those carrying the Piezo elements) can lead to mechanical instabilities. In this case a better stabilisation can be achieved with a lower controller bandwidth. Please activate the bandwidth limitation switch (see section 5.6).

9. Safety

The system has left our factory in a faultless state. Please store and operate the system in dry environments in order to maintain this state.

The device was designed and manufactured according to DIN EN 61000-3-2 and satisfies the requirements of the European EMC Directive 89/336/EWG.

Labels

Figure 18: Labels on the controller electronics (left) and on the detectors (right)

10. Check list for laser data

For the final layout of the system and for an optimal support of your integration it can be helpful to know your laser and set-up data. You can send us your data according to the following compilation:

customer	....	
wavelength / range	....	
average laser power	....	
pulse duration	....	(fill in “cw” in case of a cw laser)
repetition rate	....	(not applicable in case of a cw laser)
beam diameter	....	
beam profile	....	(qualitative specs as “Gaussian”, „elliptical”, etc. are sufficient)

10.1. Set-up data

If possible, please send us a drawing or a photo or your intended set-up. We can then give you recommendations for the integration of the stabilisation system. We have our focus on an easy arrangement of the optical components and on appropriate distances between actuators and detectors (“arm lengths”) since they determine the reachable angular resolution.

10.2. Actuated mirrors

Please let us know if we shall provide the mirrors:

Who will provide the mirrors? ☐ Customer

☐ MRC (on request, on account)

The following mirror sizes are recommended:

- standard: diameter 1", thickness 1/4" (1/8" as an alternative)
- on request: diameter 1.5" and 2"

11. Contact

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