μAligna Manual

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1 Introduction

TEM Messtechnik's *μAligna* is a multi-purpose device for controlling and stabilizing optical elements. Its ability to drive up to eight stepper motors allows it to control rotational actuators such as polarizing filters, as well as linear actuators such as mirror mounts. The *μAligna* device also features freely-assignable digital-to-analog converters which can, for instance, provide the input signals for HV-amplifiers and thus control piezo-actuators.

Input signals can be read by a high-precision analog-to-digital converter and processed for display, feedback or data logging. Examples of input devices are simple photo detectors to measure the laser intensity, position-sensitive detectors to measure the beam position and output signals from another control electronics system. These input and output capabilities can be combined to form closed regulator loops.

For instance, the *μAligna* device can act as a laser intensity stabilization system, by continuously measuring intensity values, comparing these to a specified set point and adjusting an attenuator accordingly.

In a somewhat more complex application, the *μAligna* device is able to stabilize the pointing of a laser beam. This requires two position-sensitive detectors which measure the translation and the angle of the beam and two motorized mirrors which actively adjust and regulate the beam pointing. Since the signal processing is exclusively done by a micro-controller, the *μAligna* device shows great flexibility. All important parameters and settings are accessible by interfacing the device with a PC, either using the dedicated program *Kangoo* or user-supplied software.

2 Hardware Description

2.1 μAligna Block Diagram

At the heart of the *μAligna* device lies a micro-controller, which handles all communications over the USB interface and over the I^{2}C or SPI bus. It also does most of the signal processing, such as the implementation of PID-regulators, the generation of control signals for micro-stepper motors or digital filtering. For reading input signals or acquiring data, the *μAligna* is equipped with an 8-channel, 16-bit ADC with an input range of $\pm\ 10V$. Signal output is provided in the form of two 8-channel, 16-bit digital-to-analog converter (DAC). The output range of these DACs is $\pm\ 10V$.
Furthermore, the *μAligna* device features up to eight power drivers (H-bridge drivers with PWM voltage control) capable of controlling eight micro-stepper motors simultaneously.
For beam stabilization systems with piezo actuators, the *μAligna* has a four-channel piezo driver, operating at $150V$.

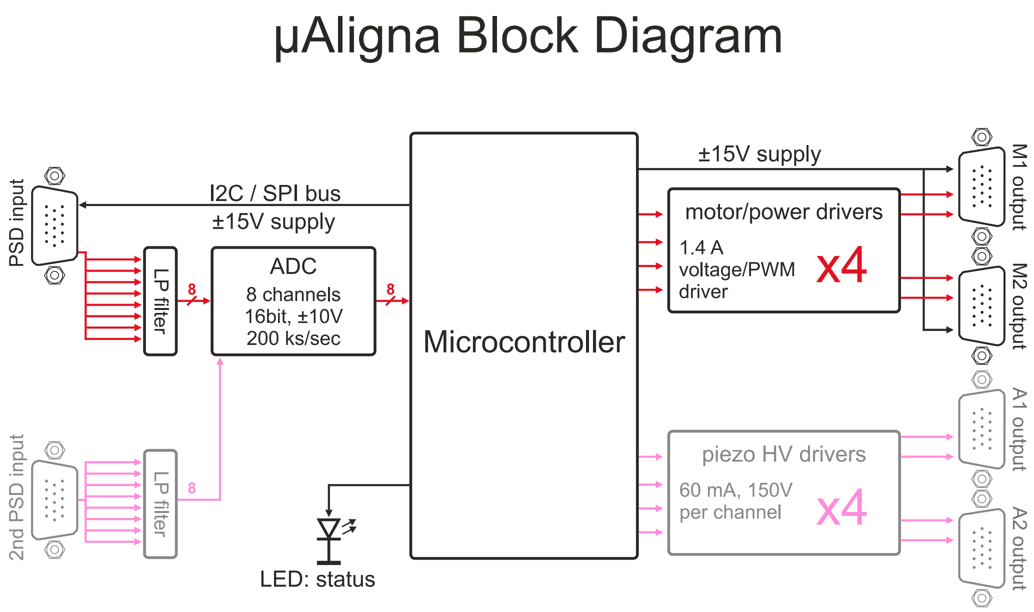


Figure 1: Block diagram. Optional components shown in gray.

The standard configuration of the *μAligna* electronics features one 8-channel input connector and two output connectors, configured to drive four stepper motors.
All input sockets (HD-15 plugs) have access to an I^{2}C/SPI data bus and to supply voltages of $\pm$15V.

2.2 Back Panel Elements

Figure 2 shows the back panel of the *μAligna* device with all connectors and UI-elements.

NOTE: The PSD detector and the actuators have identical connector cables. Please make sure that they are not interchanged before applying power to *μAligna* electronics. Plugging the detector into a motor output will most likely damage the detector.

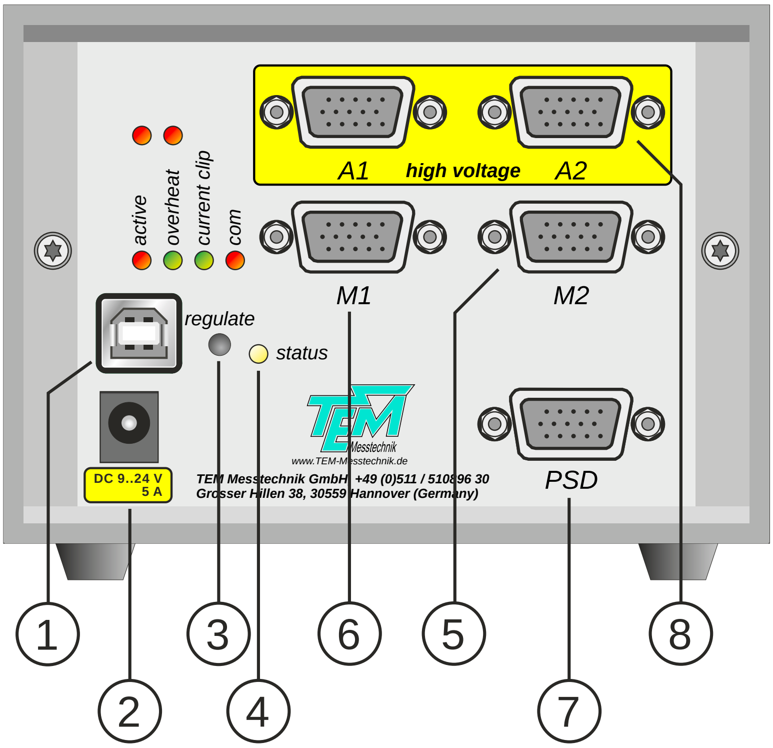


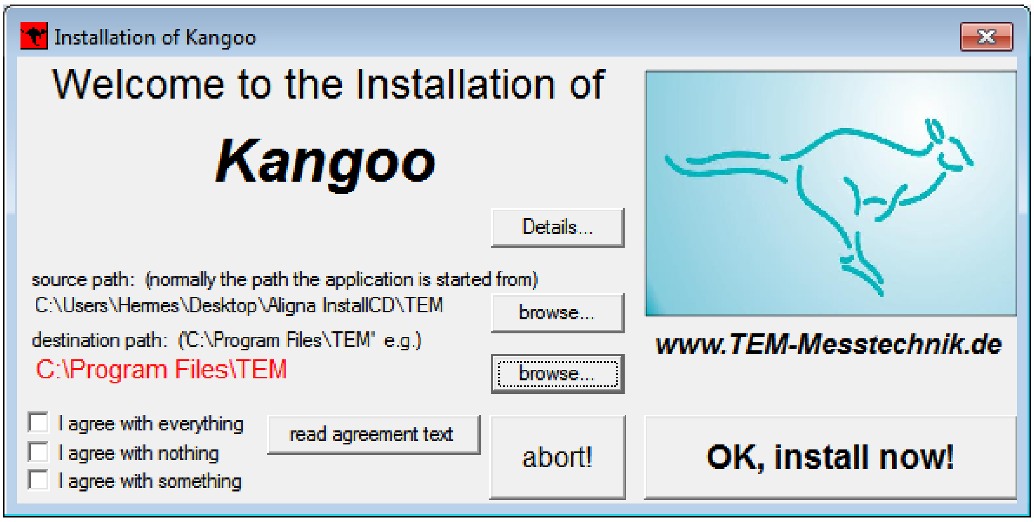
Figure 2: Back panel elements.

1	USB	USB communication with a PC, configured as a virtual COM port
2	Power	12V power jack
3	Key	switches the regulator on or off
4	LED	status LED, slow breathing: inactive, fast breathing: regulator on
5	M1	HD-15 connector (output) for motorized actuator 1
6	M2	HD-15 connector (output) for motorized actuator 2
7	PSD	HD-15 connector (input) for a PSD-4D detector
8	A1, A2	HD-15 connector (output) for piezo actuators

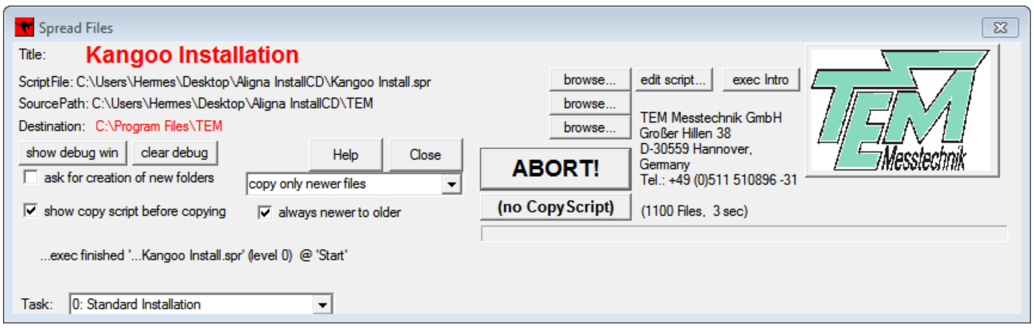
3 Software Installation

3.1 Installation of the Kangoo Software

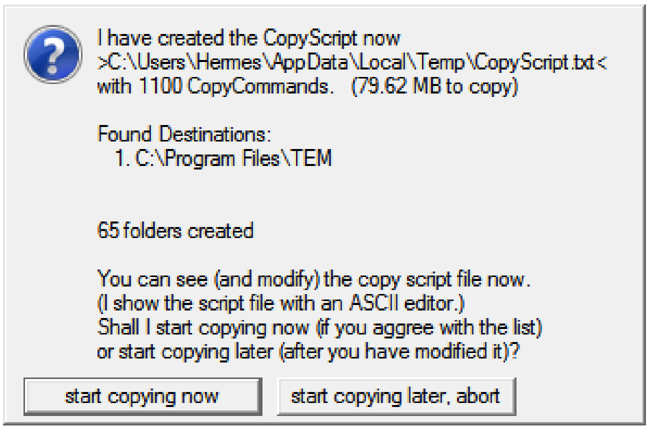
To install the Kangoo software, start the program "Install.exe" in the root directory of the installation CD. The installer will show a welcome screen with several options.

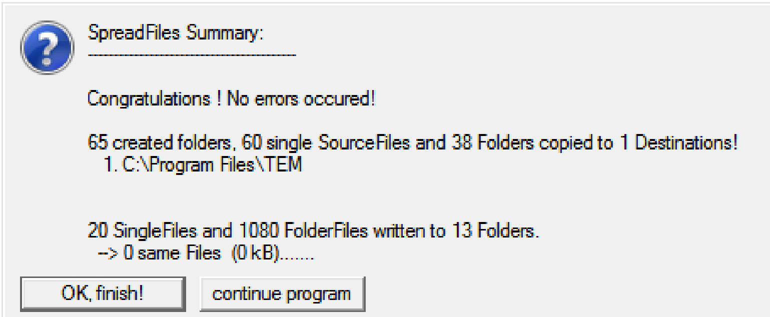


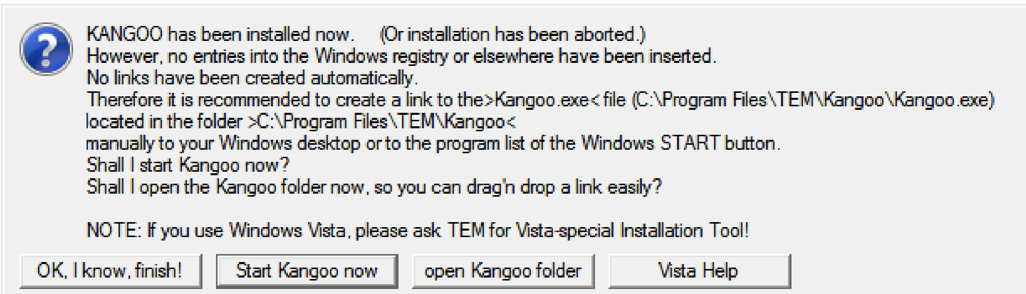
The default options should work fine, with the possible exception of the section "Destination Path", where the destination directory is specified. The standard directory is "TEM" in the "Program Files" folder. On Windows Visa or Windows 7 systems, please avoid the "Program Files" folder and choose and a different path, for example "C:/TEM". The button "OK, install now!" starts copying all required files from the source path to the destination path. During the installation procedure, the installation program checks all required files.



The program then creates a list of file copy commands. When this list is complete, you can check the list and start the copy procedure.







3.2 Installing the USB Drivers

Typically, when the USB connection between the micro-controller and a PC is first made, Windows will open the Found New Hardware Wizard. Here, choose to install drivers from a user-specified location. The necessary driver file is located in the directory "TEM/Service/USB Driver" in the Kangoo installation directory (or on the install CD). The Hardware Wizard will now finish the installation and no further configuration will be necessary.
Once the installation is complete, Windows will assign a COM-port. To find out which COM-port has been assigned, check for a new entry in the section "Ports (COM & LPT)" of the device manager.

3.3 Upgrading the Firmware

Please contact TEM Messtechnik for details about firmware upgrades.

4 Basic Operation

4.1 Using the Kangoo Software

The alignment of the parameters of a μ*Aligna* system is most easily done with the supplied software package *Kangoo*. Since the μ*Aligna* device is controlled by plain-text commands, it can be configured with any control software like LabView, TestPoint, or other programs written in VisualBasic, C++, C#, etc. However, to become acquainted with the system it is highly recommended to use *Kangoo* and benefit from the multitude of built-in functions and algorithms specifically targeted at laser beam stabilization using μ*Aligna*. Note that the *Kangoo* software and the configurations applicable to pointing stabilization are compatible with both the μ*Aligna* and the more extensive *Aligna* system.

Kangoo is a comprehensive measurement and controlling software system, which can be adapted to control completely different applications (Controlling a μ*Aligna* or *Aligna* system is just one of a long list). A detailed description of *Kangoo*'s functionalities can be found in Appendix B. Here, only a short guide of the software's basic use is given.

4.1.1 Configuration "Aligna User Menu"

The configuration *Aligna / BeamLock Menu* leads to different user configurations. A short explanation of each button and the corresponding configuration is given in the status line when the mouse pointer hovers over the respective button. Some of the individual configurations will be described in following sub-chapters.

- BeamLock Basic Use: General use of μ*Aligna* or *Aligna* systems or even PSD systems (without actuator control or servo loops)
- measure OCL Matrix: This configuration is used to teach the system the optical setup and to tune the regulator performance.
- Gray buttons are pointing to a configuration which is not enabled with your software or hardware version.

4.1.2 Configuration "BeamLock Basic"

BeamLock Basic is the main configuration for controlling the μ*Aligna* system. It provides access to the most commonly used functionalities while retaining enough simplicity for everyday use. The most important section is the "PSD input" section in the top-lefthand corner. It displays the intensity of the two PSD-detector chips on two bar-indicators and the current beam pointing in the large oscilloscope screen. Here, the red color represents the angle detector and green corresponds to the position detector. The "active" LED allows the user to disable requests of the current beam pointing. During normal operation, these should always be active. Below that LED, the "zoom" factor scales the oscilloscope display. Set this to 10 in order to see the full range of the PSD signals. Zoom in to see small beam movements or pointing fluctuations. The current beam pointing is displayed as digital numbers on the right, in the section "phys. units".
The section "PSD" controls settings inside the PSD detector. In particular, each PSD chip has a gain and electronic offsets associated with it. The gain allows the system to accommodate different laser

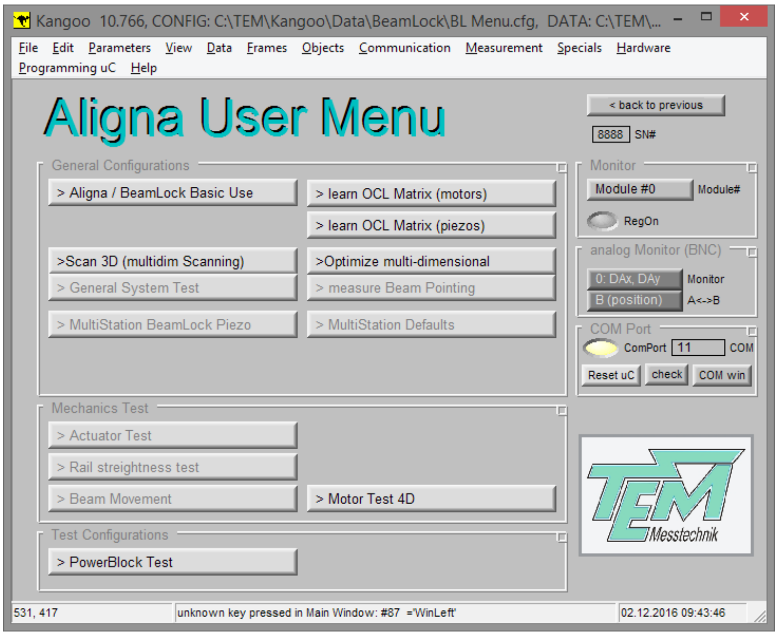


Figure 3: Kangoo configuration "Aligna User Menu"

intensities. "PSD A gain" and "PSD B gain" should always be adjusted such that the two intensity meters show about five volts. The button "AutoGain" below the intensity meters automatically adjusts both gains. Similar to the gains, there are offsets associated to each detector chips. With these offsets, the beam can be stabilized to positions other than the detectors' centers. Again, the buttons "AutoZeroA" and "AutoZeroB" automatically adjust the offsets to produce a $(0,0,0,0)$ pointing display. Please note that these gains and offsets are not stored in the detector, but in the μ*Aligna* electronics, so changing the controller does not retain the offset values.
The section "Thresholds" contains a number of threshold values for the intensity, the pointing and the regulator. Factory values should work well in most setups. For more detail, please refer to section 5.1.3.

4.1.3 Configuration "Learn OCL Motors"

The configuration *Learn OCL Motors* is used for the initial setup of your μ*Aligna* system. Here, *OCL* stands for "Output Crosslink Matrix". This matrix allows the actuators to achieve a nearly pure angle or position movement of the beam. A parallel beam movement, for example, is achieved by an angle change of the first actuator and a corresponding angle change of the second actuator by exactly the negative value of the first. Thus the resulting angle movement will be compensated for and a pure parallel beam translation results. So a position movement requires a combination movement of both actuator mirrors. By extension, a combination movement of both mirrors can act as a beam angle movement around any arbitrary point of the beam. Due to properties of the opto-mechanical setup, a movement of one actuator (say the X- direction of actuator 1) may cause an unwanted movement also in the Y-direction. This can be compensated for by suitable combination movement of all four actuators.
The *OCL matrix* translates the four detector signals (angle X,Y and position X,Y) into the corresponding actuator combination movements. In other words, this matrix stores the particular opto-mechanical setup, i.e., the positions and orientations of both actuators and the detector. Hence,

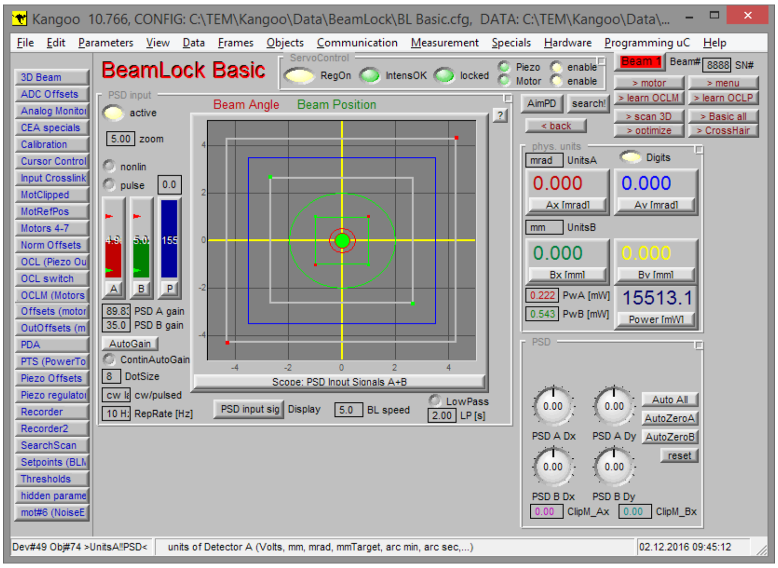


Figure 4: Kangoo configuration "BeamLock Basic"

when a *µAligna* system is first set up in a new optical layout, a new *OCL matrix* must be determined.

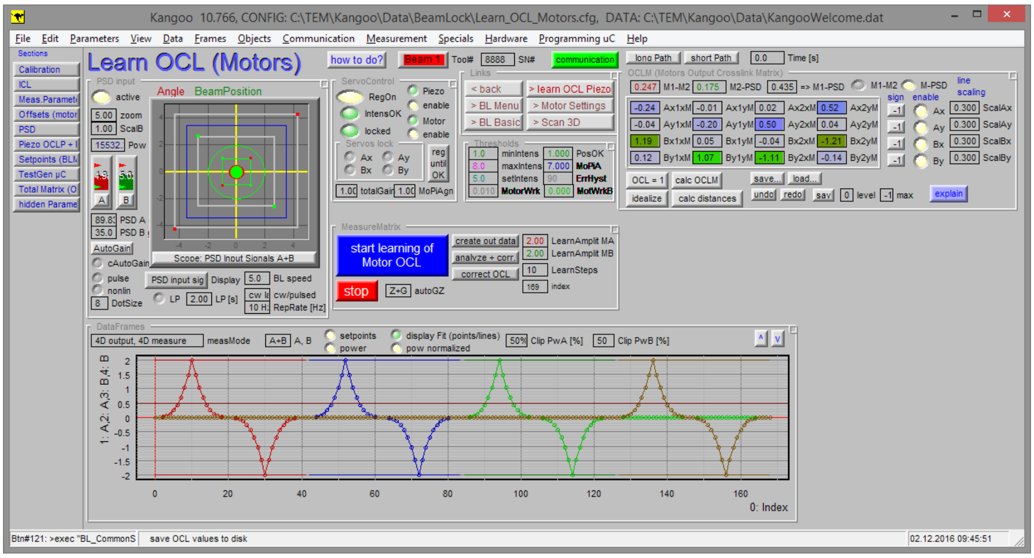


Figure 5: Kangoo configuration "measure OCL matrix"

The *Kangoo* software can perform a measurement cycle to automatically determine the correct matrix. The basic steps for this are as follows:

- Swtich on the laser and align the beam such that both detector chips (A and B) are hit.
- Run the learning procedure
- Switch on the regulator to check whether the learning procedure was successful. If not, re-run the procedure.

Rough manual alignment: Please switch on the laser and use the knobs on the actuators to bring it into alignment. If the PSD-detector is positioned correctly, both PSD-A and PSD-B should be

hit by the laser. Use the two intensity indicators to the left of the scope to verify this. Hit the "AutoGain" button, which should adjust both intensity indicators to about $5V$.
Next, try to roughly align both angle and position of the beam to the detectors' centers (say to within $\pm 2V$).

Running the learning procedure: Choose "Learn Program: Motor OCL". The system will learn the OCL for the motor servos and the "Motors Output Cross Link Matrix" will become visible.

- Click "create out data" (Triangle data ramps are created by the micro-controller, and displayed on the PC)
- Click "start measurement!", which starts the learning procedure

If "autoGZ" is set to a non-zero value, the system will first perform a "PSD AutoGain" procedure. Then all four channels (A_x, A_y, B_x, B_y) will scan all actuators, using the current OCL matrix. You can watch the red and the green dots. The better the OCL fits to the real setup, the more independently the dots will move (to the right, to the left, up, and down, back again to the middle position, both for channels A and B). When the procedure has finished, a pop-up window asks the user whether the OCL matrix should be automatically corrected. Please hit "Yes, correct".

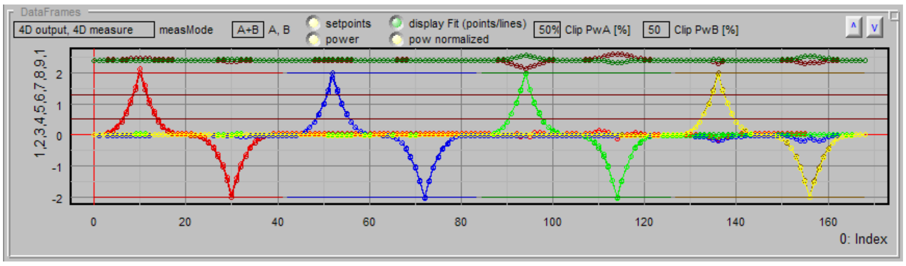


Figure 6: Measurement results with a good OCL matrix

Figure 6 shows the results of the learning procedure when the OCL matrix is well-adjusted. The four triangular curves show the detector outputs (A_x, A_y, B_x, B_y) while the actuators perform combination movements. Ideally, the results are as shown, meaning that an A_x combination movement only influences that detector channel. If a wrong OCL matrix is set, e.g. the unit matrix, the measurement results will look similar to Figure 7.

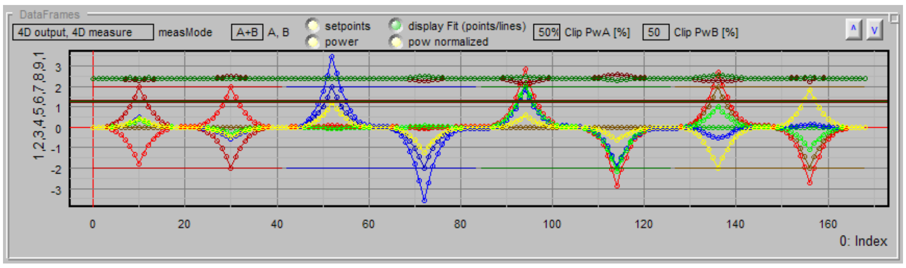


Figure 7: Measurement results with an unsuitable OCL matrix

In more complicated optical setups, it is possible that the learning procedure produces somewhat intermediate results, as shown in Figure 8. Here, the regulation will work, but not at its peak performance.

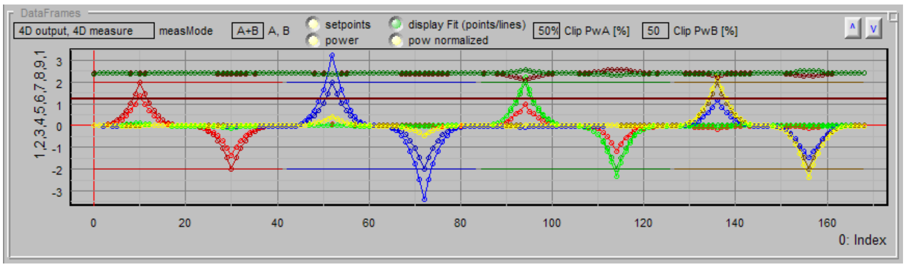
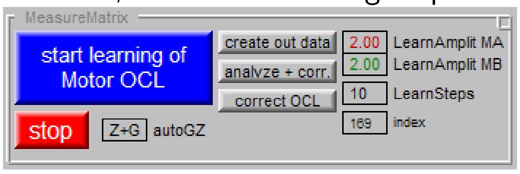


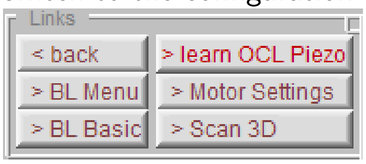
Figure 8: Measurement results with a roughly correct OCL matrix

It is recommended to re-run the learning procedure in order to improve the OCL matrix. Typically, the learning procedure should be run three times: Once to determine a good OCL matrix, a second time to improve residual errors and a third time just to verify the results (there is no need to correct the OCL when the results look good). If the automatic learning fails to produce good results, check whether the beam leaves the PSD chips during the procedure (i.e. check if the intensities fail). In this case, reduce the learning amplitude.

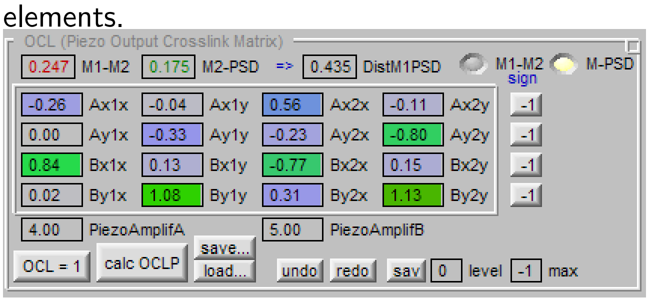


4.1.4 Piezo "OCL Matrix"

If your μ*Aligna* system has piezo actuators, those have their own dedicated OCL matrix. Please switch to the configuration "Learn OCL Piezo".



Then click on "start measurement!" to start the same learning procedure as before.
One speciality of the piezo learning procedure is the fact that the entries of the piezo OCL matrix will be clipped if their values exceed the range $-1.5 \ldots 1.5$. In this case, please increase the amplification factors "PiezoAmplifA" or "PiezoAmplifB", which will scale down the corresponding matrix elements.



Adjust "PsdPiezoAmplifA" if clipped values appear in the first two rows of the matrix and "PsdPiezoAmplifB" if clipping appears in the last two rows. Conversely, if all entries of the piezo OCL matrix are small (significantly below 1), then decrease these amplification factors. Next, repeat the automatic learning procedure.

4.1.5 Enabling the Piezo Regulator

After a satisfactory learning procedure, it is recommended to test the regulation. This is done by pressing the large "RegOn" indicator and the small Piezo enable indicator to the right of it. If your system has motor and piezo actuators, please also enable the motor regulator before saving the parameters to ensure that motors and piezos are both active. This way, the regulation system is able to compensate for both fast fluctuations and larger-amplitude slow drifts.

4.1.6 Saving Parameters

All micro-controller parameters are saved in the controller's RAM, which means that they will be lost after a reset or power cycle. It is however possible to save the current parameter settings and have them automatically loaded at start-up. This is done from the menu *Programming uC* → *Commands to uC* → *Command* >*VarSave*<, or by entering the command `VarSave` at the terminal. This procedure can be repeated at any time.

4.2 Running the Plug & Play Kit

Some *µAligna* systems are delivered with a Plug & Play kit, as show in Fig. 9. The purpose of this kit is to familiarize the user with the *µAligna* system and its parameters before transferring the opto-mechanical components into the machine or experiment.

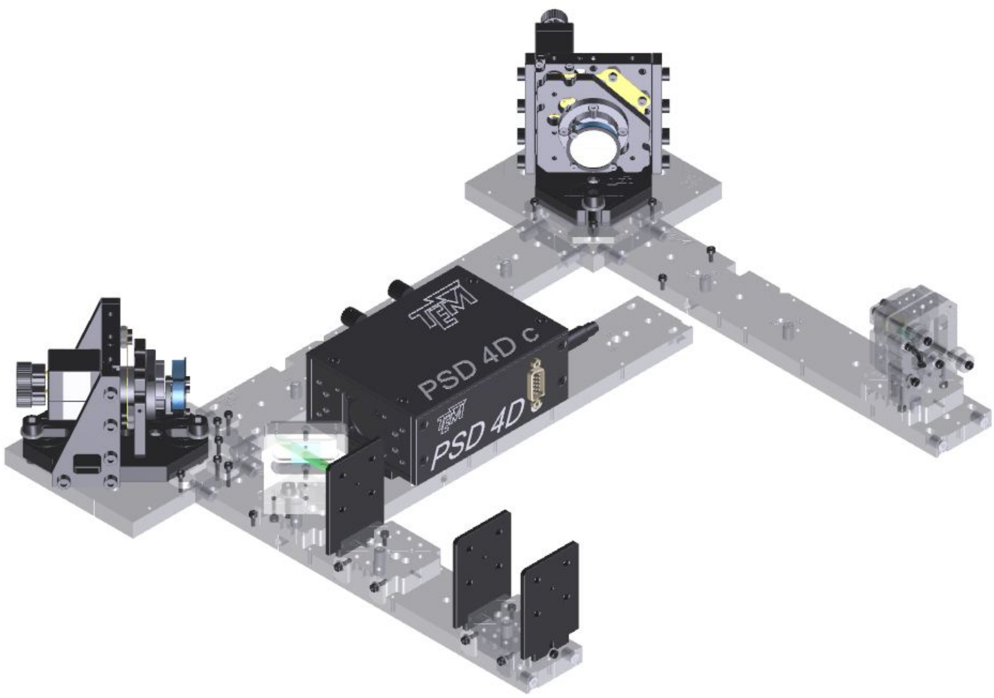


Figure 9: The *µAligna* Plug & Play Kit

The Plug & Play system includes

- some acrylic base plates

- a test laser
- the mirror mounts with actuators and mirrors (with aluminum coating for testing purposes only)
- the 4D detector
- a beam sampler plate (for testing only)
- two apertures, representing your experimental setup

The acrylic glass parts of the Plug & Play Kit connect magnetically and each connection is individually numbered, which makes the setup easy and fast. Once assembled , please connect all cables (they are also uniquely labelled), including the USB connection to a PC. Then install the USB drivers and the *Kangoo* software. Power up the *μAligna* electronics, start the software and open the configuration "BeamLock Basic". Finally, press the button "AutoGain" and activate the regulator. The *μAligna* is parameterized for the Plug & Play kit, so that the regulation will work straight away.

Next, the user is encouraged to use the Plug & Play Kit to "play" with different settings and parameters. In particular, we recommended trying

- the OCL matrix learning procedure
- manual motor offsets and reference switches
- PSD offsets with and without regulation

5 Advanced Operation

5.1 PSD

The detector delivered with a μ*Aligna* system measures the beam pointing in four dimensions, namely beam angle (A_x and A_y) and beam position (B_x and B_y). To this end, it contains two separate detector chips, A and B. In addition to these four pointing values, the detector measures the intensities at both chips, labelled Sum_A and Sum_B. These are used for normalization of the pointing signals, i.e., to make them independent of intensity fluctuations. The sum signals also indicate whether the laser hits both detector chips, and they allow the PSD-4D to be used to monitor the optical power. The detector returns its signals in the form of analog voltages to the μ*Aligna* electronics, with ranges of ± 10 V for the pointing signals and $0 - 10$ V for the sum signals. These signals can be monitored on an oscilloscope without disturbing the normal operation of the system (use the add-on "Aligna Con", which breaks out the signals to BNC connectors).

5.1.1 Beam Sampling

In almost all applications, the PSD-4D is placed behind a beam sampler which splits a sample beam off the main beam. The sample beam then enters the PSD-4D and the main beam continues to the target. The optical power required for good detector signals is about 100 µW for the visible spectrum and about 500 µW for near UV (say 355 nm) and near IR (say 1064 nm).
Clearly, for the *Aligna* system to work well, the sample beam's pointing must be a faithful representation of the main beam's pointing. Large intensity fluctuations in the sample beam can be mis-interpreted as pointing drifts by the *Aligna* system. Therefore, the beam sampling is crucial to the performance. In most applications, beam sampler glass plates with parallel surfaces or beam splitter cubes are not recommended, since they can suffer from interference effects. It is also very important to mount the glass plates without mechanical stress to avoid birefringence and deformation of the surfaces. Similarly, very thin glass plates (less than 1 mm) are not recommended. The following general points should be observed:

- A beam sampling glass plate or beam splitter cube located in the main beam path may influence the beam quality if the flatness, the transmission properties or the polishing is non-perfect. High-quality elements have to be used.

- A glass plate may cause interference effects due to multiple reflections between surfaces. Glass plates with a small angle (wedge plates) are preferred. However, they cause an angle deviation in the main beam.

- In femto-second laser applications, the glass in the beam path may cause unwanted dispersion effects. However, the problem of interference will not appear with fs laser applications, since the pulses are too short to interfere with reflected (and therefore delayed) pulses. Here it is not necessary to use wedge plates. In this case thin plates ($1...2$ mm) are preferred. In most applications, dispersion effects can then be neglected.

- An uncoated glass plate at $45°$ splits approximately 1 % of the beam for one polarization direction (p-light) and 8 % for the other polarization direction (s-light). These values differ by nearly one order of magnitude, which leads to a strong unwanted polarization dependence of the test beam intensity.

- In most applications, both values ($1\,\%$ and $8\,\%$) lead to test beam intensities far above the necessary intensities. These test beam intensities have to be reduced by strong optical filters, and they are lost for the main beam. With horizontally polarized laser light, it is possible to get very low reflections by using a reflection angle around Brewster's angle, $\approx 57°$. This angle will be slightly more difficult to align than a $45°$ angle. Alternatively, one (or both) surfaces can be AR (anti-reflex coated) for the target wavelength at $45°$ deflection. However, it is not easy (and not cheap) to find high quality broadband AR coatings with well-defined reflection grades.

- The transmission of a high reflecting mirror can be used as a sample beam. These transmissions are typically between $1\,\%$ and $0.01\,\%$. However, the polarization dependence of the transmitted beam can be large. Especially high-bred mirrors for high-power or high energy fs pulse lasers may have a polarization difference between s and p light by factor of 100 or even 1000.

5.1.2 Gains and Offsets

The PSD-4D detector has integrated pre-amplifiers, which transform the generated photo currents into voltages. These amplifiers have digitally controllable gains, which serve two purposes: Firstly, they can be adjusted to guarantee a good range of the PSD-4D's output voltages. In particular, the signals Sum_A and Sum_B should be kept at $5\,$V. Secondly, the gains allow the user to dial in detector offsets, which allows to stabilize the beam to positions other than the detector chips' centers. This is extremely useful, since it removes the need for exact mechanical placement of the PSD-4D. Changing these offsets while the regulator is active has the effect of moving the target beam in a controlled manner. In this way, the beam pointing at the experiment or target can be optimized fast and conveniently. Figure 10 shows the *Kangoo* section for setting offsets and gains. The gain values should be in the range $10 - 1000$. Lower values indicate that too much laser power

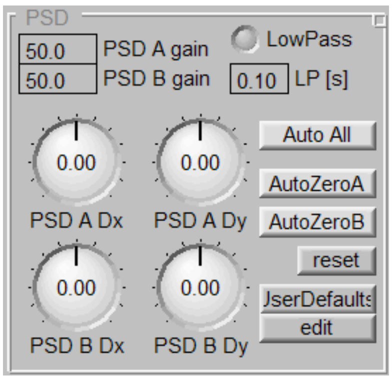


Figure 10: *Kangoo* section for setting gains and offsets.

reaches the detectors, and an optical filter or a similar method should be used to reduce the power. If the gain exceeds 1000, there is too little laser power (or the chip is not hit properly). When using the "AutoGain" button, it is advisable to check the gain levels afterwards for consistency.

5.1.3 Thresholds

The *Kangoo* section "Thresholds" allows to further control the behavior of the micro-controller. The three values *minIntens*, *maxIntens* and *setIntens* are connected to the intensity display: If either of

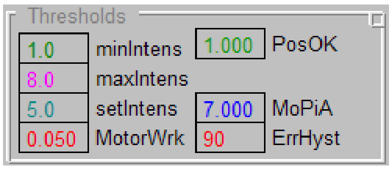


Figure 11: *Kangoo* section for setting thresholds.

the current intensity values lies outside the minimum or the maximum threshold, the regulator stops working. This is a safety feature, to ensure for example that the regulator does not react to environment light when the laser is blocked.
The *MotorWrk* threshold affects the motor regulator: If all pointing values are within this threshold, the regulator remains inactive. The *MotorWrk* value can be set to zero to ensure continuous regulation.
The threshold *PosOK* affects the reaction when the regulator is switched off. If, at that moment, all pointing values are within this threshold, the actuators remain at their current position. If however, the pointing lies outside the threshold when the regulator is switched off, the micro-controller assumes that the regulator did not work properly. It then re-sets the actuators to the position where the regulator was activated. This means that, if the regulator ever “runs away” (maybe because of an unsuitable OCL matrix), the best course of action is to simply switch off the regulator again.

5.1.4 Calibration

For a standard μ*Aligna* system , the displayed pointing values are already calibrated to physical units. The angle is shown in milli-radiants and the position in millimeters. In addition, the motorized actuators are calibrated to milli-radiants, so that an offset of "1" on any of the motors will cause the beam angle to change by one milli-radiant.

5.1.5 Pulsed Lasers

For the operation of the μ*Aligna*, one needs to distinguish between pulsed and continuous wave (CW) lasers. We will subdivide the lasers into the following categories:

1. CW lasers: These lasers are the easiest to handle, because the detectors receive continuous information about the momentary beam pointing.
2. Pulsed lasers with high repetition rates (15 kHz . . . $>$ 1 GHz): The μ*Aligna* electronics contains low-pass input filters which average over multiple pulses and flatten the electronic pointing signals before sampling. The operation is largely the same as for CW lasers, but the signal-to-noise ratio of the detector signals may be slightly worse.
3. Pulsed lasers with slow repetition rates (1 Hz . . . 15 kHz): To regulate the pointing of slowly repeating lasers requires special *sample & hold* electronics to process the detector signals. To activate these, change the setting *cw/pulsed* from “CW” to “pulsed”.
   The μ*Aligna* is able to generate an internal trigger signal from the PSD-signal. If the user wants to scan the beam and is thus leaving the detector one needs to feed in an external trigger signal. Internally, each detected laser pulse is processed and used for a single cycle of

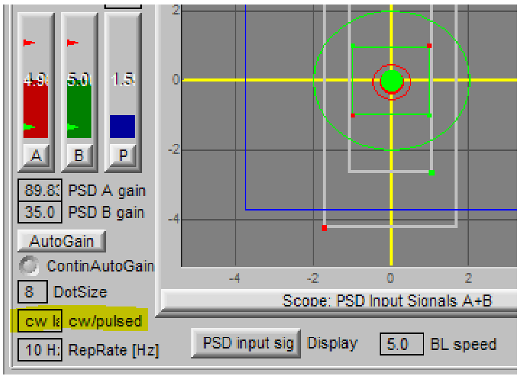


Figure 12: Location of the cw/pulsed device

the regulator. After that, the regulator goes into a hold state until the next pulse is detected. Therefore, the *μAligna* electronics work with arbitrarily low repetition rates. At low repetition rates, it may be necessary to tune the regulator gains for optimal performance.

Setting up the pulsed detection

To understand how to set up the pulsed detection of the *μAligna* we explain the detection principle of pulsed lasers used for our pointing stabilization. Usually a short pulse saturates any detecting device (photodiode, PSD) and the pointing information is corrupted. Thus the electric signal of the photodiode is stretched by a low pass filter to spread the energy over a bigger time section. This stretched pulse is processed by the μC.

The *μAligna* distinguishes between two variants to sample the signal. Below 4 kHz the beam is sampled twice. One sample is taken at the peak and on at idle level. The difference between these two samples is the photodetector value. This way DC offsets like environmental light or 50 Hz hum will be ignored. Figure 13 shows the principle of differential pulse sampling. After getting the pulse trigger the μC waits a defined *Pulse-Delay* takes the first sample and, after a second *Pulse-Delay*, takes the sample in idle state.

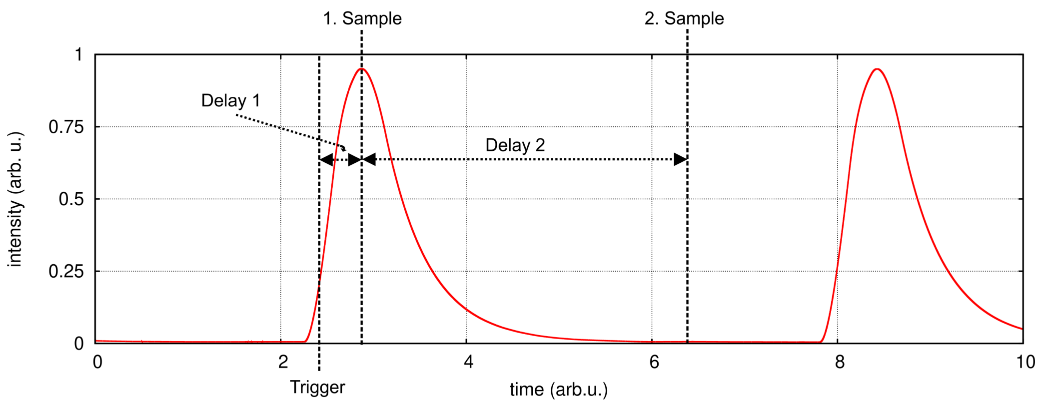


Figure 13: Differential sampling below 4 kHz

At higher repetition rates the pulses begin to overlap each other and differential sampling will lead to wrong readings. The normalization will not work properly and the autogain procedure may fail.

Therefore the system only takes one sample after a *Pulse-Delay* at repetition rates above 4 kHz (see Figure 14). Please note that the detected beam pointing may vary if you change between the two sampling methods because the single sampling will add the environmental light to the detection.

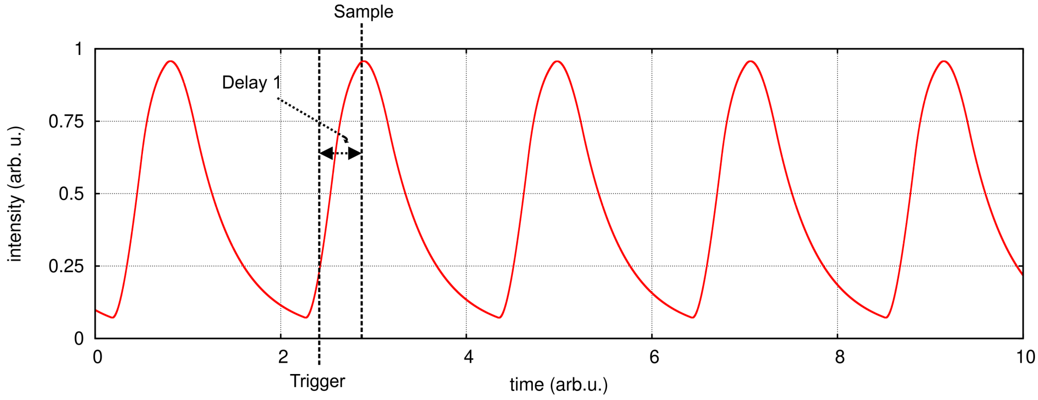


Figure 14: Single sampling above 4 kHz

To set the correct delays set the repetition rate of the system to a value $\geq$4 kHz. Then adjust the parameter *Pulse-Delay1* such that the reading is maxed. The standard value for this delay is set to 100 µs which should fit for most lasers. If you have a slow repetition laser set the repetition rate in the kangoo to a value below 4 kHz and adjust the *Pulse-Delay2* until the signal is maxed again.

Some Laser systems run in a low repetitive burst mode which has a variable burst length. In this case it might be suitable to set the system to single sampling. Otherwise the second sample may be taken when the burst is still active and the system gets no accurate signal.

5.2 Actuators

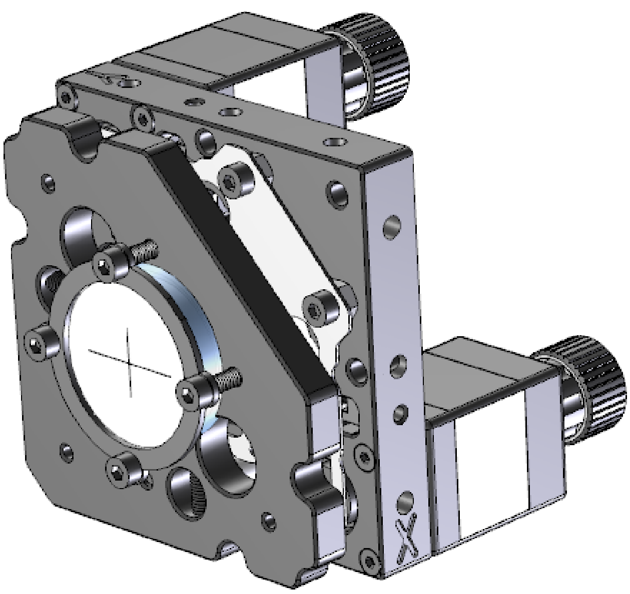


Figure 15: Standard motorized actuator *Aligna60*

The μ*Aligna* electronics are designed to drive motorized mirror mounts with micro-stepping actuators. The standard supplied actuators, *Aligna60*, are shown in Figure 15. They feature ultra-high resolution micro-stepping operation, a large angle range and optical end-switches which provide an absolute reference position. Although the actuators have knobs which allow manual mirror adjustment, it is highly recommended use the *Kangoo* software for this. The following sub-sections describe how to do this.

5.2.1 Motor Offsets

Kangoo distinguishes between "Motor Offsets" and "OutOffsets". The latter simply move the individual motors (hold down the `Alt` or the `Ctr` key while turning the offset knobs to switch to coarse or fine resolution). The former lead to combination movements by using the current "Output Cross Link" matrix. This way, the user can manually effect pure angle movements or parallel beam translations. Please note that the offsets are constantly overwritten by the regulator. Therefore, manual offsets only work when the regulator is off. The "reset offsets" button simply turns all offset knobs back to zero, and the motors return to their original positions. The button "here is zero" has a slightly different effect: It sets all offsets to zero, but without moving the motors, making the current position the new "working point" of the system.

5.2.2 Reference Switches

Each *Aligna60* actuator features two reference switches (one for X and one for Y) in order to know an absolute mirror position. The general process of using these switches is as follows:

- Adjust the actuator mirrors to good working positions.
- Learn the positions of the reference switches, by pressing the button "corr ref" in the section "Offsets (motorized)" in the *Measure OCL Matrix* configuration. All motors will run towards the reference switches and save the number of micro-steps it takes to reach the switches.
- Save the parameters ("VarSave").
- To go back to the original working positions of the mirrors, press the button "all ref". This causes all motors to run to the reference switches and then use the saved reference positions to go back to the original working positions.

5.2.3 Piezo Actuators

For the compensation of fast fluctuations, the μ*Aligna* system offers the piezo-based "BeamScan 1-inch" or "BeamScan 2-inch" actuators. They can be mounted in standard mirror mounts, and the mirrors mounted on the actuators are easily exchangeable. The "BeamScan 1-inch" has an angluar stroke of two milli-radiants, which translates to laser beam deflections of $4\,$mrad in *p*-direction and about $2.8\,$mrad in s-direction. The resonance frequency of the actuator with a 1-inch mirror attached is about $1.8\,$kHz.

In most cases, a combination of motorized and piezo actuators is the best solution, since this combines the large stroke of the motors with the fast response of the piezos. In this case, the μ*Aligna* runs the feedback loops for the two types of actuators sequentially: The piezos are always

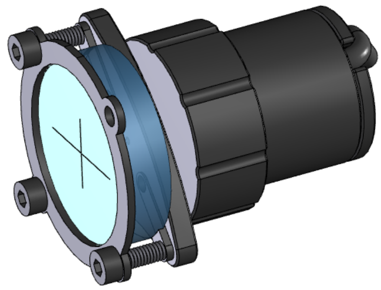
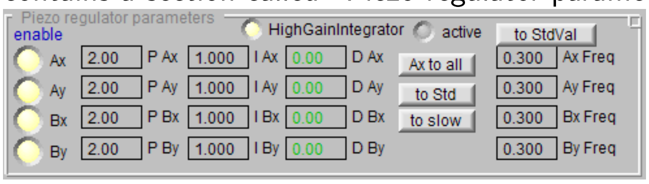


Figure 16: 1-inch piezo actuator *Aligna60*

active and compensate for all disturbances as far as their limited stroke permits. When they reach the limits of their stroke, the motor actuators activate and bring the piezos back to the middle of their working range. This way, both fast fluctuations and large thermal drifts are efficiently suppressed.

5.3 Tuning the Piezo Regulator

The piezo regulator is a digital *PI*-regulator, whose parameters can be adjusted for maximum performance. To do this, please change to the *Kangoo* configuration "measure OCL matrix", which contains a section called "Piezo regulator parameters".



At present, the *Kangoo* software cannot visualize the effects of changing the regulator settings. We recommend TEM-Messtechnik's *Aligna CON* box, which breaks out the PSD detector signals to BNC plugs, and an oscilloscope. From within *Kangoo*, the regulator setpoints can be user-adjusted. These setpoints can then be coupled to a software function generator to create a step change and visualize the regulator's step response on the oscilloscope.

5.4 PC Interface

The micro-controller of the μ*Aligna* box is accessed via USB using `ASCII`-formatted text strings. Each string hast to be terminated by a carriage return character ('`r`' or `ASCII` 13).

These strings separate into two general categories, namely variables and commands. A variable represents a user-accessible parameter which can be set, queried and stored. Examples of variables are the maximum speed of a motor, the regulator status and the serial number of the device. Commands execute single actions, such as an analog-to-digital conversion or the sending of output to the PC.

If the text string sent to the micro-controller contains an equal sign, it is interpreted as a variable. If this equal sign is followed by a space and an integer number, the text string is an assignment and the current value of the variable is updated. If the string ends after the equal sign (trailing spaces are irrelevant), the string represents a query and the micro-controller echoes the current value of the queried variable. Echoes can be suppressed by prefacing the variable name by a backslash.

text string	type	answer from μC
`SerialNumber= 8042`	assignment	`SerialNumber=8042`
`SerialNumber=`	query	`SerialNumber=8042`
`\SerialNumber=8042`	assignment, no echo	

Each variable has a maximum and a minimum value. If assignments lie outside this range, the assigned value is clipped and this clipped assignment is echoed back to the PC. The following list shows some of the more important variables which are available in the μ*Aligna* device.

variable name	range	description
`RegOnOff`	0 to 1	flag to activate the stabilization
`PsdAgain`	10 to 1000000	gain in percent for a *TEM* angle PSD
`PsdBgain`	10 to 1000000	gain in percent for a *TEM* position PSD
`MinIntens`	-1000 to 12000	minimum intensity for the stabilization
`Ax`	-10000 to 10000	current beam angle along x-direction
`Ay`	-10000 to 10000	current beam angle along y-direction
`Bx`	-10000 to 10000	current beam position along x-direction
`By`	-10000 to 10000	current beam position along y-direction
`SumA`	0 to 10000	current intensity at the angle detector
`SumB`	0 to 10000	current intensity at the position detector
`BL_IntensityOK`	0 to 5	flag to indicate if the intensities are OK
`BL_PositionOK`	0 to 1	flag to indicate if the pointing is OK

Text strings which do not contain equal signs are interpreted as commands. The possible formats are single words, a word followed by an argument or a word followed by an argument and a value. Examples are shown in the following table.

text string	type	µC action
`VarDump`	single word command	print all variable values
`ad 4`	command with argument	query ADC number 4
`da 3 7888`	cmd with argument and value	set DAC channel 3 to 7888

What follows is a list of the most important commands which the μ*Aligna* device can understand.

command name	arg	val	description
`VarSave`			save all current variable values
`VarDump`			print all vars and with current values
`CmdDump`			print all commands
`Reset`			resets the μC
`Upgrade`			sets the μC into programming mode
`AutoGain`			auto adjustment for `PsdAgain` and `PsdBgain`

6 Connectors and Electrical Specifications

6.1 Environmental Conditions

The device has been designed for operation in laboratory environments with temperatures ranging between +15°C and + 45°C. The device is not to be operated in hazardous environments. Avoid exposure to heat or to emissions of other electric equipment. Protect the system against humidity, dust, aggressive fluids or vapors.

6.2 μAligna Electronics

Dimensions:	$88 \times 125 \times 210mm$
Power adapter:	$100..240VAC, 50..60Hz$ to $12V$ DC, $3A$
Analog input voltage:	$\pm 10V$
Power consumption:	$< 60W$, typically $15W$

6.3 USB Interface

The USB connection to a PC appears as a virtual COM port with the following settings:

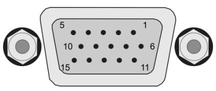
Baud rate:	standard: 57600
Data bits:	8 bits
Stop bits:	1
Hand shake:	standard: no hand shake
Command type:	simple ASCII commands

6.4 Mains Power Cable

Please use the included $12V$ power supply. When using a different power adapter, ensure that it provides a direct voltage in the range $9V$ to $24V$ and at least $3A$ of current, or $1.5A$ at $24V$.

6.5 HD-15 Connectors

CAUTION: The PSD input and the motor outputs have the same connector types. Never connect the PSD to a motor output! This will almost certainly damage the detector.
CAUTION: Never use monitor cables (VGA-cables) to connect to the μ*Aligna* electronics or extend the supplied cables! Such cables have internal connections which will almost certainly damage the electronics.
The pinning of the three HD-15 connectors are as follows:



Hd15 Socket

	PSD input	**motor outputs**	**piezo outputs**
1	Diff_A X	motor_X 0+	
2	Diff_A Y	motor_X 0-	
3	Diff_B X	motor_X 1+	
4	Diff_B Y	motor_X 1-	
5	analog GND	switch_X 0	
6	+15V	+15V	
7	-15V	-15V	
8	GND	GND	
9	I^2C clock	switch_X 1	
10	I^2C data	switch_Y 1	HV GND
11	Sum_A X	motor_Y 0+	output X
12	Sum_A Y	motor_Y 0-	output Y
13	Sum_B X	motor_Y 1+	
14	Sum_B Y	motor_Y 1-	
15	SPI clock	switch_Y 0	

7 Safety Instructions

Before operating the μ*Aligna*, please read this user guide carefully in order to avoid any damage of the device or connected equipment as well as any injury to persons.

CAUTION! The μ*Aligna* device is intended for laboratory use only. The μ*Aligna* device should be operated by trained personnel.

CAUTION! The μ*Aligna* device is used with lasers emitting visible or invisible radiation. Do not stare into the laser beam! Take precautions to avoid exposure of direct or reflected laser radiation.

CAUTION! The user is responsible for keeping the legal rules concerning laser safety that apply in their country. In Germany, this is the "Unfallverhütungsvorschrift BGV B2" of the "Berufsgenossenschaft der Feinmechanik und Elektrotechnik".

CAUTION! Use only the supplied power adapter and plugs or the corresponding ones for your country, as only this guarantees safe operation and grounding of the device.

CAUTION! The μ*Aligna* is intended for indoor operation with a temperature range of $+15°C$ to $+45°C$. Do not subject to heat, direct sunlight or the influence of other electric devices. Protect from humidity, dust, aggressive liquids and vapors.

CAUTION! The μ*Aligna* should be opened by trained technical personnel only. Before opening the housing, the device must be disconnected from the supply voltage, for example by pulling the power plug.

Please keep this manual within easy reach to refer to if needed. Give your μ*Aligna* to third parties only with this manual.

Appendices

A Principles of Beam Pointing Stabilization

A.1 Reasons for Pointing Instabilities

Laser beams, used in experiments or in industrial applications, can move in space for many reasons. Even small movements at the laser outlet may result in rather large movements of the laser spot, depending on the distance to the target and on the optical components in the beam path. In the following, some of the most important reasons of pointing instabilities are listed.

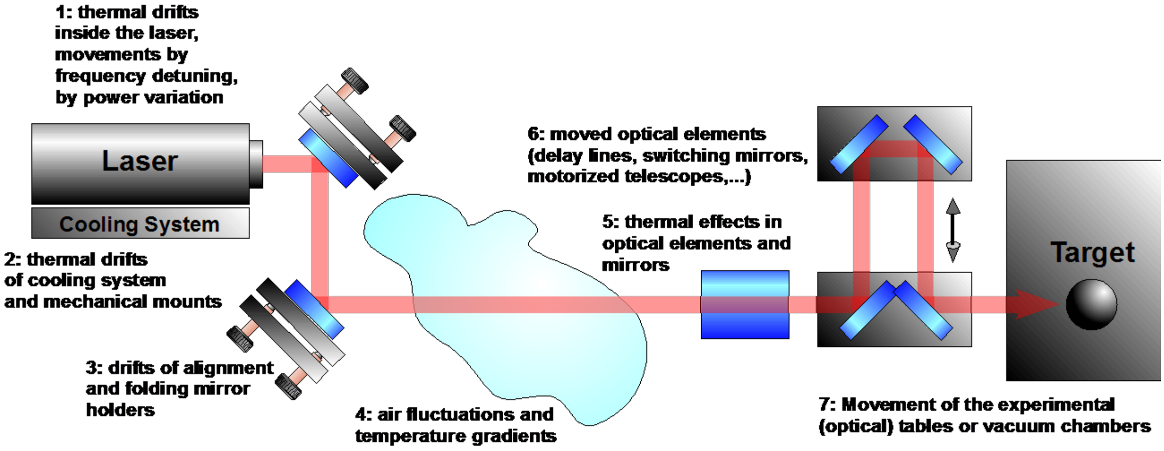


Figure 17: Reasons for pointing instabilities.

A.1.1 Thermal Properties of the Laser

Often large amounts of power is dissipated in small spatial regions; even small thermal movements can be transformed by collimating lenses of short focal lengths to relatively large angle movements. Local heating may be caused by pump diodes, by gas discharges, flash lamps, or by electrical excitation of the laser medium itself.

A.1.2 Thermal Movements caused by the Laser Cooling System

If the laser medium is dissipating heat, the laser is often cooled by Thermo-Electric Coolers, by fans or by water cooling systems. Those techniques create temperature gradients within the mechanical setup. If the laser is not constructed in a perfectly temperature-compensated manner, position and angle changes will result. Even if the laser medium itself is stabilized and held at constant temperature, the cooling system has to react to temperature changes of the environment and it has to compensate for the temperature change of the heat sinks. This will lead to pointing drifts.

A.1.3 Drifts of Alignment and Folding Mirrors

Adjustment tools and optical mounts typically consist of different materials: Aluminum, stainless steel, brass and other materials, each with different thermal expansion coefficients. Caused by changes of the environment temperature, the different thermal expansions can lead to position and — more critically — angle movements of the laser beam. The extend of these effects strongly depends on the construction, the materials, and of course on the temperature variations of the environment.

A.1.4 Air Turbulences and Temperature Gradients in the Air

Air fluctuations may cause large pointing fluctuations, particularly at long distances. But even one meter distance can produce pointing fluctuations of the order of some ten microns, which may be too much for critical applications. Using evacuated tubes for beam guiding over long distances helps, but even small angle changes in the path from the laser outlet to the vacuum tube will be transformed to large offsets at the end of the long tube. Please note that using evacuated tubes may cause drifts from local air pressure variations. In addition, evacuated tubes are expensive, bulky and inconvenient to handle. If a laser is lead between different rooms through holes in the wall, temperature and pressure differences between these rooms may lead to strong local air density gradients and thus to strong pointing drifts. Local pressure differences between the rooms (from air conditioning systems or laminar flow systems) will cause a strong air flow and air density turbulences.

A.1.5 Thermal Effects of Optical Elements

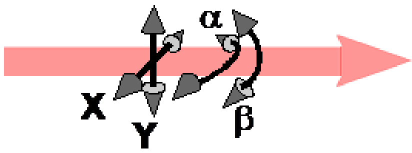
Every optical element absorbs a distinct amount of the laser beam, which is true for both reflecting and transmitting elements. So-called thermal lenses lead to well-known influences on the collimation properties of the laser beam. With high-quality materials and coatings or at low intensities the defocusing effects may be negligible. However even very small amounts of absorbed power lead to local temperature changes and thus to temperature gradients, which lead to a pointing deviations. The related time constants can be very slow (sometimes many hours).

A.1.6 Mechanically Moved Optical Elements

Sometimes optical elements have to be moved within the application:
Delay lines: In short pulse laser systems (ps or fs pulse durations), so-called delay lines are often used to superimpose two laser pulses in time. A set of several mirrors is moved by a motorized sleigh which has to be aligned exactly parallel to the optical path. This can only be achieved within limits: it is difficult to align better than some ten micro-radiants. In addition, a motorized rail is never perfectly straight. There will typically be curvatures of the order of some ten microns.
Motorized or manual telescopes or zoom expanders: In some applications, setups of optical lenses have to be moved (telescopes, zoom telescopes, expanders, . . .). It is impossible to position and move these elements exactly at the optical axis. Thus, a beam pointing movement will result from the movement of the optical element.
Switching mirrors: In certain applications, the laser beam is switched between two paths of the experiment by a manually operated or motorized switching mirror. The reproducibility of the mirror position may be very high, but it will not be perfect. Residual uncertainties of about ten micro-radiant are typical.
Movement of the optical table or vacuum chamber: Often the laser and the experimental target are mounted at different optical tables. Many experiments are located in small or large vacuum chambers. Those components will be at different and changing temperature values. This leads to relative pointing drifts, even if each element is very stable by itself.

A.2 2D or 4D Stabilization

The movement of a collimated beam can be separated into four dimensions: two translational ("X", "Y") and two rotational ("α", "β") degrees of freedom.



These degrees of freedom are not really independent: If, for example, one mirror mount drifts by $100\mu rad$ due to a change in the room temperature, then the translation error will be negligible close to the mirror. After one meter free propagation, however, this leads to a movement of $0.1mm$, after 10 meters this is $1mm$, which is certainly not negligible any more. (Note: the angle drift does not depend on the propagation length L in this example. In reality, however, angle changes due to air fluctuations increase with the length as $\sqrt{L}$).

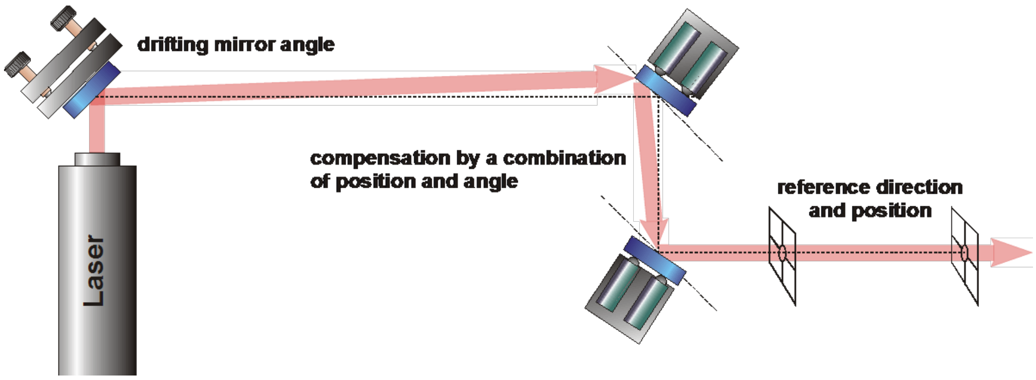


Figure 18: 2D drifts necessitate 4D compensation.

Even if the nature of the drift in this example is a pure angle drift it leads to a combination of angle and position movements at a certain distance, close to the experiment. This cannot be compensated for by a single moving mirror. It has to be compensated for by a combination of position and angle corrections, e.g. by two 2D moved mirrors, as depicted in Fig. 18.

In many applications it is not really necessary to keep the laser beam fixed both in position and direction at the place of the experimental target. In the case of laser material processing, for example, it is very important to keep the focused laser spot at an exactly defined position on the target surface. The angle, however, is not that critical. Therefore one might think that a 2D correction might be sufficient. A beam splitter separates a small part of the main beam. This part is handled exactly as the main beam (distances, focusing elements, etc.). If the laser spot is actively fixed by the actuator at the detector position, it will be fixed in the plane of the target, too. This works in principle.

However, the detector has to be positioned in an exact image of the target. Thus, its mechanical alignment has to be very precise. Often it is difficult to find the correct $z-$position for the detector. If this $z-$position is wrong, the stabilization can even increase the pointing fluctuations, rather than reduce them (see Figure 19).

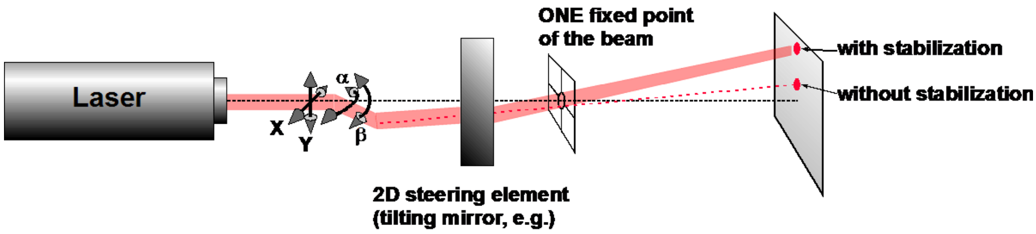


Figure 19: 2D stabilization can decrease pointing accuracies.

This shows that the fixed point of a laser beam has to be well-matched with the target requirements. In normal cases this requires additional optics in the detection path and it requires the precise alignment of the detector and the related optics.

With a 4D stabilization, in contrast, two points of the beam are fixed in space, instead of just one point in case of 2D. As a result, *all* points of the output beam are fixed. For this, it is not important *which* two points are fixed. They only need to have a certain distance from each other to achieve enough resolution for the angle measurement. The $z-$positions of the detectors are not critical at all.

If PSDs are used, rather than quadrant detectors, it is not important to hit exactly the center of the detectors: PSDs create a linear signal proportional to the spot position within the detector area, independent of the spot size and of the spot shape. Thus, PSDs do not have to be aligned precisely in X and Y position, because the servo loop (the user, respectively) can select the working point by applying a set point signal (X and Y, α and β) to the regulator. As a result, the PSD 4D detector box only has to be roughly aligned. The exact reference optical axis can be controlled by electronic signals, instead of fine mechanical alignment.

Of course a 4D lock system requires slightly higher effort in the control electronics (two 2D detectors, two actuator mirrors), but:

- A 4D stabilization leads to a much more robust and easy-to-handle system, without the necessity of mechanical fine alignment and with very low mechanical drifts.
- It compensates for both angle *and* position shifting effects.
- Both position *and* angle will be corrected without optimizing for one of them, without detailed analysis of the movements and drifts.
- No fine adjustment of the detectors is necessary.

The μ*Aligna* system gives you both possibilities: It can be switched to 2D or to 4D stabilization. Even in 2D mode, you have the advantage of monitoring both position and direction with the 4D detector. In addition, a 2D stabilization can be performed by a combination movement of all four actuators. Moreover, the servo speeds may be selected differently for angle and position stabilizations, which leads to increased precisions.

A.3 Actuator Placement

The *μAligna* system is very tolerant when it comes to actuator and detector placement. Naturally, the PSD-4D should be placed as close as possible to the experimental target, since any disturbances after the detector cannot be compensated for. Furthermore, observing the following points will lead to the best system performance.

- The two actuators should not be placed too close together (at least $50cm$ is recommended).
- The first actuator should be placed close to the laser (or to the main source of drifts).
- The second actuator should be placed close to the PSD-4D.

Additional optical elements between the actuators do not matter, as long as they do not clip the beam during the automatic learning procedure. Also, long distances between the actuators are not a problem.

B Advanced Kangoo Usage

8 Customer Service

In case of service needs, general questions, need of repair or warranty claims you will get quick and effective support at:

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Notes