Operating Manual

Translation of the original instructions

MicroSpotMonitor MSM

LaserDiagnosticsSoftware LDS 2.98

Revision 02/2019 EN

IMPORTANT!

READ CAREFULLY BEFORE USE.

KEEP FOR FUTURE USE.

Table of Contents

PRIMES - The Company

PRIMES manufactures measuring devices used to analyze laser beams. These devices are employed for the diagnostics of high-power lasers ranging from CO_2 lasers and solid-state lasers to diode lasers. A wavelength range from infrared through to near UV is covered, offering a wide variety of measuring devices to determine the following beam parameters:

- Laser power
- Beam dimensions and position of an unfocused beam
- Beam dimensions and position of a focused beam
- Beam quality factor M^2

PRIMES is responsible for both the development, production, and calibration of the measuring devices. This guarantees optimum quality, excellent service, and a short reaction time, providing the basis for us to meet all of our customers' requirements quickly and reliably.

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1 Basic safety instructions

Intended Use

The MicrsoSpotMonitor MSM has been designed exclusively for measurements carried out in or near the optical path of high-power lasers. Please observe and adhere to the specifications and limit values given in chapter 19, „Technical data“, on page 114. Other uses are considered to be improper. The information contained in this operating manual must be strictly observed to ensure proper use of the device.

Using the device for unspecified use is strictly prohibited by the manufacturer. By usage other than intended the device can be damaged or destroyed. This poses an increased health hazard up to fatal injuries. When operating the device, it must be ensured that there are no potential hazards to human health.

The device itself does not emit any laser radiation. During the measurement, however, the laser beam is guided onto the device which causes reflected radiation (**laser class 4**). That is why the applying safety regulations are to be observed and necessary protective measures need to be taken.
Observing applicable safety regulations

Observing applicable safety regulations

Please observe valid national and international safety regulations as stipulated in ISO/CEN/TR standards as well as in the IEC-60825-1 regulation, in ANSI Z 136 “Laser Safety Standards” and ANSI Z 136.1 “Safe Use of Lasers”, published by the American National Standards Institute, and additional publications, such as the “Laser Safety Basics”, the “LIA Laser Safety Guide”, the “Guide for the Selection of Laser Eye Protection” and the “Laser Safety Bulletin”, published by the Laser Institute of America, as well as the “Guide of Control of Laser Hazards” by ACGIH.

Necessary safety measures

DANGER

Serious eye or skin injury due to laser radiation

During the measurement the laser beam is guided on the device, which causes scattered or directed reflection of the laser beam (laser class 4). The reflected beam is usually not visible.

▶ **Please take the following precautions.**

If people are present within the danger zone of visible or invisible laser radiation, for example near laser systems that are only partly covered, open beam guidance systems, or laser processing areas, the following safety measures must be implemented:

- Please wear **safety goggles** adapted to the power, power density, laser wave length and operating mode of the laser beam source in use.
- Depending on the laser source, it may be necessary to wear suitable **protective clothing** or **protective gloves**.
- Protect yourself from direct laser radiation, scattered radiation, and beams generated from laser radiation (by using appropriate shielding walls, for example, or by weakening the radiation to a harmless level).
- Use beam guidance or beam absorber elements that do not emit any hazardous substances when they come in to contact with laser radiation and that can withstand the beam sufficiently.
- Install safety switches and/or emergency safety mechanisms that enable immediate closure of the laser shutter.
- Ensure that the device is mounted securely to prevent any movement of the device relative to the beam axis and thus reduce the risk of scattered radiation. This in the only way to ensure optimum performance during the measurement.

Employing qualified personnel

The device may only be operated by qualified personnel. The qualified personnel must have been instructed in the installation and operation of the device and must have a basic understanding of working with high-power lasers, beam guiding systems and focusing units.

Conversions and modifications

The device must not be modified, neither constructionally nor safety-related, without our explicit permission. The device must not be opened e.g. to carry out unauthorized repairs. Modifications of any kind will result in the exclusion of our liability for resulting damages.

Liability disclaimer

The manufacturer and the distributor of the measuring devices do not claim liability for damages or injuries of any kind resulting from an improper use or handling of the devices or the associated software. Neither the manufacturer nor the distributor can be held liable by the buyer or the user for damages to people, material or financial losses due to a direct or indirect use of the measuring devices.

2 Symbol explanations

The following symbols and signal words indicate possible residual risks:

DANGER

Means that death or serious physical injuries **will** occur if necessary safety precautions are not taken.

WARNING

Means that death or serious physical injuries **may** occur if necessary safety precautions are not taken.

CAUTION

Means that minor physical injury **may** occur if necessary safety precautions are not taken.

NOTICE

Means that property damage **may** occur if necessary safety precautions are not taken.

The following symbols indicating requirements and possible dangers are used on the device:

Hand injuries warning

Components susceptible to ESD

Read and observe the operating instructions and safety guidelines before startup!

Further symbols that are not safety-related:

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i Here you can find useful information and helpful tips.

CE With the CE designation, the manufacturer guarantees that its product meets the requirements of the relevant EC guidelines.

▶ Call for action

3 About this operating manual

This documentation describes how to work with the MicroSpotMonitor MSM and operate it with the LaserDiagnosticsSoftware LDS 2.98.
The software description includes a brief introduction on using the device for measurements.

This operating manual describes the software version valid at the time of printing.
Since the user software is continuously being developed further, the supplied data medium may have a different version number. Correct functioning of the device is, however, still guaranteed with the software.

Should you have any questions, please specify the software version installed on your device. The software version can be found under the following menu item: ***Help > About LaserDiagnosticsSoftware***.

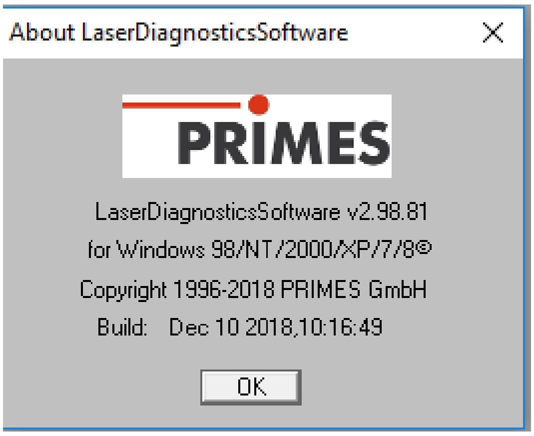

Fig. 3.1: Information regarding the current software version

4 Conditions at the installation site

- The device must not be operated in a condensing atmosphere.
- The ambient air must be free of organic gases.
- Protect the device from splashes of water and dust.
- Operate the device in closed rooms only.

5 Introduction

5.1 System description

The MicroSpotMonitor MSM determines beam parameters of focused laser beams with medium powers up to 200 W in a range between 20 micro meters and one millimeter directly in the processing zone.
The air-cooled system depicts the laser beam, which is attenuated by different beam splitter and neutral density filters, on a CCD sensor. On the basis of the determined beam distribution of a plane, the beam position as well as the beam radius can be derived. By means of the integrated z-axis and the measurement at different positions of the laser beam the described beam parameters are determined and logged.

The measuring objectives of the MicroSpotMonitor MSM are selected individually, depending on the beam source that is supposed to be measured. In this regard, the wavelength (248 up to 1 090 nm) as well as the magnification (3.3:1, 5:1, 10:1), which is determined by the focus diameter, are the essential parameters.

The dynamic range of the integrated CCD sensor is amplified to more than 130 dB via an irradiation time control, which enables caustic measurements over more than four Rayleigh lengths, as demanded in the standard ISO 11146.

Optionally, the MicroSpotMonitor MSM can be equipped with a filter wheel with neutral density filters (OD1 to OD5). This filter wheel enables the measurement of power densities between several W/cm² up to several MW/cm² without having to modify the system.

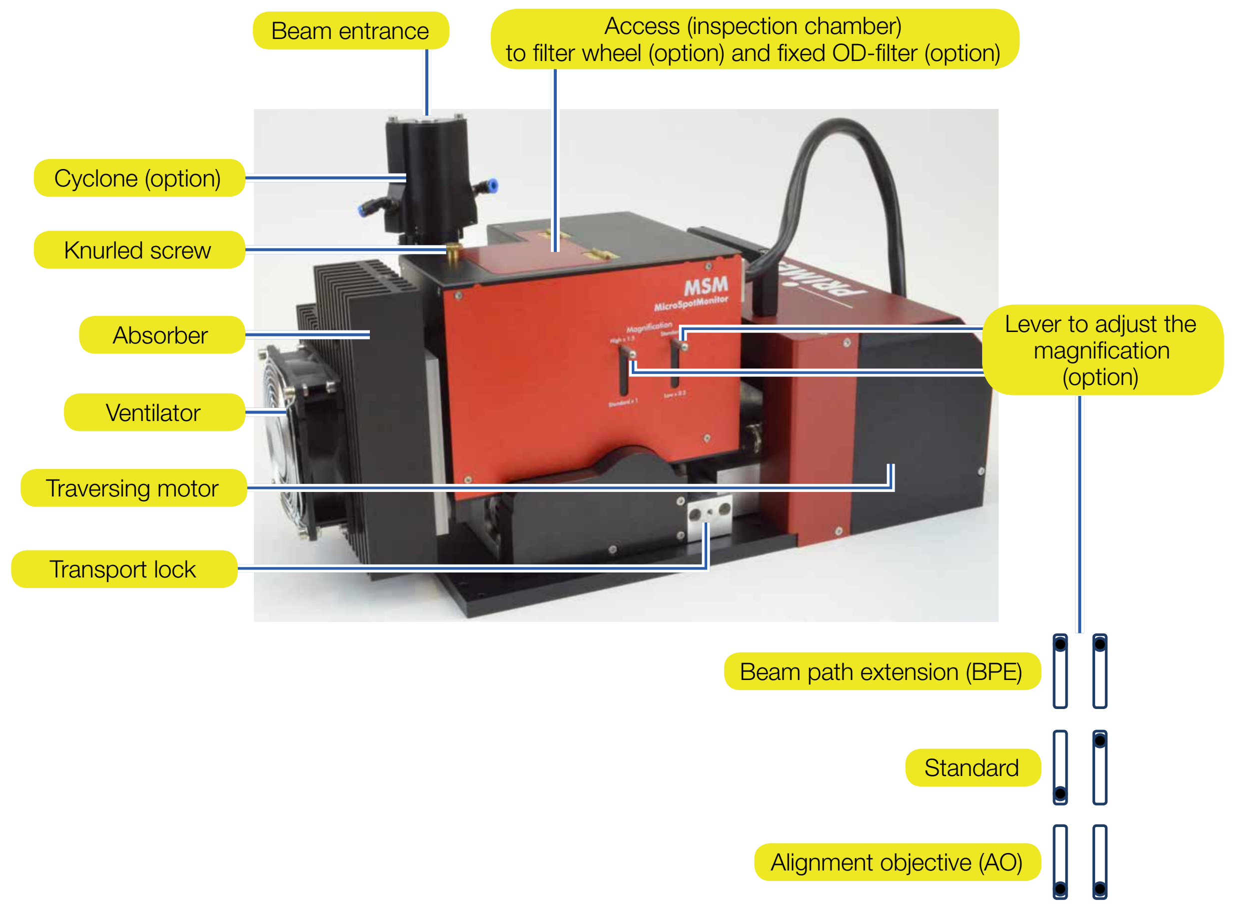

Fig. 5.1: Components of the MicroSpotMonitor MSM

5.2 Measuring principle

The MicroSpotMonitor MSM is a camera-based measuring system. Depending on the application, up to 7 different optical components can be in the beam path. The purpose and functioning of individual components is described in chapter 21.4, „Optical components“, on page 120.

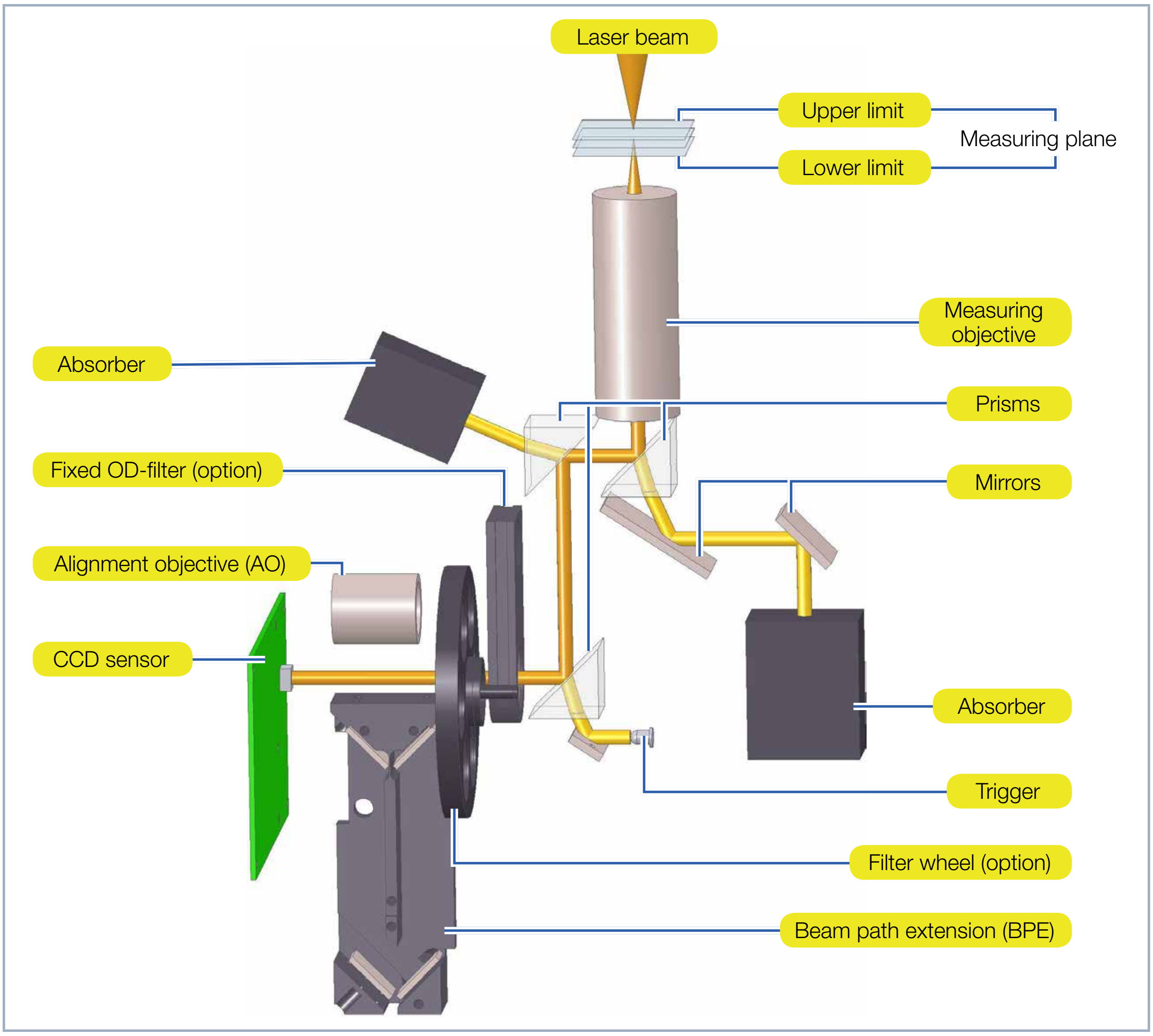

Fig. 5.2: Optomechanical design

5.3 Short overview installation

1. Taking safety precautions	Chapter 1 on page 9
2. Transport • Disassemble the transport lock	Chapter 6 on page 16
3. Installation • Make preparations • Set the installation position • Align the device manually • Mount the device firmly	Chapter 7 on page 17
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5. Electrical connection • Establish voltage supply	Chapter 9 on page 25
6. Connect with the PC • Via Ethernet or LAN	Chapter 9.3 on page 27
7. Installing the LaserDiagnosticsSoftware LDS on the PC • Software is part of the scope of delivery • Connect the MicroSpotMonitor MSM with the LaserDiagnosticsSoftware LDS	Chapter 11 on page 29
8. Measure • Follow the safety instructions • Select and insert the measuring objective • Observe damage thresholds • Perform measurement	Chapter 13 on page 82

6 Transport

WARNING

Risk of injury when lifting or dropping the device

Lifting and positioning heavy devices can, for example, stress intervertebral disks and cause chronic changes to the lumbar or cervical spine. The device may fall.

- **Use a lifting device to lift and position the device.**

NOTICE

Damaging/destroying the device

Optical components may be damaged if the device is subjected to hard shocks or is allowed to fall.

- **Handle the measuring device carefully when transporting or installing it.**
- **To avoid contamination, close the measuring objective with the cover provided.**
- **Only transport the device in the original PRIMES transport box (option).**

6.1 Disassemble the transport lock

After unpacking the device, the transport lock has to be removed first. The transport lock secures the linear actuator of the z-axis. It is located on the bottom plate and is fastened by means of 3 screws (see Fig. 6.1 on page 16).

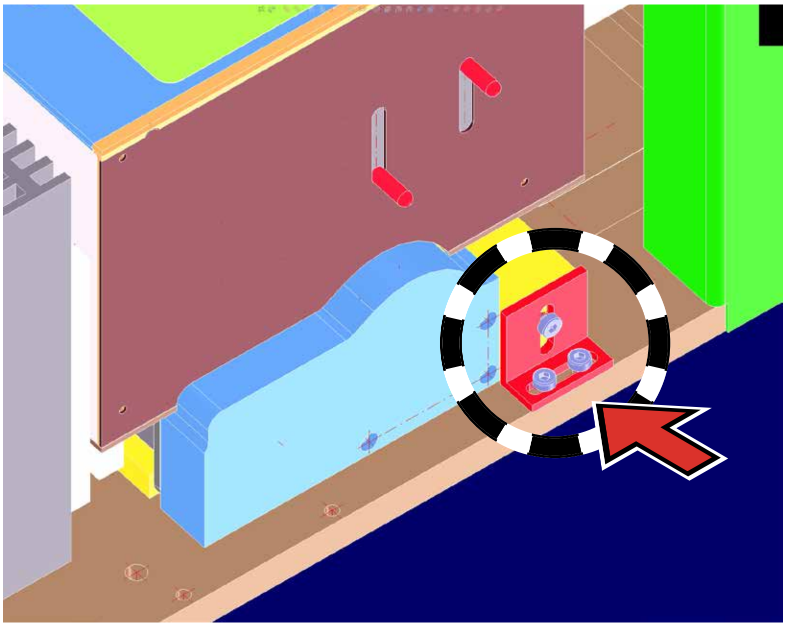


Fig. 6.1: Position of the transport lock

6.2 Assemble the transport lock

NOTICE

Damaging/destroying the device

The device must only be transported with a mounted transport lock.

- **Keep the transport lock for future use.**

Before transportation, move the MicroSpotMonitor MSM into the parking position (see chapter 12.5.17, „Position (menu Presentation > Position)“, on page 77) and mount the transport lock.

7 Installation

7.1 Preparation and mounting position

Check the space available before mounting the device, especially the required space for the connection cables and the movement range of the z-axis (see chapter 20, „Dimensions“, on page 116). The device must be set up so that it is stable and fastened with screw (see chapter 7.3 on page 21).

The MicroSpotMonitor MSM is designed to operate in a horizontal position with a beam incidence from above. With an optional side plate (order no. 801-004-060), operation with horizontal beam incidence is also possible.

NOTICE

Damaging/destroying the device

Obstacles in the movement range of the MicroSpotMonitor MSM can lead to collisions and damage the device.

- **Keep the movement range free of obstacles (cutting nozzle, pressure rolls, etc.).**

7.2 Manually aligning the MicroSpotMonitor MSM

7.2.1 Important conditions for the position of the focused laser beam

Due to the imaging characteristics of the measuring objective (see chapter 21.4.1, „Measuring objective“, on page 121) it is necessary for the laser beam focus to be positioned in a certain range above the measuring objective.

NOTICE

Damaging/destroying the device

The focus has to be in a defined range with reference to the measuring objective. In case it is too close or too distant, the optics might be damage in case of high beam intensities.

▶ **Use the enclosed alignment tool for the alignment.**

The size of the range in which the focus is to be positioned before the first measurement depends on the chosen measuring objective, the used wavelength and the type of focusing. The measurement range lies within an upper and a lower limit.

Upper limit

If the focus is located too high above the measuring objective, a focus on the image-sided beam path can develop. Together with too high beam intensities, the optics might be damaged.

Measuring plane

The beam distribution of the measuring plane is displayed on the CCD sensor.

Lower limit

If the focus is too close to the measuring objective, it can – depending on the type of focusing and the power used – damage the entrance lens.

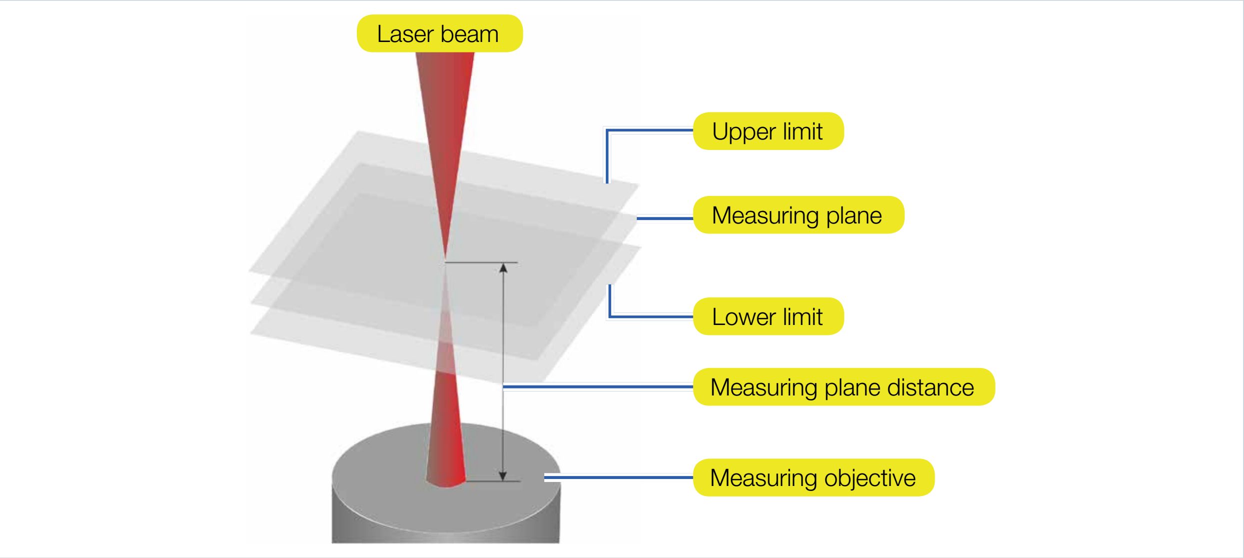


Fig. 7.1: Measuring range of the MicroSpotMonitor MSM

7.2.2 Positioning the focused laser beam above the measuring objective

The measuring plane distance equals the distance of the measuring plane from the upper corner of the measuring objective or the protective glass.
In order to be able to align the MicroSpotMonitor MSM beneath the laser, an associated alignment tool is provided with each measuring objective. By means of this alignment tool and a pilot laser beam, you can position the device with the necessary accuracy.

1. Place the alignment tool directly on the measuring objective (see Fig. 7.2 on page 19) or on the protective window holder on the measuring objective (see Fig. 7.3 on page 19).
- The upper edge of the measuring objective corresponds to the z position of the measuring plane.
- When using a protective window with a thickness of 1.5 mm, the measuring plane moves upwards by approx. 500 µm.
2. Turn on the pilot laser. If the laser hits the marking in the alignment tool vertically, it is displayed centrally on the CCD sensor.

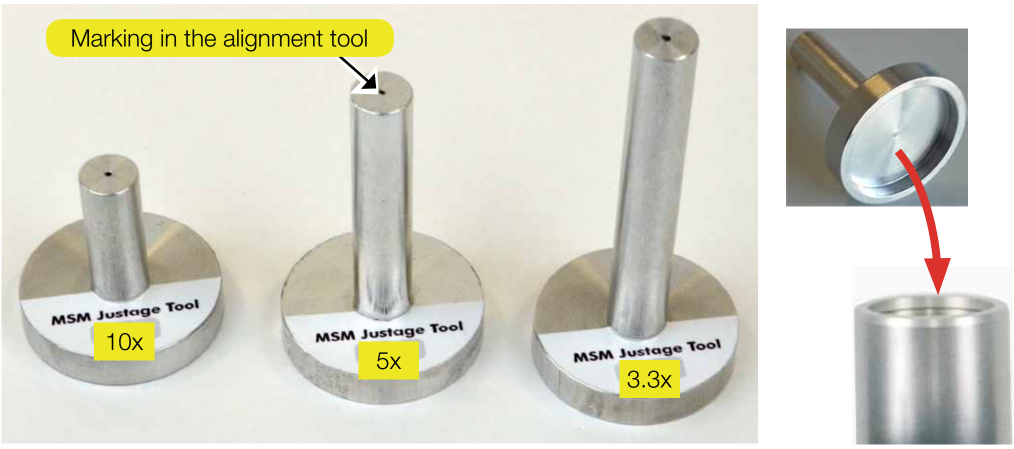


Fig. 7.2: Alignment tools for direct placement on the measuring objective

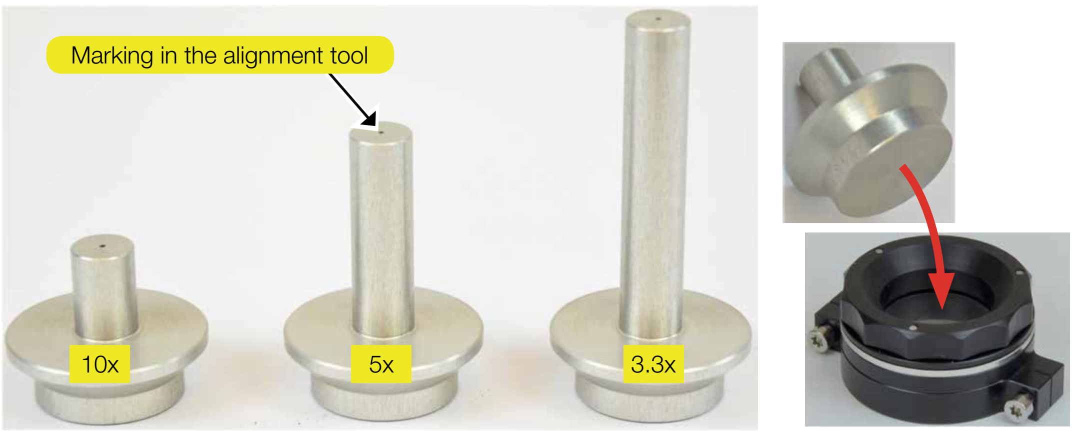


Fig. 7.3: Alignment tools for placement on the protective window holder on the measuring objective

The measuring plane distance equals the distance of the imaging plane from the upper corner of the measuring objective. It does not only depend on the beam path (standard, beam path extension BPE, alignment objective AO) but also on the wavelength (see Tab. 7.1 on page 20).

When using a protective window with a thickness of 1.5 mm, the measuring plane moves upwards by approx. 500 µm.

Measuring objective MOB	NA limit values	Typ. magnification			Measuring plane distance in mm		
		Standard	BPE	AO	Standard	BPE	AO
3.3x							
1 064 nm	1	3.12	5.65	1.12	73	64.6	63.7
532 nm	0.1	3.23	5.81	1.11	70.5	62.6	61.5
355 nm	0.09	3.36	6.02	*)	67.3	60.1	57.7
5x							
1 064 nm	0.19	4.96	8.31	1.63	51.1	47.1	46.7
532 nm	0.18	5.15	8.6	1.59	49.3	45.7	45.1
355 nm	0.14	5.35	8.92	*)	47.2	43.8	42.7
10x							
1 064 nm	0.24	8.84	14.39	2.77	29.9	27.9	27.6
532 nm	0.24	9.17	14.91	2.72	-	-	-
355 nm	0.17	9.62	15.6	*)	-	-	-

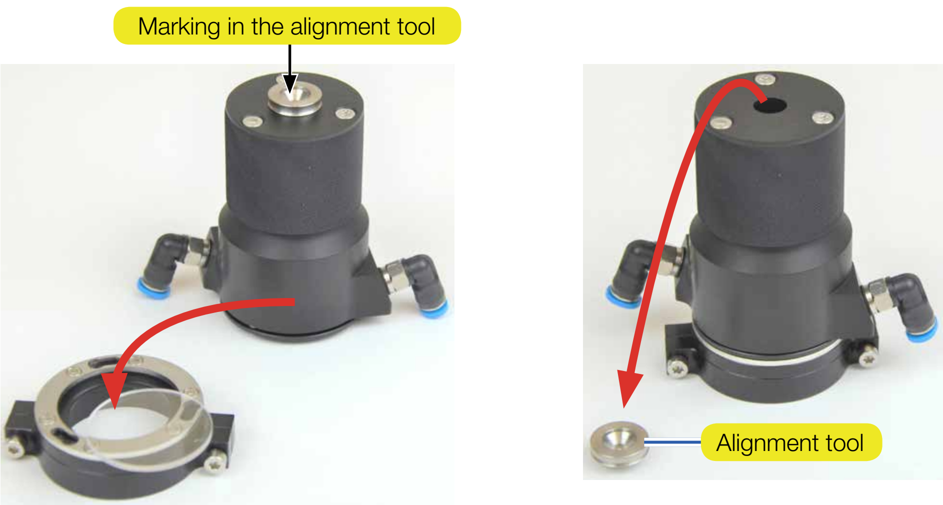
Tab. 7.1: Measuring plane distances

*) Only suitable for adjustment

Due to the production tolerances, the values of the measuring plane distance contain a deviation of ± 800 µm. However, it is possible to have the measuring distance of the measuring objective calibrated to ± 50 µm (TCP calibration).

7.2.3 Positioning the focused laser beam above the optional cyclone

For measuring objectives with a cyclone or a protective window special alignment aids are provided.



Cyclone with disassembled protective window holder and attached alignment tool

Cyclone with mounted protective window holder and removed alignment tool

Fig. 7.4: Alignment tool for an optional cyclone using the example of a measuring objective with 3.3x magnification

7.3 Install the MicroSpotMonitor MSM

DANGER

Serious eye or skin injury due to laser radiation

If the device is moved from its calibrated position, increased reflected radiation (laser class 4) may result during measuring operation.

- **When mounting the device, please ensure that it cannot be moved, neither due to an unintended push or a pull on the cables and hoses.**

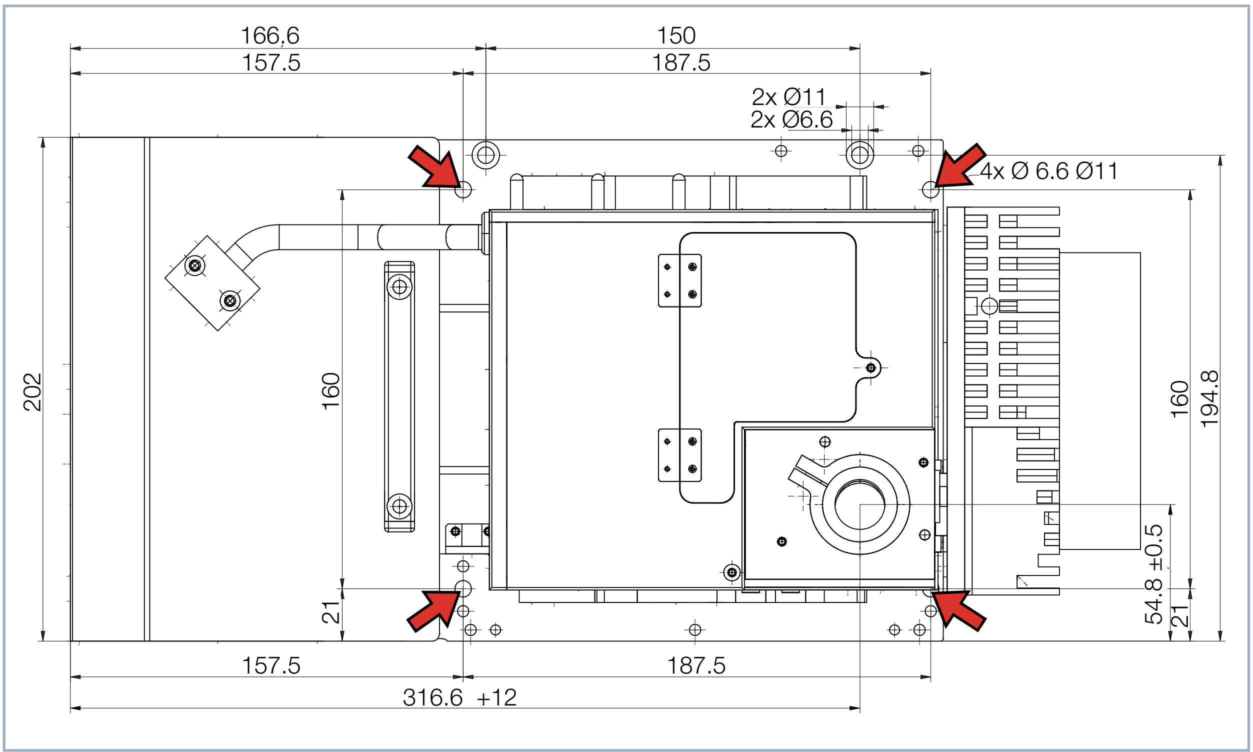


Fig. 7.5: Fastening bores, view from above

For the installation onto a holder provided by the customer, there are four mounting holes Ø 6,6 mm in the bottom plate. We recommend screws M6 of the strength class 8.8 and a tightening torque of 20 N·m.

➡ 4 Mounting holes Ø 6,6 mm

8 Connect cooling circuit (500 W version only)

DANGER

Fire hazard; Damage/Destruction of the device due to overheating

If there is no water cooling or a water flow rate which is insufficient, there is a danger of overheating, which can damage the device or set it on fire.

▶ **Operate the device with a connected water cooling and a sufficient water flow rate only.**

8.1 Water quality

NOTICE

Damage/Destruction of the device due to different chemical potentials

The parts of the device which get in contact with cooling water consist of copper, brass or stainless steel. Connecting the unit to a colling curcuit containing aluminum components may cause corrosion of the aluminum due to the different chemical potentials.

▶ **Do not connect the device on a cooling circuit in which aluminum components are installed.**

- The device can be operated with tap water as well as demineralized water.
- Do not operate the device on a cooling circuit containing additives such as anti-freeze.
- Do not operate the device on a cooling circuit in which aluminum components are installed. Especially when it comes to the operation with high powers and power densities, it may otherwise lead to corrosion in the cooling circuit. In the long term, this reduces the efficiency of the cooling circuit.
- Should the cooling fail, the device can withstand the laser radiation for a few seconds. In this case, please check the device as well as the water connections for damages.
- Large dirt particles or teflon tape may block internal cooling circuits. Therefore, please thoroughly rinse the system before connecting it.

8.2 Water pressure

Normally, 2 bar primary pressure at the entrance of the absorber are sufficient in case of an unpressurized outflow.

NOTICE

Damage/Destruction of the device due to overpressure

▶ **The maximum permissible water inlet pressure must not exceed 4 bar.**

8.3 Humidity

- The device must not be operated in a condensing atmosphere. The humidity has to be considered in order to prevent condensates within and outside the device.
- The temperature of the cooling water must not be lower than the dew point (see Tab. 8.1 on page 23).

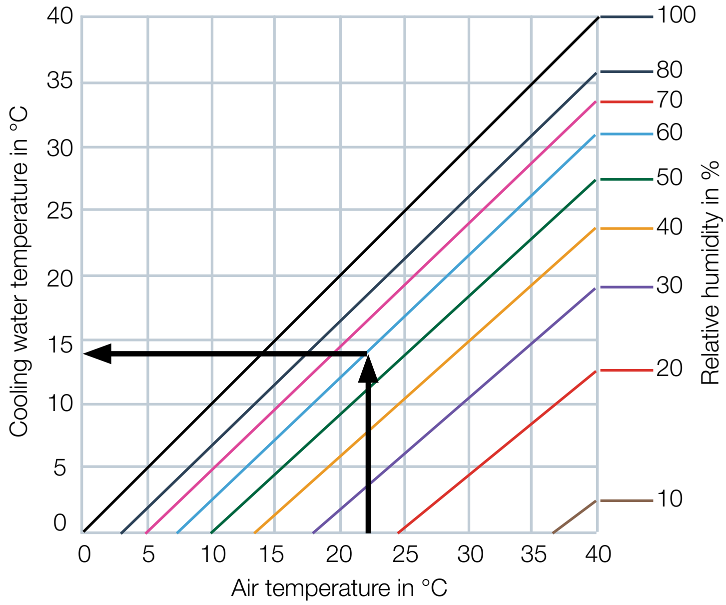
NOTICE

Damage/Destruction of the device due to condensing water

Condensation water inside of the objective will lead to damage.

▶ **Mind the dew-point in Tab. 8.1 on page 23.**

Do only cool the device during the measuring operation. We recommend starting the cooling approx. 2 minutes before the measurement and terminating it approx. 1 minute after the measurement.



Tab. 8.1: Dew point diagram

Example

Air temperature: 22 °C
Relative humidity: 60 %

The cooling water temperature cannot fall below 14 °C.

8.4 Water connections and water flow rate

Connection diameter	Recommended flow rate	Minimum flow rate
PE hoses 12 mm	1.5 l/min (1 l/(min · kW)	Not lower than 1.0 l/min

Tab. 8.2: Water connections and water flow rate

Remove the sealing plugs of the water connections

1. Please push down the release ring of the connection and pull out the plug with your free hand.
2. Remove the sealing plugs of the water connections and keep it in a save place.
3. Close the flow line (Water In) and the return flow (Water Out) of the device, by inserting the hose as far as possible (approx. 2 cm deep).

Fig. 8.1: Remove the sealing plugs of the water connections

9 Electrical connection

The MicroSpotMonitor MSM requires a supply voltage of 24 V ±5 % (DC) for the operation. A suitable power supply with an adapter is included in the scope of delivery. Please use only the provided connection lines.

Please ensure that all electrical connections have been established and switch the device on before starting the LaserDiagnosticsSoftware LDS.
The MicroSpotMonitor MSM serves as a dongle for the software on the PC in order to enable certain software functions.

9.1 Connections

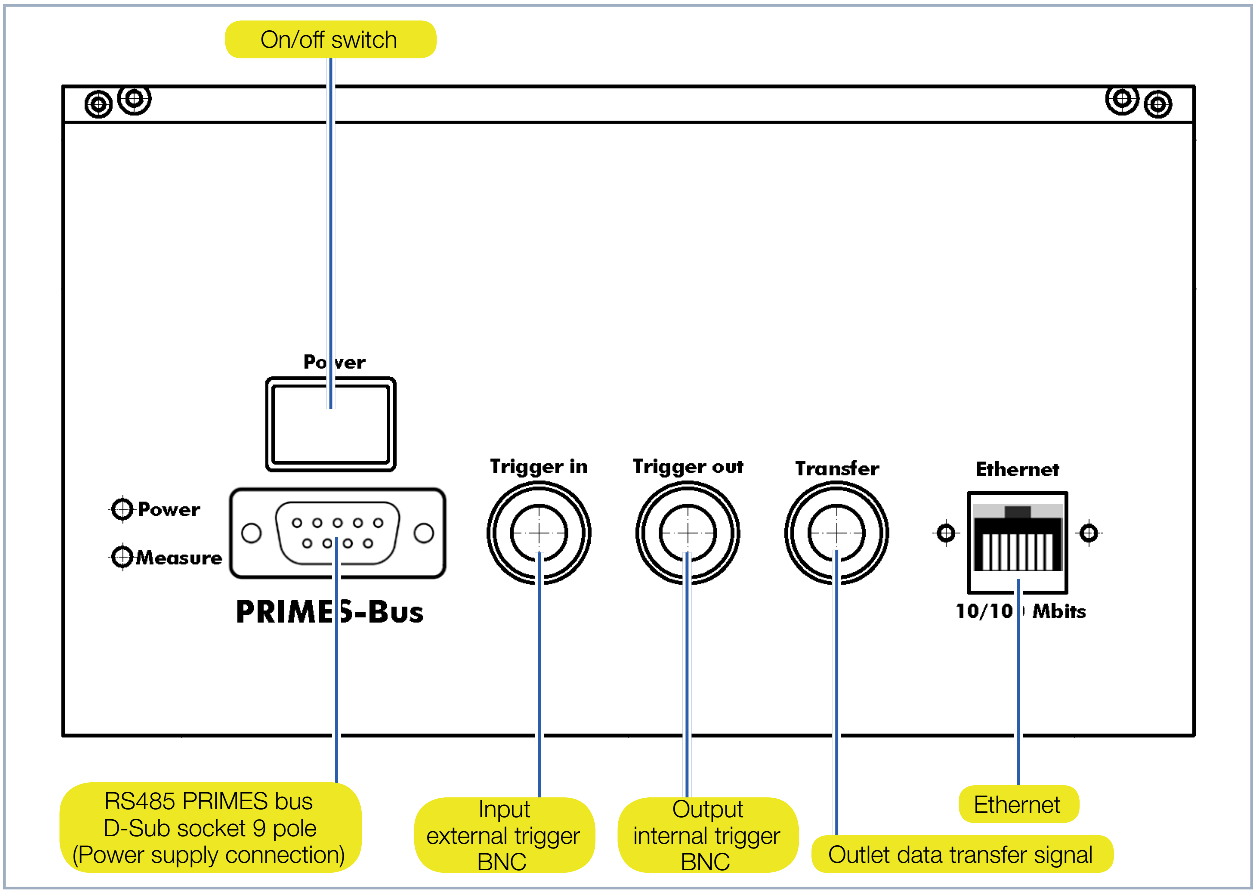
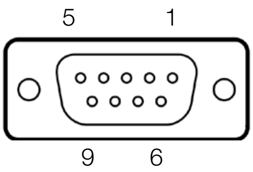


Fig. 9.1: Connections

9.2 Pin assignment

9.2.1 Power supply

D-Sub socket, 9-pin (view: connector side)

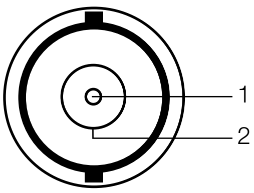


Pin	Function
1	GND
2	RS485 (+)
3	+24 V
4	Trigger RS485 (+)
5	Not assigned
6	GND
7	RS485 (–)
8	+24 V
9	Trigger RS485 (–)

Tab. 9.1: D-Sub socket RS485

9.2.2 Inlet external trigger

BNC connector (view: connector side)

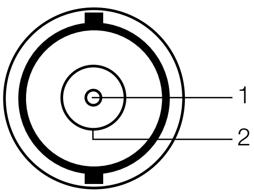


Pin	Function
1	+5 V (Trigger signal)
2	GND

Fig. 9.2: Connection socket inlet for an external trigger in the connection panel

9.2.3 Outlet internal trigger

BNC connector (view: connector side)

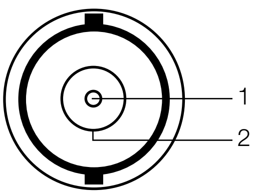


Pin	Function
1	+5 V (Trigger signal)
2	GND

Fig. 9.3: Connection socket outlet for the internal trigger in the connection panel

9.2.4 Outlet internal data-transfer signal

BNC connector (view: connector side)



Pin	Function
1	+5 V (Trigger signal)
2	GND

Fig. 9.4: Connection socket outlet for the internal data-transfer signal in the connection panel

9.3 Connection to the PC and connect power supply

NOTICE

Damage/Destruction of the device

When the electrical cables are disconnected during operation (when the power supply is applied), voltage peaks occur which can destroy the communication components of the measuring device.

▶ **Please turn off the PRIMES power supply before disconnecting the cables.**

1. Connect the device with the PC via a crossover cable or with the network via a patch cable.
2. Use the adapter to connect the power supply to the 9-pin D-sub socket (RS485) of the device.

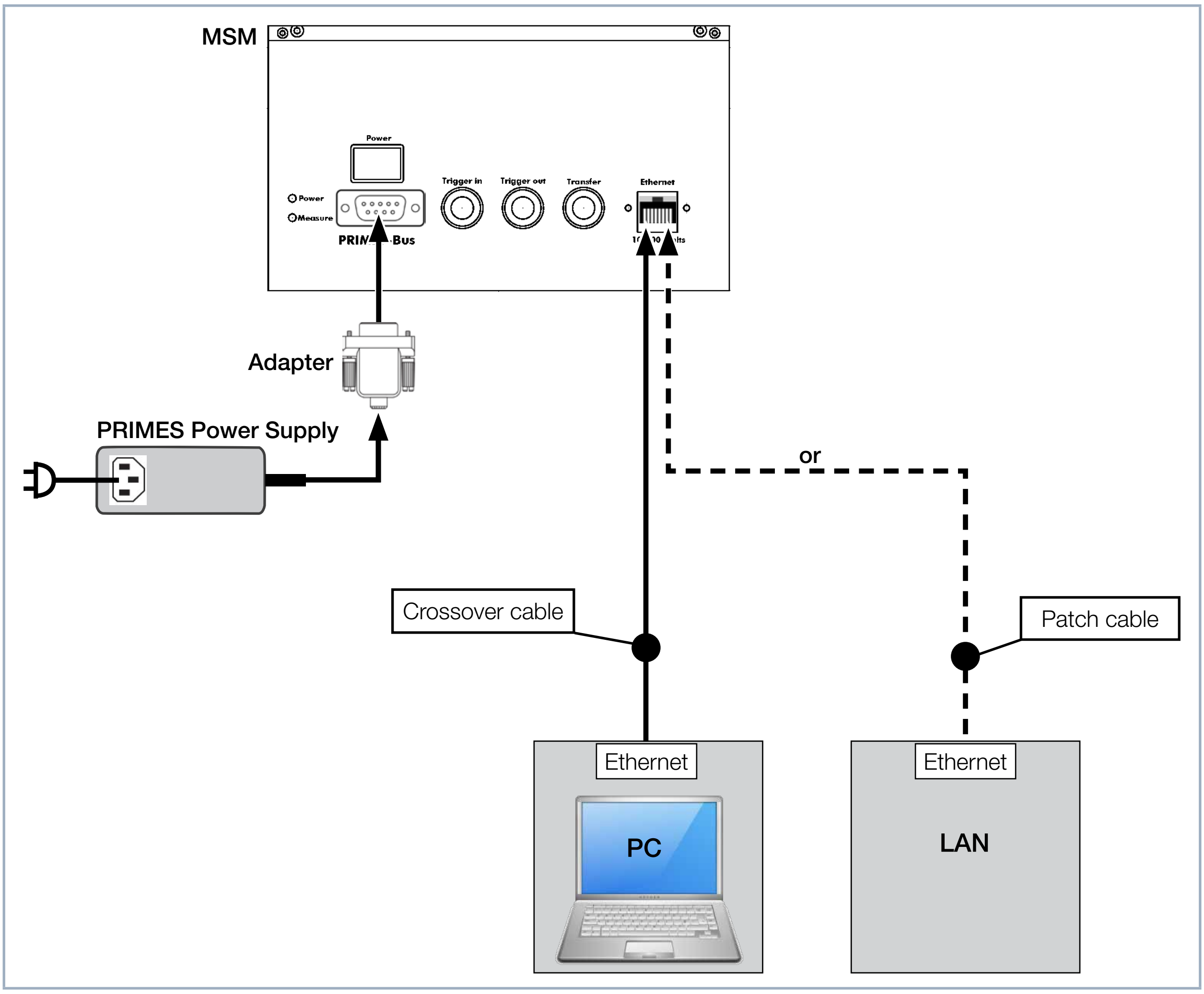


Fig. 9.5: Connection via Ethernet with a PC or a local network

10 Status LEDs

The device has two status LEDs.

Bezeichnung	Farbe	Bedeutung
Power	Green	The power supply is switched on
Measuring	Yellow	A measurement is running

Tab. 10.1: Description of the status LEDs on the MicroSpotMonitor MSM

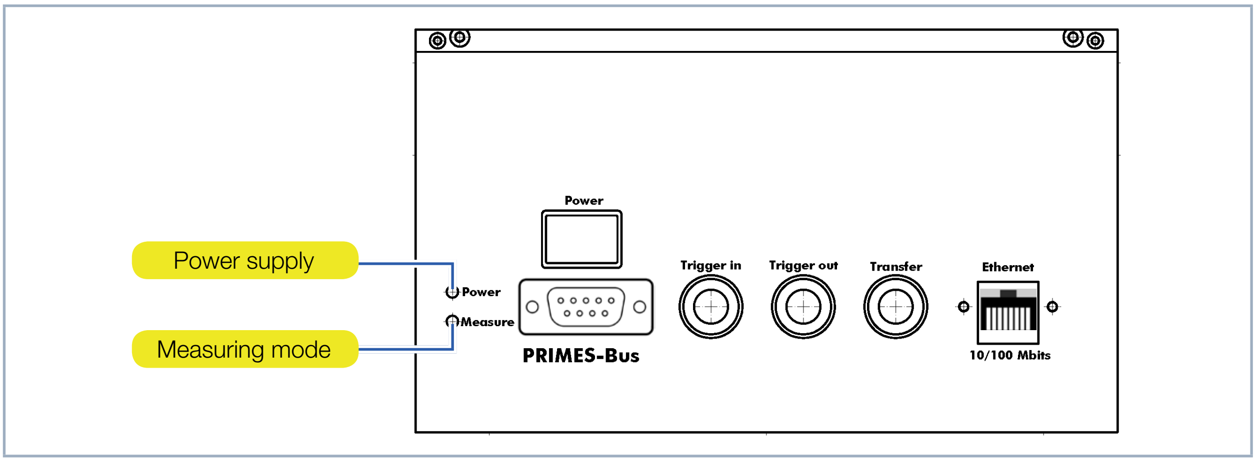


Fig. 10.1: Status LEDs on the MicroSpotMonitor MSM

11 Installation and configuration of the LaserDiagnosticsSoftware LDS

In order to operate the measuring device, the PRIMES LaserDiagnosticsSoftware LDS has to be installed on the computer. The program can be found on the enclosed medium.
You will find the latest version on the PRIMES website at: https://www.primes.de/en/support/downloads/software.html.

11.1 System requirements

Operating system:	Windows® 7/10
Processor:	Intel® Pentium® 1 GHz (or comparable processor)
Free disc space:	15 MB
Monitor:	19“ screen diagonal is recommended, resolution at least 1024x768
LDS-Version:	2.98 or higher

11.2 Installing the software

The installation of the software is menu driven and is effected by means of the enclosed medium. Please start the installation by double-clicking the file “Setup LDS v.X.X.exe” (X = placeholder for version number) and follow the instructions.

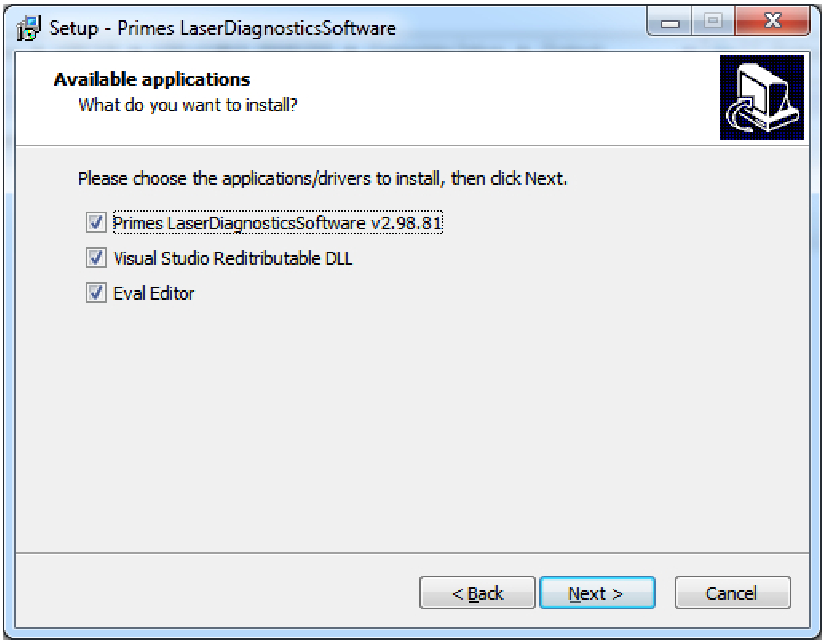


Fig. 11.1: Setup of the PRIMES LaserDiagnosticsSoftware LDS

If not stipulated differently, the installation software stores the main program “LaserDiagnosticsSoftware.exe” in the directory “Programs/PRIMES/LDS”. Moreover, the settings file “laserds.ini” is also copied into this directory. In the file “laserds.ini” the setting parameters for the PRIMES measuring devices are stored.

11.3 Ethernet configuration

11.3.1 Enter IP address

The MicroSpotMonitor MSM has a fixed IP address that is specified on the type plate:

- If the MicroSpotMonitor MSM is connected directly to the PC, enter the fixed IP address in the menu ***Communication > Free Communication*** (see chapter 11.3.2 on page 31).
- If the MicroSpotMonitor MSM is connected over a network, the MicroSpotMonitor MSM will spend about one minute pulling up a variable IP address in the network.
  You can read off this variable IP address with the provided software, “PrimesFindIp” and enter it into the ***Communication > Free Communication*** (see chapter 11.3.2 on page 31)
- If you want to connect the MicroSpotMonitor MSM to the network using the fixed IP address, first turn on the MicroSpotMonitor MSM and then connect the network cable to the MicroSpot-Monitor MSM. Then enter the fixed IP address in the menu ***Communication > Free Communication*** (see chapter 11.3.2 on page 31).

The standard IP address of the MicroSpotMonitor MSM is:

IP Address: 192.168.116.84
Subnet mask: 255.255.255.0

The PC must also have an IP address in the same subnet, for example:

IP Address: 192.168.116.XXX
Subnet mask: 255.255.255.0

The first three blocks of the IP address must match the IP of the MicroSpotMonitor MSM.

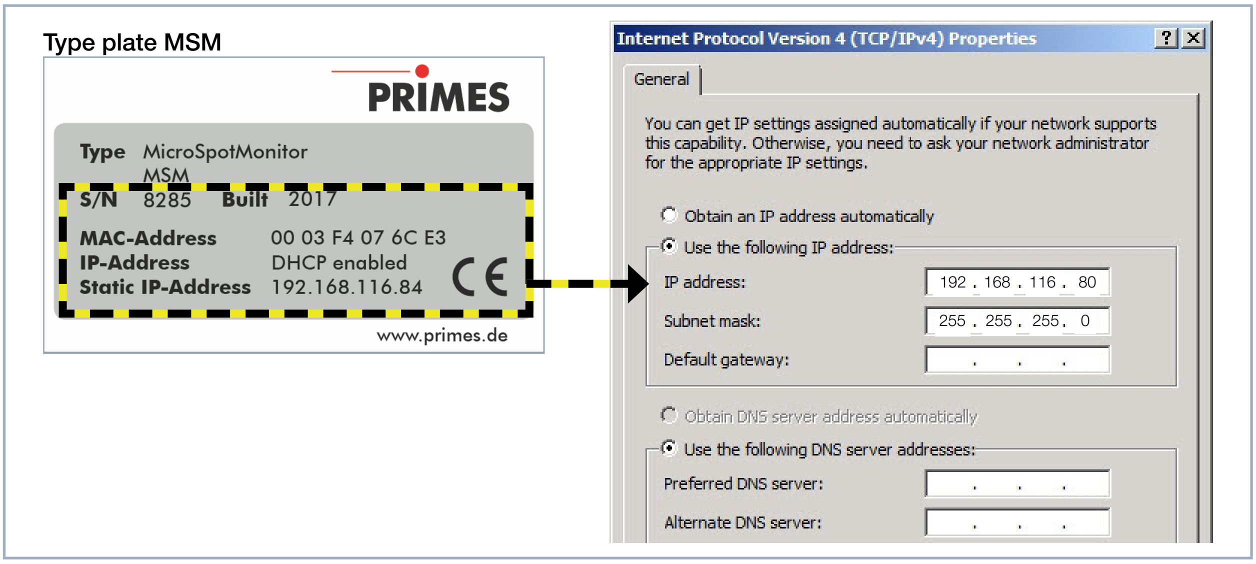


Fig. 11.2: Ethernet configuration in the dialogue window ***Ethernet***

11.3.2 Establishing a connection to PC (menu *Communication* > *Free Communication*)

1. Please start the LaserDiagnosticsSoftware LDS (see chapter 12 on page 34).
2. Open the dialogue window ***Communication > Free Communication***.
3. Choose in the field “Mode” ***TCP*** (the option “Second IP” must not be activated!).
4. Enter in the field “TCP” the IP Address.
5. Click on the ***Connect*** button (“connected” appears in the bus monitor).
6. Click on the ***Find Primes Devices*** button.
7. Click on the ***Safe Config*** button (the configuration is saved and does not need to be re-entered when starting the LaserDiagnosticsSoftware LDS again).

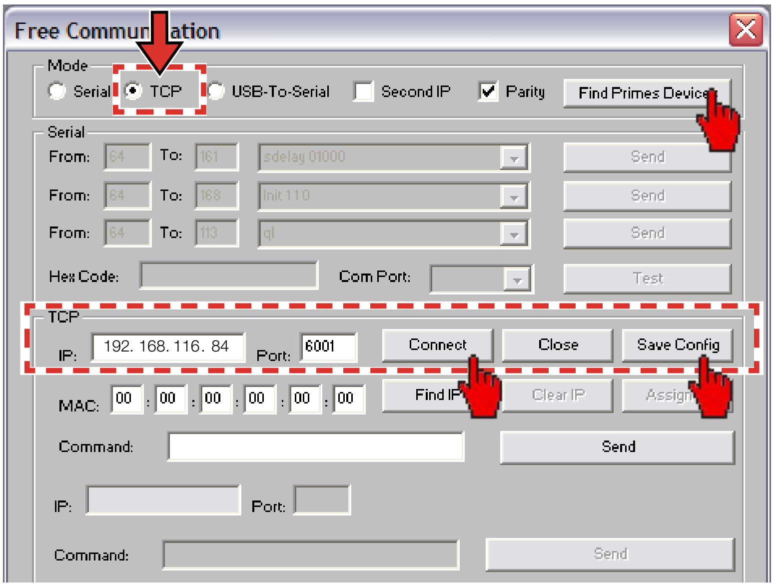


Fig. 11.3: Establishing a connection in the dialogue window ***Free Communication***

11.3.3 Changing the standard IP address of the device (menu *Communication* > *Free Communication*)

If the fixed IP address of the MicroSpotMonitor MSM conflicts with another device bearing the same IP address on the network, the fixed IP address of the MicroSpotMonitor MSM can be changed.

NOTICE

Device malfunction due to erroneous entries

While changing the IP address, it is possible that another EE cell might be overwritten by a mistype, for example, and the MicroSpotMonitor MSM could thus be rendered unusable.

- ▶ **Only very skilled users should attempt to change the IP address.**

You can change the preset IP address in the menu ***Communication*** > ***Free communication*** by means of the following commands:

IP-address (Sample address)	192.	168.	116.	85
	↑	↑	↑	↑
Commands	se0328✶xyz	se0329✶xyz	se0330✶xyz	se0331✶xyz

Tab. 11.1: Changing the IP address

In this case **xyz** are place holders of the four IP-address bytes (values 1 - 254) which always have to be entered with three digits!
For example, the number 84 has to be entered like this: 084.
For reasons of clarity the symbol ✶ marks a space.

Example: You will change the IP address from 192.168.116.**85** to 192.168.116.**86**.

1. Please start the LaserDiagnosticsSoftware LDS (see chapter 12 on page 34).
2. Open the dialogue window ***Communication > Free Communication***.
3. Choose in the field “Mode” ***TCP*** (the option “Second IP” must not be activated!).
4. Enter the current IP address in the “TCP” ***field***.
5. Click on the ***Connect*** button (“connected” appears in the bus monitor).
6. Activate the check box ***Write bus protocol*** (the protocol can be helpful in case of problems):
- The protocol is stored in the installation index of the LaserDiagnosticsSoftware LDS.
- The file name is buspro.log.YYYY/MM/DD (YYYY/MM/DD = date file was created).
7. Enter the following in the field “Command”: **se0331 ✶ 086**
   (please make sure that the blank character ✶ is entered correctly).
8. Click on the ***Send*** button and wait for the confirmation in the bus monitor
   (see Fig. 11.4 on page 33 „-> Adr:0331 Wert: 086“)
9. Please turn off the device and turn it on again. After the restart the IP-address is updated.

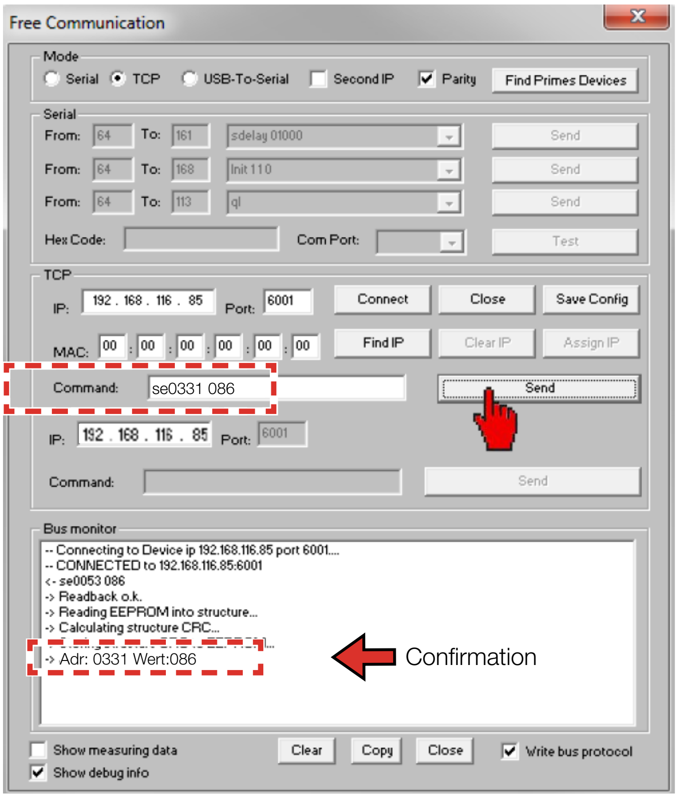


Fig. 11.4: Changing the IP address in the dialogue window ***Free Communication***

12 Description of the LaserDiagnosticsSoftware LDS

The LaserDiagnosticsSoftware LDS is the control centre for all PRIMES measuring devices which measures the beam distribution as well as focus geometries by means of which the beam propagation characteristics can be determined.
The LaserDiagnosticsSoftware LDS includes all functions necessary for the control of measurements and displays the measuring results graphically.
Moreover, the systems uses the measured data to carry out an evaluation in order to give the operator of the beam diagnosis an information regarding the reliability of the measuring results.

Please do not start the LaserDiagnosticsSoftware LDS before all devices are connected and turned on.

Please start the program by double-clicking the LDS symbol in the new start menu group or the desktop link.

12.1 Graphical user interface

Firstly, a start window is opened in which you can choose, whether you would like to measure or whether you would just like to depict an existing measurement (factory setting “measurement”).

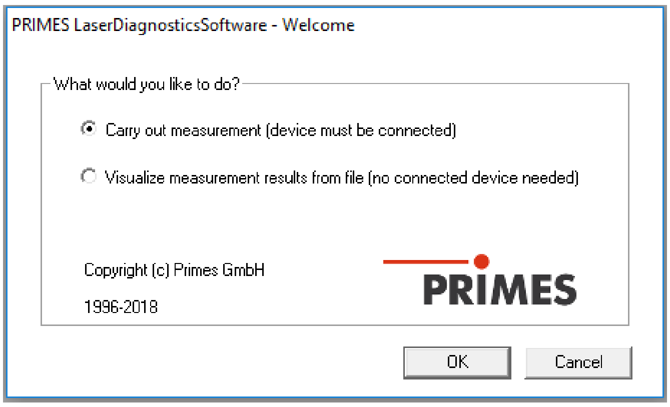


Fig. 12.1: Start window of the LaserDiagnosticsSoftware LDS

After the detection of the connected device, the graphical user interface and several important dialogue windows are opened.

In order to ensure that corresponding information can be assigned quickly, special markups for menu items, menu paths and texts of the user interface will be used in the following chapters.

Markup	Description
Text	Marks menu items. Example: Dialogue window ***Sensor parameters***
Text1 > Text2	Marks the navigation to certain menu items. The Order of the menus is depicted by means of the Sign “>” Example: ***Presentation > Caustic***
Text	Marks buttons, options and fields. Example: With the button ***Start***

Fig. 12.2: Special markups for menu items, menu paths and texts

The graphical user interface mainly consists of the menu as well as the toolbar by means of which different dialogue or display windows can be called up.

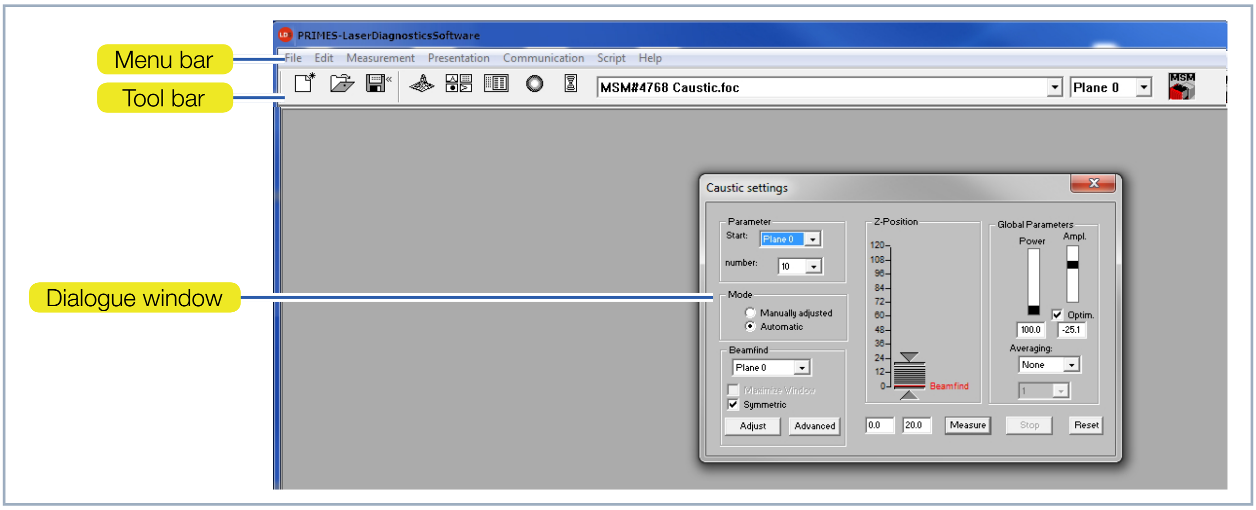


Fig. 12.3: The main elements of the user interface

It is possible to open several measuring and dialogue windows simultaneously. In this case, windows that are basically important (for the measurement or the communication) remain in the foreground. All other dialog windows fade into the background as soon as a new window opens.

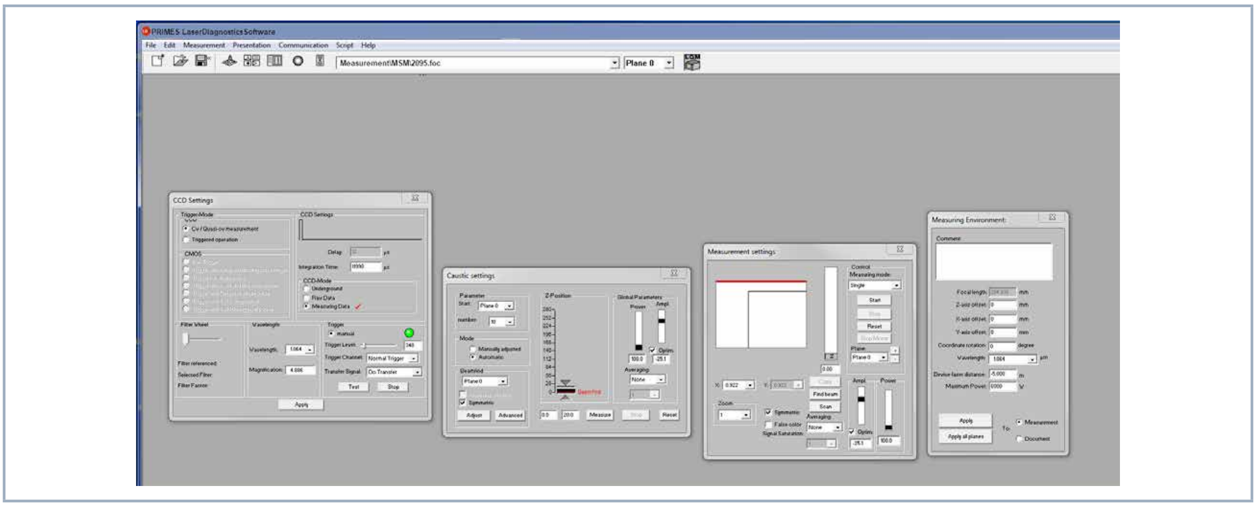


Fig. 12.4: The main dialogue windows

12.1.1 The menu bar

In the menu bar, all main and sub menus offered by the program can be opened.

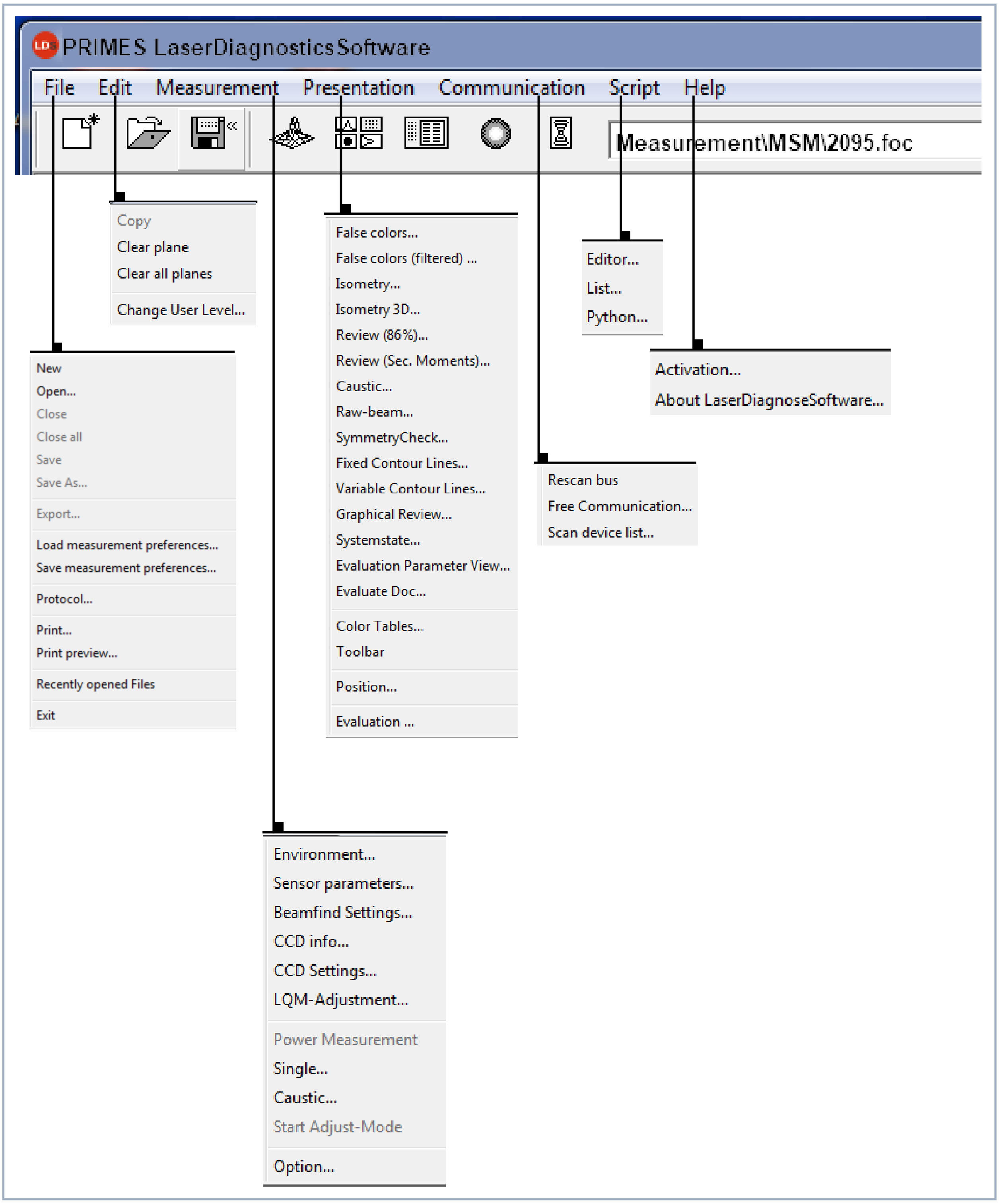


Fig. 12.5: Menu bar

12.1.2 The toolbar

By clicking the symbols in the toolbar, the following program menus can be opened.

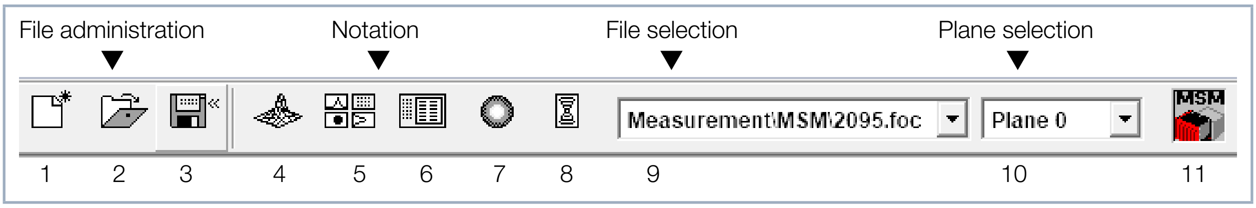


Fig. 12.6: Symbols in the toolbar

1 - Create a new data record
2 - Open an existing data record
3 - Save the current data record
4 - Open the isometric view of the selected data record
5 - Open the variable contours line view
6 - Open review (86%)
7 - Open false color depiction
8 - Caustic presentation 2D
9 - List with all data records opened
10 - Display of the selected measuring plane
11 - Display of the measuring devices available for the bus by means of graphical symbols

All measuring results are always written into the document selected in the toolbar.
It is only possible to display documents chosen here. After opening, the data set has to be explicitly selected.

12.1.3 Menu overview

File	
New	Opens a new file for the measuring data
Open	Opens a measuring file with the extensions ".foc" or ".mdf"
Close	Closes the file selected in the toolbar
Close all	Closes all files opened
Save	Saves the current file in foc- or mdf format
Save as	Opens the menu for the storage of the files selected in the toolbar. Only files with the extensions ".foc" or ".mdf" can be imported safely
Export	Exports all current data in protocol format ".xls" and ".pkl"
Load measurement preferences	Opens a file with measurement settings with the extension ".ptx"
Save measurement preferences	Opens the menu to save the settings of the last program run. Only files with the extension ".ptx" can be opened
Protocol	Starts a protocol of the numeric results. They can either be written into a file or a data base
Print	Opens the standard print menu
Print preview	Shows the content of the printing order
Recently opened files	Shows the file opened before
Exit	Terminates the program
Edit	
Copy	Copies the current window to the clipboard
Clear plane	Deletes the data of the plane selected in the toolbar
Clear all planes	Deletes all data of the file selected in the toolbar
Change user level	By entering a password a different user level can be activated.
Measurement	
Environment	Different system parameters can be entered, e.g.: - Reference value for the laser power - Focal length - Wavelength - Comment - Device offset (Not relevant for MicrosSpotMonitor MSM)
Sensor parameters	The following device parameters can be e.g. set here: - The mechanical locked area of the z-axis - The spatial resolution (32, 64, 128 or 256 Pixel) - The manual settings of the z-axis - Choosing the measuring devices connected to the bus - Deactivating the z-axis
Beamfind settings	Not relevant for MicrosSpotMonitor MSM
CCD info	Provides information on device parameters
CCD settings	Special settings can be made, e.g.: - Trigger mode - Trigger level - Exposure time - Wave length

LQM-Adjustment	Not relevant for MicrosSpotMonitor MSM
Power measurement	Not relevant for MicrosSpotMonitor MSM
Single	This menu item enables the start of single measurements, of the monitor mode and the video mode
Caustic	Enables the start of a caustic measurement. Not only automatic measurements but also serial measurements of manually set parameters are possible. The automatic measurement starts with a beam search and then caries out the entire measuring procedure independently. Only the z-range that is to be examined as well as the desired measuring plane have to entered
Start adjustment mode	Not relevant for MicrosSpotMonitor MSM
Options	Enables the setting of device parameters
Presentation	
False colors	False color display of the spatial power density distribution
False colors (filtered)	Usage of a spatial filtration (spline function) on the false color display of the power density distribution
Isometry	3-dimensional display of the spatial power density distribution
Isometry 3D	Allows a 3D display of caustic and power density distribution with spatial rotation as well as an optional isophote display
Review (86%)	Numerical overview of measuring results in the different layers basing on the 86% beam radius definition
Review (2. moment)	Numerical overview of the measuring results in the different layers basing on the 2. moment beam radius definition
Caustic	Results of the caustic measurement and the results of the caustic fit – such as beam quality factor M^2, focus position and focus radius
Raw beam	Not relevant for MicrosSpotMonitor MSM
Symmetry check	Analysis tool to check the beam symmetry especially for the alignment of laser resonators. No standard feature of the device
Fixed contour lines	Display of the spatial laser density distribution with fixed intersection lines for 6 different power levels
Variable contour lines	Display of the spatial power density distribution with freely selectable intersection lines
Graphical review	Enables a selection of graphical displays – among them the radius, the x- and y- position above the z-position and the time
System state	Not relevant for MicrosSpotMonitor MSM
Evaluation parameter	Loading stored evaluation parameters
Color tables	Different color charts are available in order to analyse e.g. diffraction phenomena in detail
Toolbar	In order to display or to hide the toolbar
Position	Moving the device into a defined position
Evaluation	Comparison of the measured values with defined limit values and evaluation (optionally)
Communication	
Rescan bus	The system searches the bus for the different device addresses. This is necessary whenever the device configuration at the PRIMES bus was changed after starting the software.
Free Communication	Display of the communication on the PRIMES bus
Scan device list	Lists the device addresses of the single PRIMES devices

Script	
Editor	Opens the script generator, a tool, by means of which complex measuring procedures are controlled automatically (with a script language developed by PRIMES).
List	Shows a list of the opened windows
Python	Opens the script generator in order to control complex measuring procedures automatically (scripting language Python)
Help	
Activation	Enables the activation of special functions
About LaserDiagnostics-Software LDS	Provides information regarding the software version

Tab. 12.1: Menü overview

12.2 File

This menu includes – among others – the administration of measurement and setting data.

12.2.1 New (menu *File* > *New*)

By means of New a new file is created.

12.2.2 Open (menu *File* > *Open*)

By means of ***Open*** a selected file is opened.

12.2.3 Close/Close all (menu *File* > *Close/Close all*)

Close will close the file that is currently open. ***Close all*** will close all files currently open.

12.2.4 Save (menu *File* > *Save*)

The file currently opened is stored. The standard type of file is a binary file format with a minimal memory requirements. The file ending for a measuring file of this type is ".foc". As an alternative, it is possible to store the data in a ASCII format with the extension ".mdf". Information regarding the file format ".mdf" can be found enclosed. Only files with this formats can be opened by the program (see also chapter 21.3 on page 119).

12.2.5 Save as (menu *File* > *Save As*)

You have to assign a file name, choose the storage location and the file format.

Only save the measurement data with the extensions ".foc" or ".mdf". You can only view measurement data if the respective file was explicitly selected in the toolbar.

12.2.6 Export (menu *File* > *Export*)

Exports the pixel information of the power density distribution to a Excel table (*.xls). As an alternative, the numeric results from a ".foc" file can be stored in a tab-separated text file (*.pkl) which can be imported into Microsoft Excel. The pkl export function has a coordinate origin in the middle of the measuring area (yellow dot).

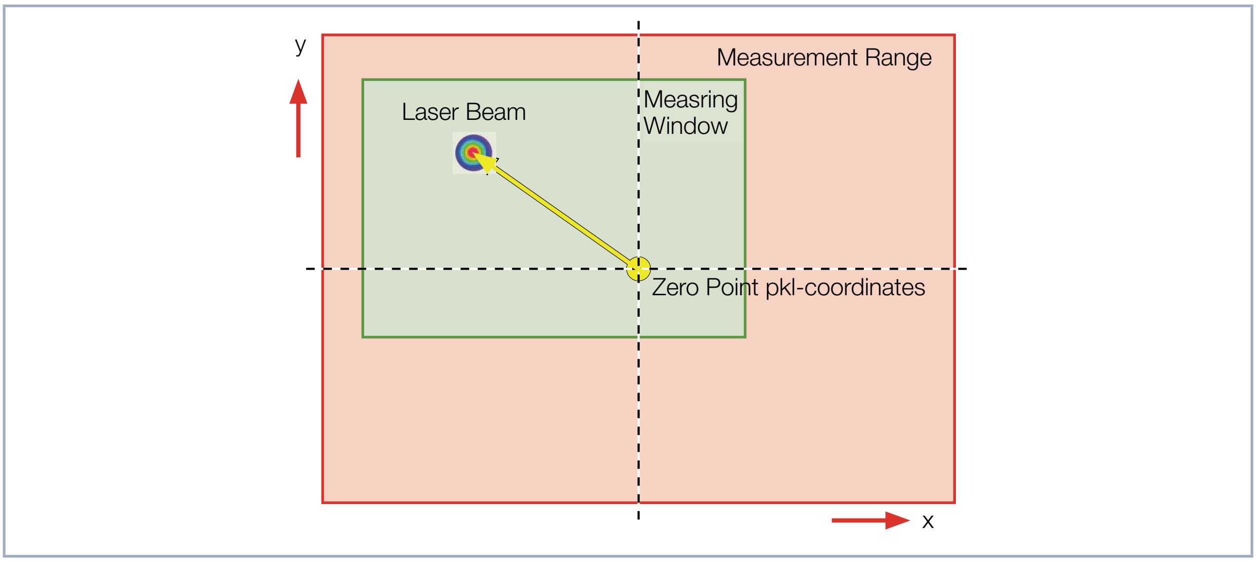


Fig. 12.7: Coordinates of the pkl-export function (the illustration is not to scale)

12.2.7 Load measurement preferences (menu *File* > *Load measurement preferences*)

Stored settings can be resorted to with ***Load measurement preferences***. The standardized extension for a setting file of the MicroSpotMonitor MSM is ".ptx".

12.2.8 Save measurement preferences (menu *File* > *Save measurement preferences*)

The current measurement settings are stored (.ptx-file).

12.2.9 Protocol (menu *File* > *Protocol*)

The calculated measurement results from a single plane can directly be written into a text file.
The following is stored:

- Date and time of the measurement
- Beam position and beam radius (according to 86 %- and 2. moment method definition)

Therefore please activate the check box ***Write***. Then you can directly enter the name in the field ***Filename*** or you can use the standard selection menu with the button ***Browse***.

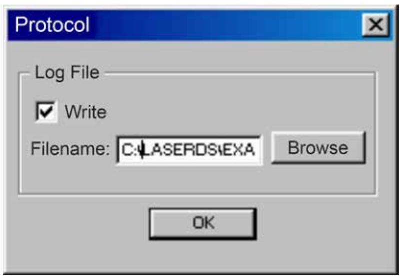


Fig. 12.8: Window ***Protocol***

12.2.10 Print (menu *File* > *Print*)

You can print directly from the program. The current window can be printed with the menu point ***Print*** in the menu ***File***. With the menu point ***Settings*** it is also possible to change the settings as far as the formats etc. are concerned.

12.2.11 Print preview (menu *File* > *Print preview*)

Shows a preview of your printing order.

12.2.12 Recently opened files (menu *File* > *Recently opened Files*)

Selection of the files processed before.

12.2.13 Exit (menu *File* > *Exit*)

Terminates the program.

12.3 Edit

12.3.1 Copy (menu *Edit* > *Copy*)

By means of the copy function a direct export of graphics to other programs is possible. In this case the content of the current window is transmitted to the Windows clipboard.

12.3.2 Clear plane (menu *Edit* > *Clear plane*)

The content of the actual displayed measurement plane of the measurement data set selected in the toolbar is deleted.

12.3.3 Clear all planes (menu *Edit* > *Clear all planes*)

The content of all measurement planes of the measurement data set selected in the toolbar is deleted.

12.3.4 Change user level (menu *Edit* > *Change User Level*)

By entering a password a different user level can be activated.

12.4 Measurement

12.4.1 Measuring environment (menu *Measurement* > *Environment*)

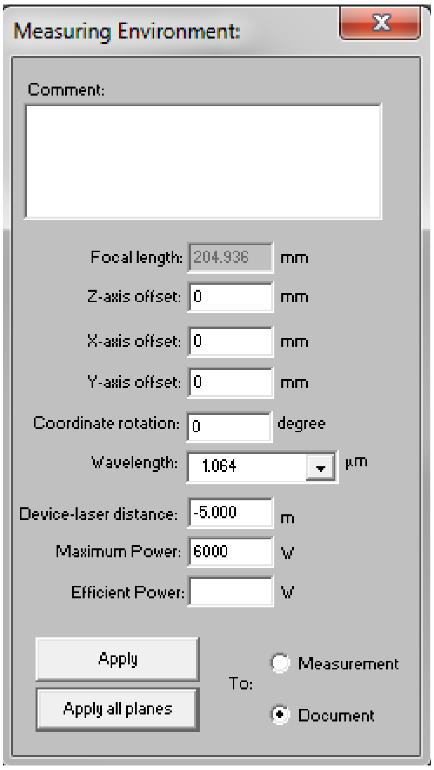


Fig. 12.9: Dialogue window ***Measuring Environment***

In the dialogue window ***Measuring Environment*** data such as the laser type, focal length etc. can be stored. These data can be read via ***Presentation*** > ***Review***.

Focal length

Stating the focal length is relevant for the evaluation of the caustic measurements. From the caustic process and the entered focal length the raw beam diameter on the focussing optic can be calculated.

Wave length

The wave-length is the basis for a correct determination of the beam quality factor M^2. There are the following options:

- 1.064 µm for Nd:YAG laser
- 0.532 µm for Green laser
- 0.355 µm for UV laser

A wavelength can also be typed in numerically.

While only the calibration points of the measuring objective can be configured in the ***CCD Setting***dialog window, the exact value of the laser's wavelength can be entered in this window. This value is used in all numeric evaluations, such as the calculation of the beam quality factor M^2.

Caution: If the wavelength is newly selected in the ***CCD Setting*** dialog window, the value in this window will be overwritten with the selected calibration point.

Application

By means of the button ***Apply*** the entries can also be changed after a measurement. With the button ***Apply all planes*** the entered values are inserted and settled, while the button ***Apply*** only refers to the value in the current plane.

Laser power

Entering the laser power is a reference value for the relative power position in the menu point ***Single measurement*** or ***Caustic measurement***. Furthermore, a z-axes offset as well as a coordinate rotation angle can be entered.

Comment

Please do not use the character # in the comment field "Comment". This character is used as a separator in the software. If it is entered in the field "Comment", problems could occur when it comes to storing or activating measuring data.
A line break can be enforced by means of the key combination: **<Ctrl> + <Enter>**.

12.4.2 Sensor parameters (menu *Measurement* > *Sensor parameter*)

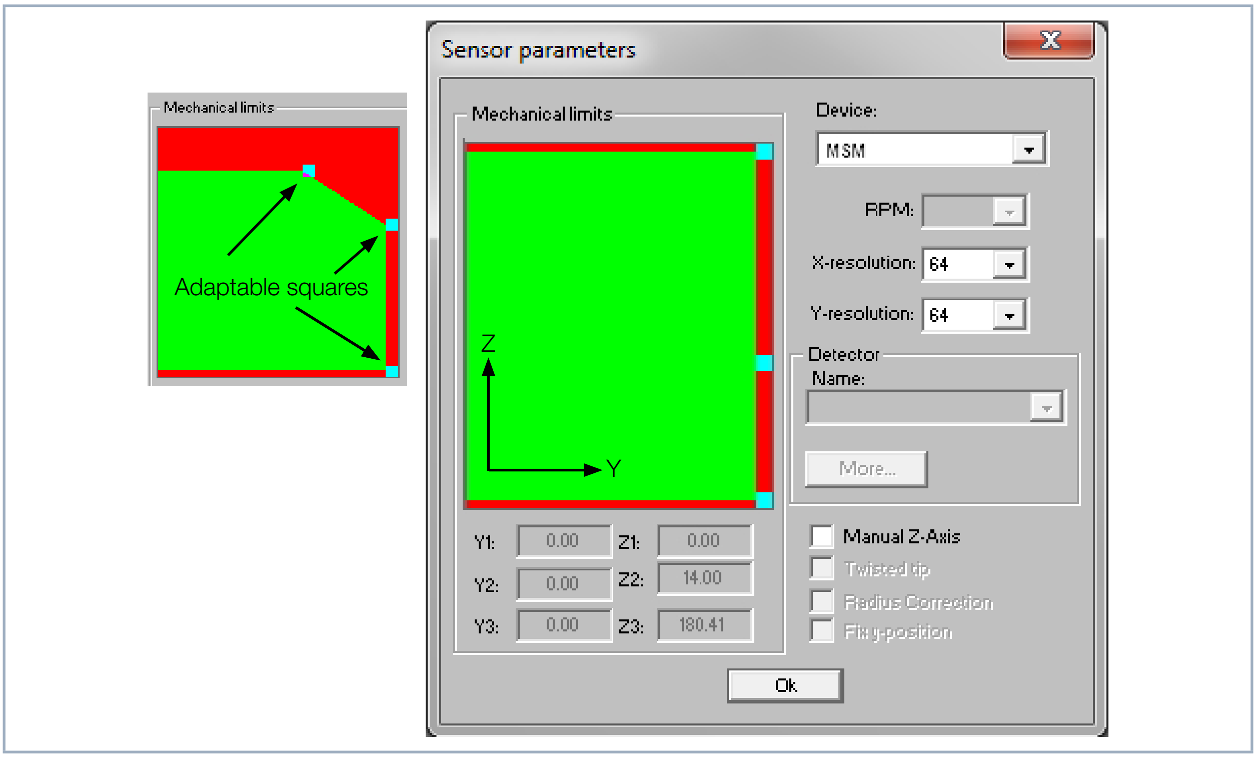


Fig. 12.10: Dialogue window ***Sensor parameters***

Mechanical limits

By pulling the turquoise square with the mouse pointer you can restrict the movement range of the y- and z-axis. Therewith you can prevent damages in case other components reach into the movement range of your device. The maximum value corresponds to the value Y3 and Z3.

Device

By means of this option, you can select the device which is supposed to be operated. Depending on the number of devices connected, additional device numbers are assigned.

RPM

Not relevant for MicrosSpotMonitor MSM.

Resolution

Here you can enter the number of pixels in the measuring window, ranging from 32 x 32 to 256 x 256 pixels. Generally, 64 pixels per line and a total of 64 lines is sufficient. Please keep in mind that the more pixels there are, the longer the measurement will take.

Detector

Not relevant for MicrosSpotMonitor MSM.

Manual z-axis

With this function you can deactivate the z-axes of the measuring system. This is useful if you want to use external movement axes. In this case you can manually assign a z-value to every measurement plane in the dialogue window ***Single measurement***.

12.4.3 Beam find settings (menu *Measurement* > *BeamFind Settings: Beamfind*

Not relevant for MicrosSpotMonitor MSM.

12.4.4 CCD info (menu *Measurement* > *CCD Info*)

The most important device data is shown in the menu ***Measurement > CCD Device Info***. Here you can see the magnification information for the measuring objective and also check which beam path is turned on.
If obvious default values (1:1) are shown instead of the actual magnification, then please check the mounting of the measurement objective.

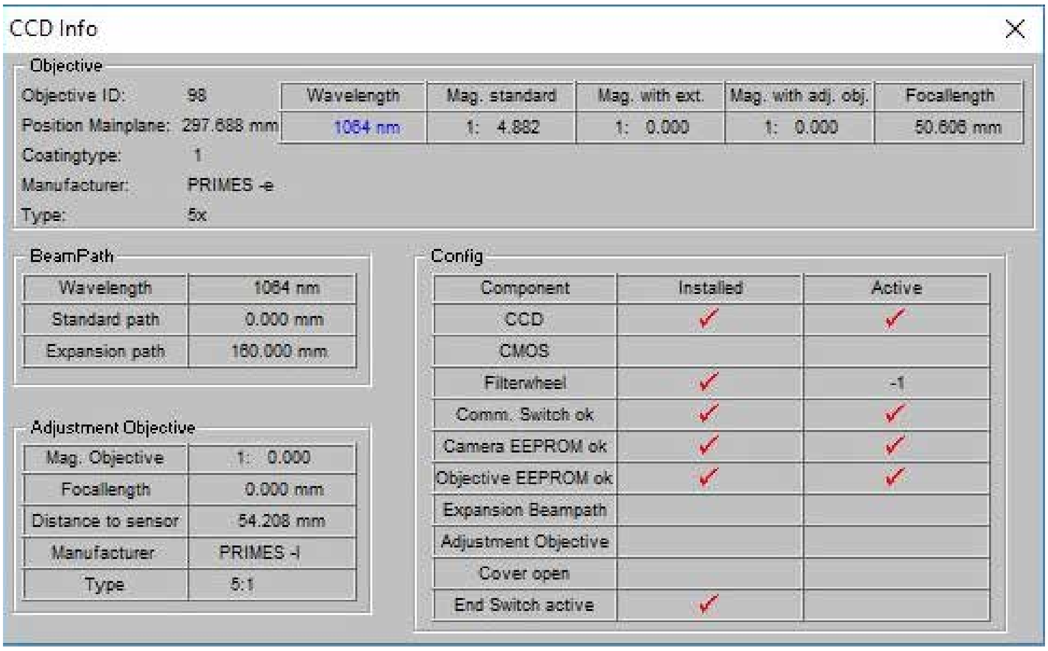


Fig. 12.11: Window ***CCD Info***

12.4.5 CCD settings (menu *Measurement* > *CCD Settings*)

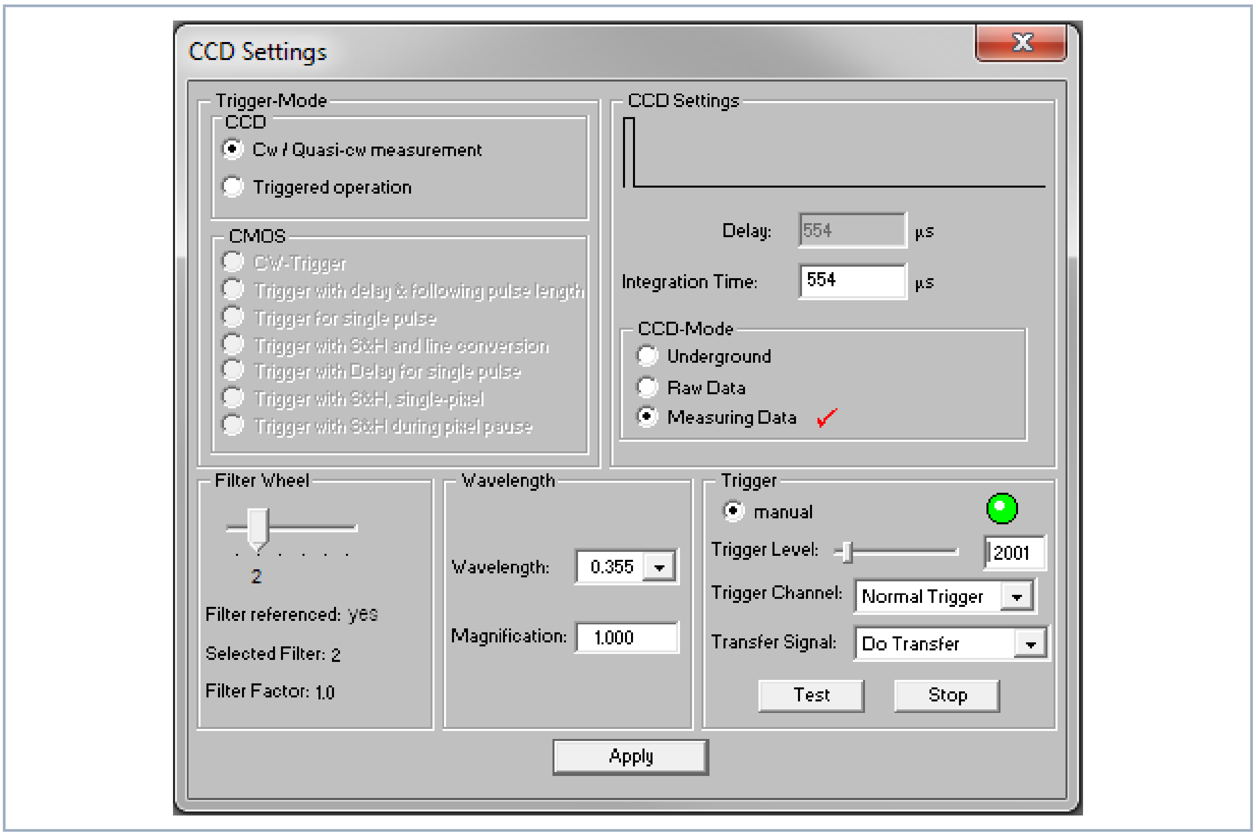


Fig. 12.12: Dialogue window ***CCD Settings***

The wavelength, attenuation, and operating mode are all set in the ***CCD Settings*** dialog window.

Trigger modes

The appropriate settings must be configured here in keeping with the operating mode of the laser to be measured. Here it is important to consider that pulsed lasers with a pulse frequency of more than 500 Hz can be measured in cw mode. If, however, the operating mode is set to pulsed and a cw laser system is involved, the measuring device will always display the error message “Error Black Pixel Measurement” or “Time Out During Measurement” in reaction to a measurement request.

Delay

This function can only be used with a “triggered operation” trigger mode. The time the measuring system should wait between when it detects the trigger pulse and the start of the measurement is set here. Together with the function “Integration Duration”, defined “Windows” from the plus cycles can be measured (e.g. exactly one pulse or parts of an ms pulse. The minimum delay is 12 µs.

CCD operating modes

Three different modes can be set here. If the ***Raw Data*** setting is activated, the measuring system will return the uncompensated data of the CCD when a measurement is requested. Especially with NIR irradiation, these can be riddled with measuring errors such as “smear effect” readout noise. Even the numeric beam data generated generated from this data will be affected by this.
If a ***Background*** is selected as the operating mode, only correction data will be returned while measuring. ***Measuring Data*** mode should always be the default setting here though. Only when this mode is turned on can the measuring system deliver reliable measuring values.

Integration duration

This function sets a defined integration duration. The optimizer must be deactivated before this can be accomplished, since otherwise the measuring device itself will optimize and thus change the integration duration. This function is also used mainly in measuring pulsed laser systems.

Filter wheel

Which filter is needed for measuring depends on the wavelength and the intensity of the laser beam being measured and the appropriate one must be chosen specifically for each measuring task.
A filter can be considered suitable when all measuring planes of a caustic measurement can be measured using an exposure time between 18 ms (-20 dB) and 0.18 ms (-60 dB). Outside of these limits, the S/N ratio of the CCD declines, thus reducing the accuracy.

Wavelength

Due to the wavelength-dependent overall magnification of the camera-based measuring system, it is important to check that the right selections have been made before each measurement. The wavelengths shown here represent the calibration points of the measuring objective. As a result of the achromatic properties of the measuring objective, a wavelength range between 1 030 and 1 100 can be achieved, for example, with a calibration point at 1 064 nm without causing generating measuring errors.

Trigger

The trigger menu is only pertinent when measuring pulsed laser systems. A fixed value (2 001) is generally specified for the trigger diode by default. This value describes the threshold value at which a trigger signal is emitted. If you switch the trigger to automatic, the trigger level will first be set to the maximum value. The ***Test*** button is renamed in ***Optimize***. In the optimize routine (laser must be turned on), the trigger threshold is lowered gradually until the MicroSpotMonitor starts receiving trigger signals (lower trigger level). The trigger level is then increased until the MicroSpotMonitor stops receiving trigger signals (top trigger level). The final trigger level is determined by calculating the arithmetic mean of the two limit values. External trigger entry can be activated via the menu point ***Trigger Channel***. Transfer signal pertains to the transfer output of the MicroSpotMonitor. Here it is possible to define the CCD sensor state at which there should be a trigger signal (e.g. for turning on the laser).

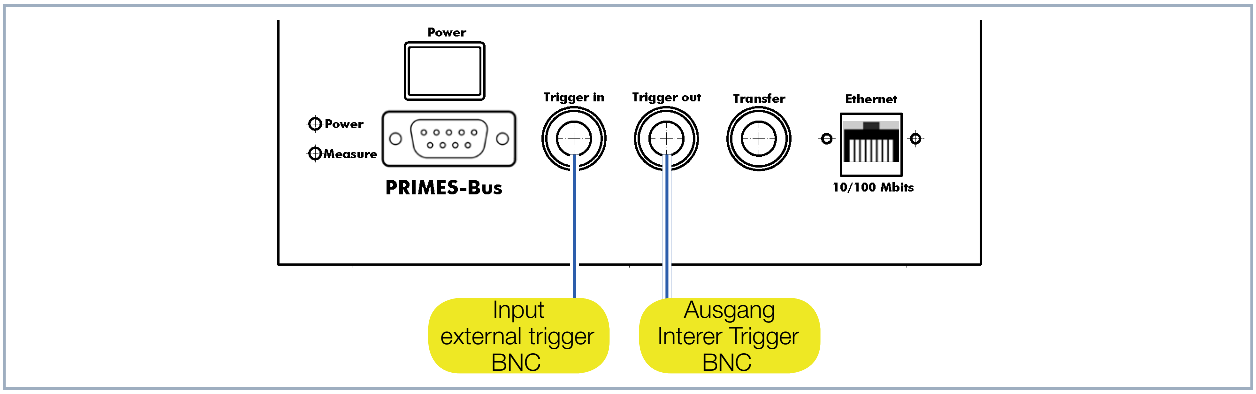


Fig. 12.13: Trigger connections

12.4.6 LQM adjustment (menu *Measurement* > *LQM Adjustment*)

Not relevant for MicrosSpotMonitor MSM.

12.4.7 Power measurement (menu *Measurement* > *Power Measurement*)

Not relevant for MicrosSpotMonitor MSM.

12.4.8 Single (menu *Measurement* > *Single*)

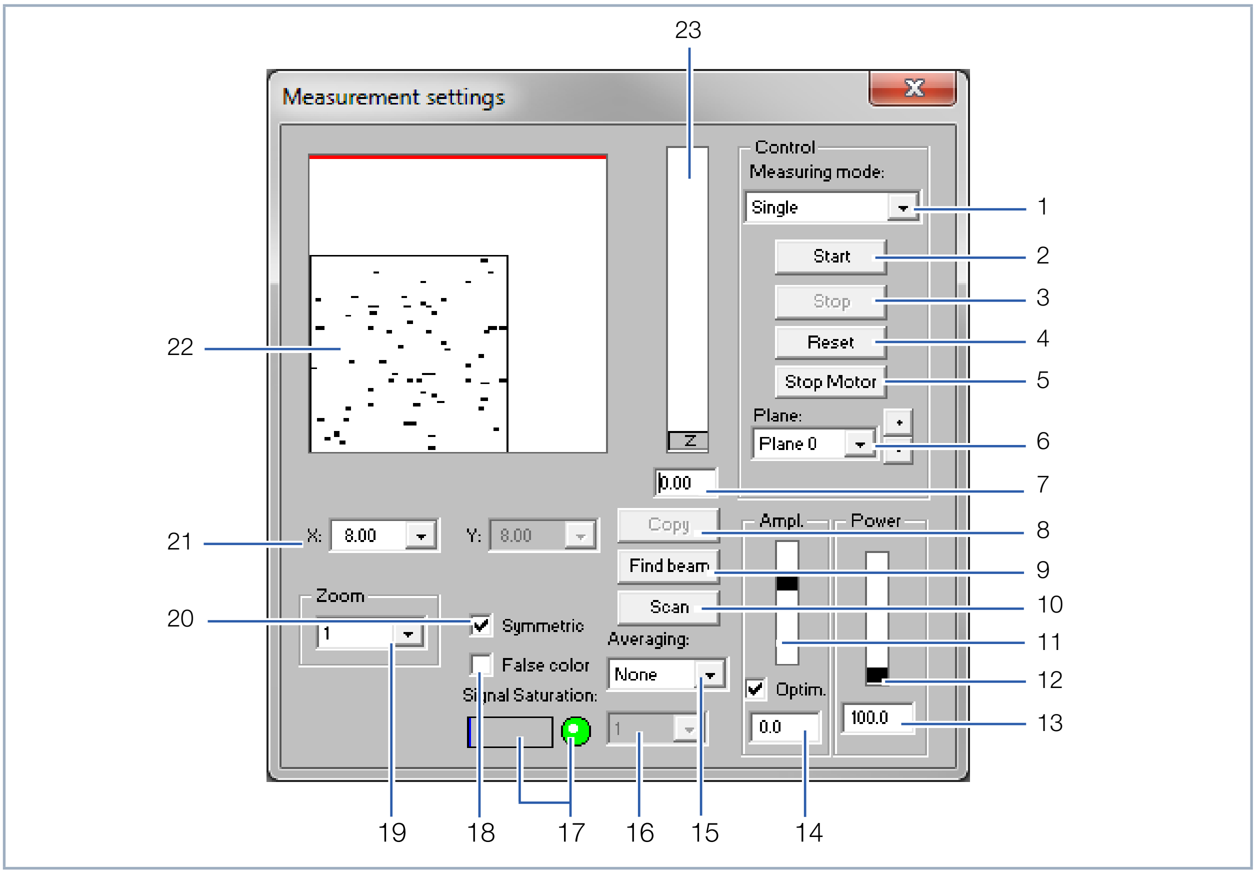


Fig. 12.14: Dialogue window ***Measurement settings***

1	Single Monitor Video Mode	Starts a measurement in the chosen plane Starts repeated measurements in the chosen plane automatically
2	Start	Starts a measurement in the currently chosen plane
3	Stop	Finishes the measurement in the currently chosen plane
4	Reset	The measuring device is reset
5	Stop Motor	Not relevant for MicrosSpotMonitor MSM
6	Plane	Selection of the measuring plane (0-49) either explicit or by means of the buttons (+/-)
7	Entry field	Numerical entry of the z-position
8	Copy	Copies all settings (window size and window position; x, y, z; etc.) from the former plane to the current plane (e.g. 1>>2)
9	Find beam	Starts an automatic beam search in the current measuring plane
10	Scan	Starts an automatic beam search with the MicrosSpotMonitor MSM. The algorithm works at a fixed z-position and searches only within the range of the specified measuring window.
11	Ampl.	Slide control in order to adjust the optical amplification (exposure time of the CCD)
12	Power	Slide control in order to adjust the laser power to save it in the software
13	Entry field Power	Numerical input of the laser power to save it in the software
14	Entry field Ampl.	Numerical input of the electrical amplification
15	Averaging	Analysis of the serial measurements. Averaging algorithms: average value, values of the maximum pixels and the value of the maximum trace
16	Averaging	Selectable number (1 – 50) of single measurements for the averaging
17	LED symbol and bar graph display	Display for the degree of the signal saturation (LED green ≙ ok, red ≙ not ok)
18	False color	Activates the option of the false color presentation
19	Zoom	Magnification settings for the measuring window
20	Symmetric	This option enforces the usage of square measurement windows, whose size is only adjustable via x.
21	X/Y	Set the measurement window size for non-square windows
22	Display	Measuring window shows the current measuring result
23	Z	Slide control in order to set the z-position

Tab. 12.2: Explanation of input and setting elements

With the dialogue window ***Measurement settings*** either single measurements or repeated measurements can be carried out. The measuring window position can be set either manually or automatically.

Controlling measuring modes (individual measurement, monitor, and video mode)

There is a total of three different measuring modes that can be selected here. In the ***Individual Measurement*** and ***Monitor*** measuring mode, all necessary compensations (smear effect, diffusion) and exposure time adjustments are performed every time a new measurement is carried out. Valid measuring data is generated in this mode.

The measuring mode ***VideoMode*** does not produce valid measurement data. Here the exposure time is carried over from the last measurement and does not vary. Compensation measurements are not performed, making it unnecessary to consider or compensate for measuring artifacts such as smear effects.
Due to the "high" measuring frequency of about 5 Hz, this operating mode is particularly suited for use when aligning the device. The numeric results should not be interpreted absolutely, but rather always relative to each other.

Power

The slider sets the actual laser power, so the software algorithm can calculate the spacial power density. It can be set to any power up to the maximum.
The maximum power is entered in the menu under ***Measurement*** > ***Environment***. The power density is calculated in relation to the power values set here. Up to 50 individual measurements can be recorded in a measurement file. The results can be easily compared and analyzed with the various presentation functions of the LaserDiagnosticsSoftware LDS.

Optical amplification (opt. ampl.)

This function activates the automatic adjustment of the exposure time of the CCD for every measurement. The function must be activated in order to keep the signal/noise ratio consistently high for a caustic measurement.
For special measuring applications, however, it might make sense to deactivate this function and set the exposure time to a fixed value between 12 µs and 200 ms. Here it is important to ensure sufficient attenuation of the laser beam with the help of the fixed ND filter or the filter wheel.

Copy

Using the ***Copy*** button, you can apply the measurement settings for window size, window position, power, and amplification from the previous measuring plane.

Beam search

The ***Beam Search*** will initiate an automatic beam search. When this happens, the system will only search the area of the currently set window for the set z position.
If the beam search is completed successfully, a measuring window with the appropriate size and position will appear on the display screen. The beam can then be accepted using the ***Start*** button. The size of the measuring window depends on the magnification of the measuring objective. The measuring objective and the wavelength are the influencing variables here.

Scan

For devices such as the LaserQualityMonitor LQM, the measuring window is much smaller than the measuring area defined with the x- and y-axis (2 mm x 2 mm). The beam search is therefore supplemented with the ***Scan*** command. Once a scan is initiated, the MicroSpotMonitor MSM will automatically sense the measuring area. If a point of maximum intensity can be identified, the MicroSpotMonitor MSM will automatically zoom in on this area and adjust the measuring window size accordingly.

Size of the measuring window

During a manual beam search, you can define the location and size of the measuring window yourself in the dropdown menu within the mechanical limits. You can change the location of the measuring window by clicking on it and dragging the frame with the mouse.

Z-Slider

The location of the window in the z direction (height) can be set by the z-slider or entering a numeric value.

Symmetrical

Once this function is activated, only rectangular measuring windows will be allowed. In cases where an elliptical or even a square laser beam is being measured, this function should be deactivated so that the measuring window can be optimally adjusted.

False color rendering

False color rendering is activated by clicking on the corresponding button. A measurement is initiated by clicking on the ***Start*** button. Selecting ***Monitor*** and pressing the ***Start*** button will initiate an ongoing, repeating measurement with the current settings. The repeat rate depends on the spacial resolution and the type of communication between the PC and the MicroSpotMonitor MSM.

Zoom function

The zoom function allows for detailed magnification of the measuring area.

12.4.9 Caustic measurement (menu *Measurement* > *Caustic*)

The caustic measurement is a serial measurement where the z position is varied. The results are stored in different planes. A different z-position is assigned to every measuring plane. As the beam radius as well as the power density change in every z position, the position as well as the size of the window and the signal strength can vary from plane to plane. The parameters are automatically adjusted in the process and can also be configured separately for each measuring plane.

Parameters (start number of the plane)

Under Start, the start number at which the measurement is initiated can be entered for the plane. By default, the start number is generally set to zero and should only be changed when you are measuring in an existing document and don't want the existing measurement data to be overwritten. If, for example, you have measured a caustic with 21 planes and want to magnify the measuring area to the smaller z-values, you can set the start plane to 21 and modify the measuring area appropriately. The new measuring values will then be written into the existing document starting with plane 21.

In the Quantity selection field, the number of planes to be measured in the specified z range is set. The following should be considered here:

- Since the LaserDiagnosticsSoftware LDS always sets the measuring plane distances so they are equidistant (equal spacing) and the measuring area is almost always situated symmetrically around the focal point, an odd number of measuring planes should be selected. This ensures that the focus plane is measured.
- Beam measurement norm DIN 11146 specifies that at least 10 measuring planes should be measured. Furthermore, five measurements should also be taken within a Rayleigh length and the other beyond 5 Rayleigh lengths. In order to meet all of the requirements with equidistant distribution, at least 17 measuring planes must be measured in a range of ± 3 Rayleigh lengths.

Mode (automatic and manual settings)

There are two different measuring modes for caustic measurement. In “Automatic” mode, the measuring system and the LDS determine the ideal measuring window position (x- and y-direction) for each measuring plane and the optimal measuring window size for the fill factor. Furthermore, the plane location in the z-direction is also calculated based on the specifications (number of measuring planes, measuring limits z-direction).

Especially when adjusting the measuring window size and the measuring window position in the x- and y-direction, the number of iterations (max. three per plane) can result in an extended measurement duration.

It is therefore possible to change the measuring mode to “Manual Settings” for recurring measuring tasks and for repeating measurements. In this case, the measuring system will take the measuring window positions and measuring window sizes from the previous measurement or from a .ptx file. This reduces the measurement duration considerably, but does require that the location and parameters of the laser beam change only minimally.

Beam search

This selection field specifies which plane the caustic measurement should be started in. If the optional ***Beam Find*** function is activated in the ***Options*** dialog window, that is also the plane in which this function will be performed. When the Beam Find function is deactivated, this plane must be manually measured ahead of time to make sure that the laser beam is found.

The window can be adjusted under the ***Adjust*** menu point. The settings for spacial resolution of the beam search, the threshold value, and the minimum signal strength can be entered under the ***Details*** menu point.

Beam search can be turned off in the ***Measurement > Option (only for advanced users) menu*** by deactivating the checkbox ***Enable Beam Find Process***.

Automatic caustic measurement (menu *Measurement* > *Caustic* > *Automatic)*

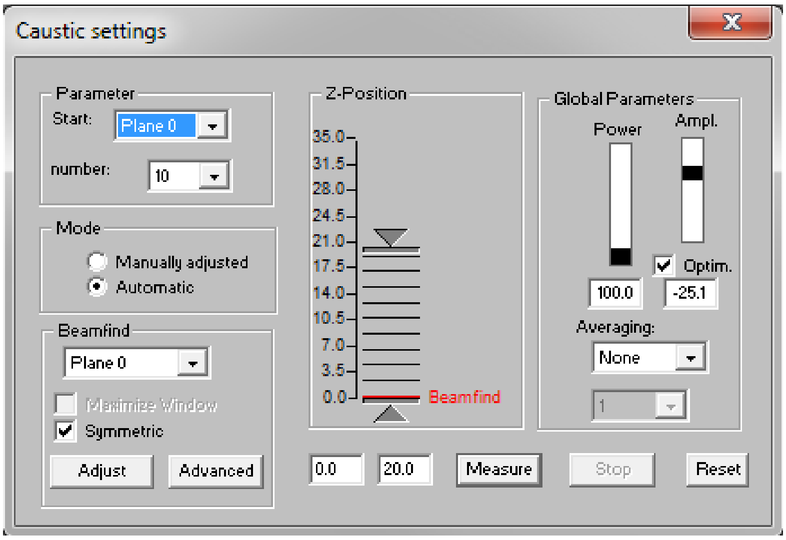


Fig. 12.15: Dialogue window ***Caustic settings***

During automatic caustic measurement, the minimum and maximum z-position is selected together with the number of measuring planes. The measurement cycle begins with an automatic beam search in the specified starting plane. The beam search only occurs within the area of the starting plane's measurement window.

Settings can be entered manually. After manually entering the settings for the measurement planes as described in the following section, the caustic measurement can be repeated automatically by choosing the ***Manually adjusted*** mode.

It is also possible to store measurement settings such as window size, position, etc. in a data file to be reloaded again if necessary (***File*** > ***Safe/Load measurement preferences***).

A measurement cycle is started by pressing the ***Measure*** button. All planes will be measured then one after the other during the measurement cycle.

Manual caustic measurement as time series (menu *Measurement* > *Caustic* > *Manually adjusted)*

The manual caustic measurement consists of a series of individual measurements at various z-positions, with the results being stored in their own planes.

12.4.10 Start adjust mode (menu *Measurement* > *Start Adjust mode*)

Not relevant for MicrosSpotMonitor MSM.

12.4.11 Option (advanced user only) (menu *Measurement* > *Option*)

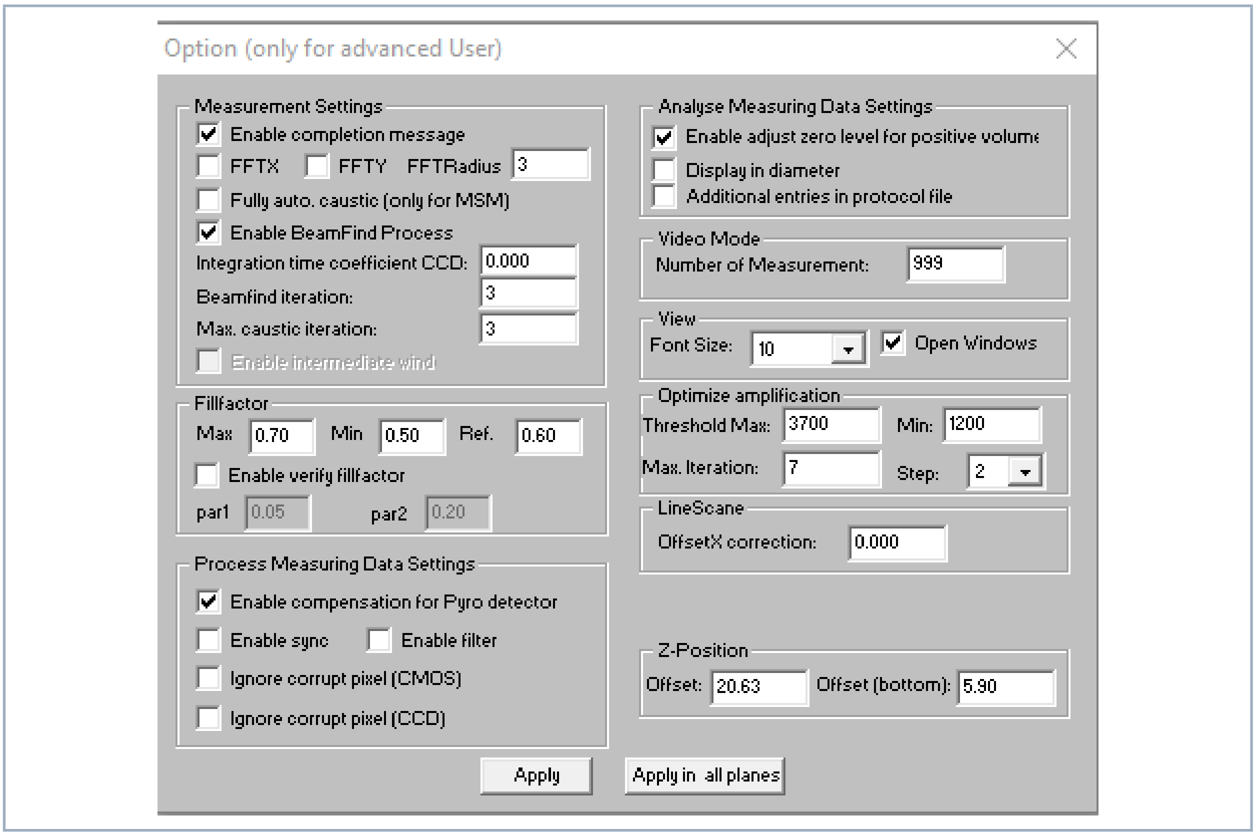


Fig. 12.16: Dialog window ***Option***

Enable beam find process

The Beam Find function must be used for caustic measurement. This involves an algorithm that separates the measuring signal from the measurement artifacts (e.g. noise) via an adjustable trigger threshold and adapts the size of the measuring window to this signal. This algorithm is only executed in the beam search plane (Dialog window ***Caustic***). On all other measuring planes, the measuring window size is determined using the fill factor.

If this function is deactivated, the beam search plane must be manually "premeasured" in the measuring system. Otherwise the measuring system might end up positioning the measuring window on the edge of the measuring area where there is no measuring signal. This makes it impossible to take a meaningful measurement.

If you turn the Beam Find function off and have the measuring measure the beam search plane system before each caustic measurement, you can save about 20 sec of measuring time per caustic measurement.

Summary: This function should be activated by default and only deactivated by experienced users. Turning off this function can shorten the time for caustic measurements by about 15 %.

Fillfactor

The fill factor is the quotient of the beam diameter and the length of the sides of the measuring window. As long as the measuring signal is not cut off and there are no noise components in the measuring result and now errors in the offset determination, the fill factor won't influence the accuracy at all. But since every real measuring signal is tainted with noise and since the precision with which the zero level of a measuring signal can be determined is finite, very small fill factors can lead to a high level of accuracy. Depending on how substantial the RMS noise is and the errors in the zero level determination of a measuring plane, the optimal fill factor value to produce the best possible mathematical result will be different.

For TopHat and Gaussian beam shaped laser beams, the fill factor should range between 0.5 and 0.7. If the beam has diffraction rings, however, and if these are located completely within the measuring window, the optimal value for the fill factor can be between 0.5 and 0.6.

By default, the value should be set to: “Max 0.7 Min 0.5 Target 0.6”. For extremely deformed beams, the value may be changed to “Max 0.6 Min 0.4 Target 0.5”.

Font size

The font size for the most important display window can be changed here.
It is set to 10 points at the factory.

Open windows

When the window opening function is activated, some basic windows are opened when the LDS is started. If you don’t want this to happen, the function can be deactivated.

12.5 Presentation

This chapter describes the presentation, analysis and storage of measuring results.

In order to carry out comparisons between different measurements, the program can manage several measuring data sets simultaneously. The opened data sets are shown in the toolbar. In order to open one presentation, the data which is to be examined is selected in the list of the data selection and afterwards the desired kind of presentation is chosen.

File management functions as well as various display types can be pulled up directly with the symbols in the menu bar.

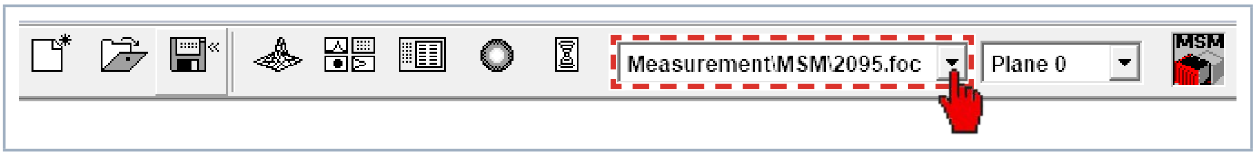


Fig. 12.17: Selection of a data set

On the selection plane, it is possible to switch back and forth between different image storages of the measuring series. When plane selection is activated, it is possible to move up or down by clicking the cursor. When plane selection is set to ***Global*** in the display menu, then it is also possible to move up/down with the cursor button.

In the menus for the notation of single measurements (***Presentation > Variable contour lines***, ***Presentation > Isometry*** and ***Presentation > False color presentation***) the option ***Autoscale*** effects the usage of the entire display range for the measuring values.

Moreover, you have the possibility of switching between different image memories of series of measurements by means of the ***Plane selection***. Switching is also possible by means of the cursor keys up/down if the plane selection is selected. If the plane selection in the display menus is set on ***Global***, switching simultaneously between the planes is possible via the selection in the toolbar.
The title of the dialogue window indicates the name of the data sets shown.

For the parallel evaluation of several measurements the program has 50 image memories which can record one measurement each. These image memories (measuring plane) can also be used in order to record changed measurement values in case of a parameter variation.

Due to the variation of the z-position in the different planes a caustic measurement is realized. Due to a change of the laser power it is possible to simulate, e.g. the thermal inflow-behavior of the system. Similarly, time series are possible. Respective displays are, for instance, possible by means of the menu item ***Presentation > Graphical review***.

12.5.1 False colors (menu *Presentation* > *False colors*)

Here, a false color presentation of the measured power density distribution is generated.

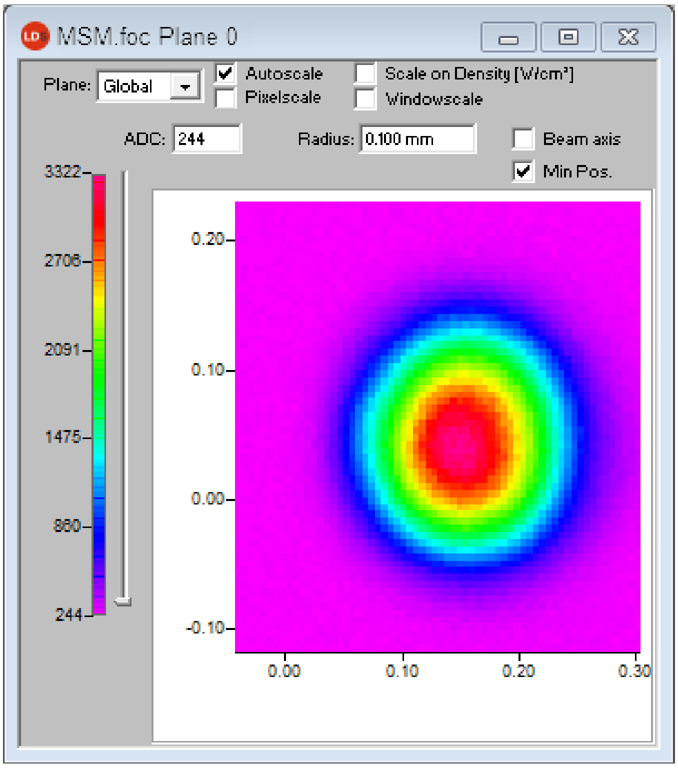


Fig. 12.18: Dialogue window ***False colors***

The used color scale is shown on the left. For a higher sensitivity, e.g. for the analysis of diffraction figures, it is possible to switch the used color scale in the menu ***Presentation > Color Tables***. By means of the slide control on the left hand side of the color scale you can display the sections of different ADC values with the corresponding radii.

Apart from the automatic scaling, there are three more types of scaling:

Scale on density

All planes of a caustic measurement are scaled on the maximum measured power density. This is supposed to help comparing the different planes more easily.

Pixel scale

This scaling is only interesting when it comes to the usage of asymmetric measuring windows. In this case the axis of the windows are no longer a function of the measuring window size but of the number of pixels measured.

Window scale

With regard to this function, all measuring windows of a caustic measurement are enlarged to the size of the maximum measuring window. This function, too, is supposed to help comparing the different measuring planes of a caustic measurement more easily.
The beam axes can be displayed in all types of scaling by activatng the check box ***Beam axis***.

Rule function

The beam can be measured in any direction by left-clicking on the image.

12.5.2 False colors (filtered) (menu *Presentation* > *False colors (filtered)*)

The special function of the filter is called spline – function. It is characterized by the fact that the position of the maximum is maintained. The single pixels in the matrix are weighed by means of a 1-2-1 filter in order to reduce the noise.
This filter can also be used multiple times without the position of the maxima being moved.

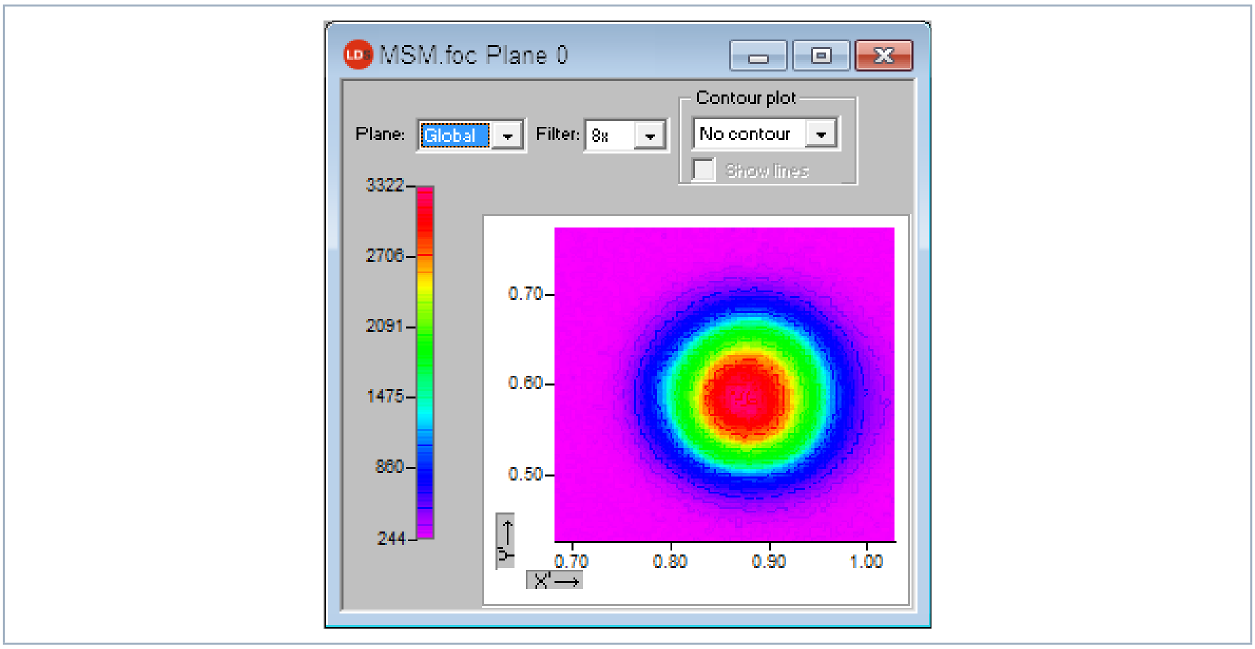


Fig. 12.19: Dialogue window ***False colors (filtered)***

12.5.3 Isometry (menu *Presentation* > *Isometry*)

This menu item generates a spatial display of the measured power density distribution of a plane. The false color display can be deactivated. A turn of the distribution by 90°, 180° and 270° each is possible.

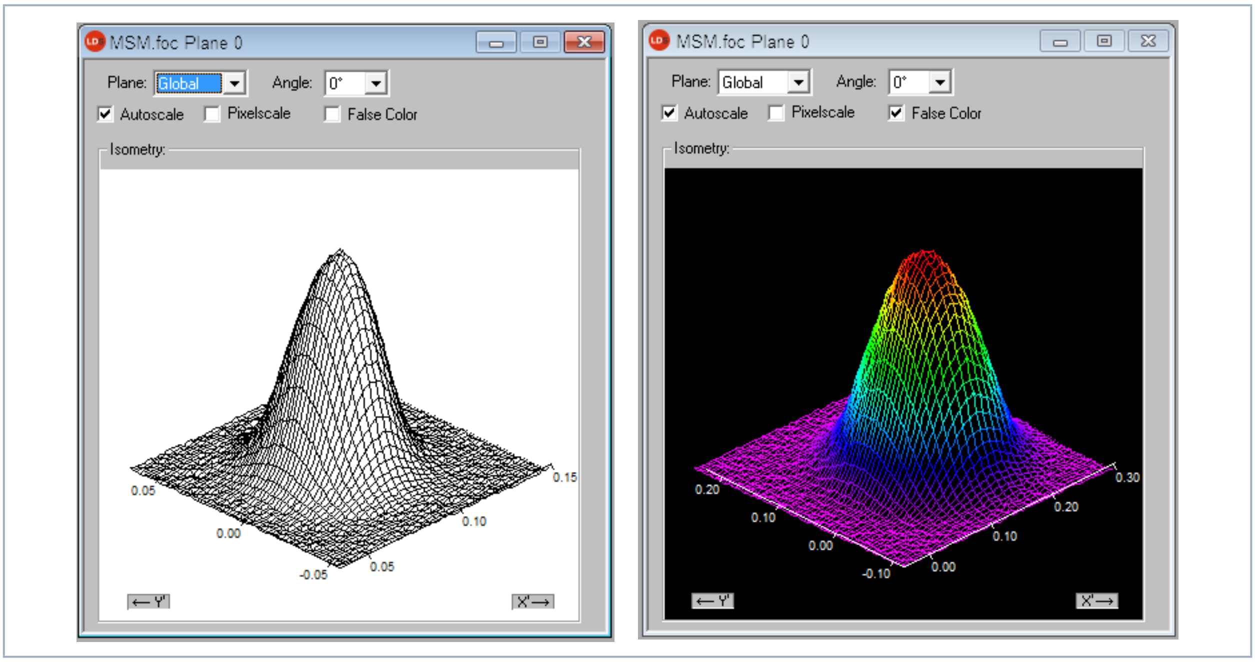


Fig. 12.20: Dialogue window ***Isometry*** (on the left with a deactivated color display)

12.5.4 Isometry 3D (menu *Presentation* > *Isometry 3D*)

This function generates three-dimensional displays of the power density distribution of a plane and all planes in false colors.
The presentation window is divided. On the left the caustic, on the right the power density distribution in a plane is displayed. The horizontal size of the single windows can be changed by drawing the separating bar by means of your mouse.
The graphics can be rotated along all three axis with the left mouse button and with the right mouse button they can be positioned in the window.

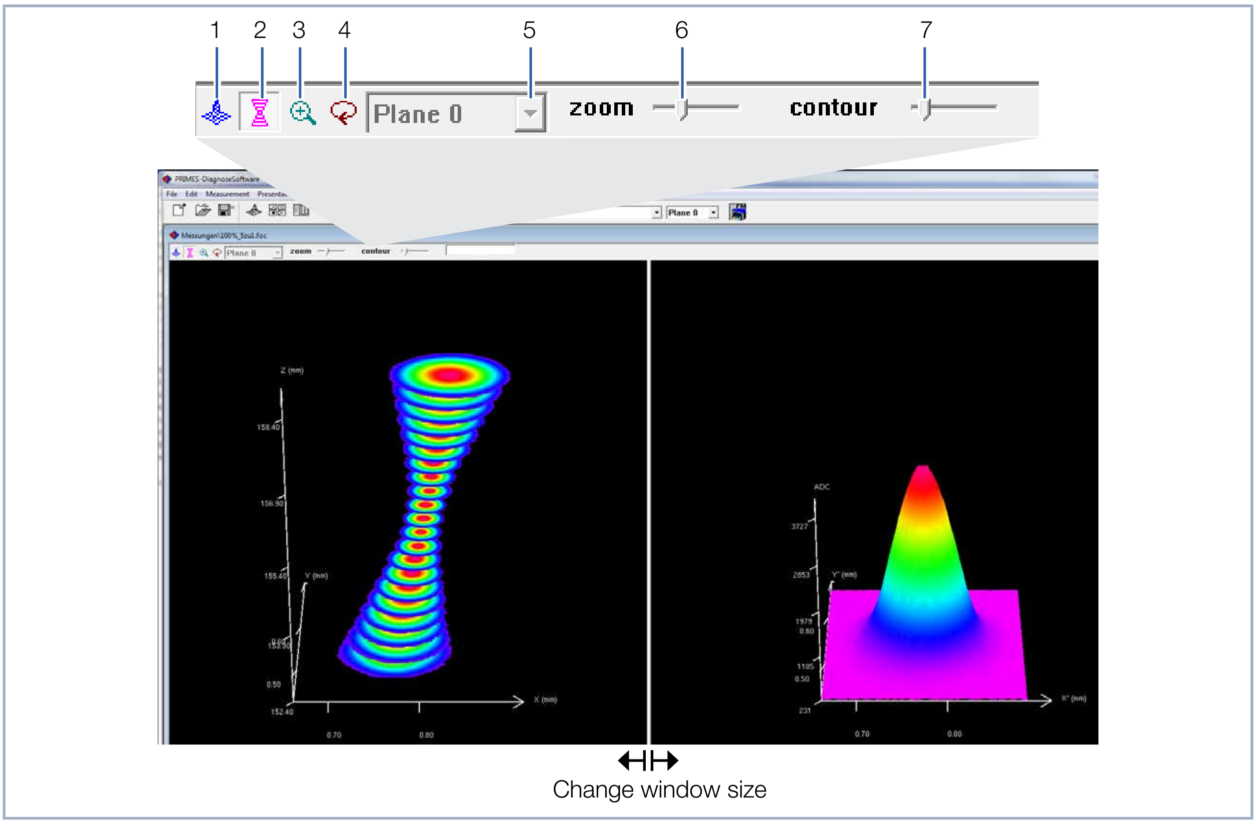


Fig. 12.21: Dialogue window ***Isometry 3D***

1	3D presentation of the plane	Inserts the 3D presentation of the power density distribution in the plane in the display window.
2	3D presentation of the caustic	Additionally inserts the 3D presentation of the caustic in the presentation window.
3	Magnification in the plane	In the left part of the presentation window a magnification of the plane displayed on the right is inserted (the desired area can be clicked by means of the left mouse button in the right window).
4	Rotation	Causes a rotation of both graphics along the z-axis.
5	Plane selection	Here the plane, which is to be displayed, can be chosen (you can also choose the desired plane in the 3D caustic by means of the left mouse button).
6	Zoom	Slide control for a continuous magnification of the presentation
7	Contour	Slide control for a contour trimming along the power density.

Tab. 12.3: Explanation of selection and setting elements

12.5.5 Review 86 % or 2. moment (menu *Presentation* > *Review (86%)/(2. moment)*)

For the radius definition there are two basic determination possibilities:

- Determination of the beam radii according to the 86% - power definition, (see chapter 22.2.4 on page 145).
- Determination of the beam radii according to the 2. moment method (ISO 11146), (see chapter 22.2.3 on page 144).

MSM.foc - 86% Review

Plane:	Plane 0	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5	Plane 6	Plane 7	Plane 8	Plane 9	Plane 10
Radius [mm]	0.100	0.092	0.084	0.075	0.067	0.060	0.053	0.046	0.040	0.035	0.030
Position X [mm]	0.152	0.146	0.143	0.137	0.131	0.126	0.122	0.115	0.109	0.103	0.097
Position Y [mm]	0.043	0.040	0.033	0.032	0.028	0.023	0.021	0.017	0.012	0.010	0.006
Position Z [mm]	142.700	143.400	144.100	144.800	145.500	146.200	146.900	147.600	148.300	149.000	149.700
Zero level [A/D-Cnts]	261.750	260.000	265.000	264.750	264.750	264.500	258.750	262.000	258.750	259.000	261.000
Power [kW]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Radius inten. [kW/cm²]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Peak inten. [kW/cm²]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Date:	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014
Time:	10:26:56	10:26:59	10:28: 7	10:27: 9	10:27:11	10:27:13	10:27:17	10:27:19	10:27:22	10:27:25	10:27:28
Focal length [mm]	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000
Z-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coord.rotation [deg.]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wavelength [µm]	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064
Fill Factor	0.577	0.528	0.483	0.645	0.582	0.516	0.604	0.534	0.686	0.601	0.519
Comment:											

Tab. 12.4: Result window ***86% Review***

MSM.foc - 2. Moments Review

Plane:	Plane 0	Plane 1	Plane 2	Plane 3	Plane 4	Plane 5	Plane 6	Plane 7	Plane 8	Plane 9	Plane 10
Radius [mm]	0.102	0.093	0.085	0.076	0.069	0.061	0.053	0.046	0.039	0.035	0.031
Radius X [mm]	0.101	0.094	0.085	0.075	0.068	0.060	0.052	0.045	0.038	0.034	0.030
Radius Y [mm]	0.102	0.093	0.086	0.076	0.069	0.062	0.054	0.047	0.040	0.036	0.032
Angle [°] (x/y-plane)	37.7	-44.5	40.2	24.3	16.8	10.5	5.5	1.1	2.7	-0.8	-3.6
Position X [mm]	0.153	0.147	0.144	0.137	0.131	0.125	0.121	0.115	0.108	0.103	0.097
Position Y [mm]	0.042	0.039	0.033	0.031	0.028	0.023	0.021	0.017	0.013	0.010	0.007
Position Z [mm]	142.700	143.400	144.100	144.800	145.500	146.200	146.900	147.600	148.300	149.000	149.700
Zero level [A/D-Cnts]	261.750	260.000	265.000	264.750	264.750	264.500	258.750	262.000	258.750	259.000	261.000
Power [kW]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Peak inten. [kW/cm²]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Date:	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014	24. 6.2014
Time:	10:26:56	10:26:59	10:28: 7	10:27: 9	10:27:11	10:27:13	10:27:17	10:27:19	10:27:22	10:27:25	10:27:28
Focal length [mm]	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000	205.000
Z-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
X-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y-axis-offset	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Coord.rotation [deg.]	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Wavelength [µm]	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064	1.064
Radius X' [mm]	0.102	0.093	0.085	0.076	0.068	0.060	0.052	0.045	0.038	0.034	0.030
Radius Y' [mm]	0.102	0.093	0.085	0.076	0.069	0.062	0.054	0.047	0.040	0.036	0.032
Fill Factor	0.584	0.537	0.491	0.655	0.592	0.526	0.608	0.531	0.674	0.597	0.530
Ellipticity (Rmin/Rmax)	0.991	0.988	0.987	0.988	0.985	0.978	0.968	0.958	0.955	0.949	0.948
RadiusX/RadiusX'	0.997	1.006	0.994	0.998	0.999	0.999	1.000	1.000	1.000	1.000	1.000
RadiusY/RadiusY'	1.003	0.994	1.006	1.002	1.001	1.001	1.000	1.000	1.000	1.000	1.000
3*RadiusX'/WindowsizeX	0.876	0.806	0.735	0.978	0.883	0.781	0.897	0.779	0.987	0.872	0.774
3*RadiusY'/WindowsizeY	0.878	0.806	0.737	0.986	0.894	0.797	0.927	0.813	1.033	0.919	0.816
Comment:											

Tab. 12.5: Result window ***2. Moment Review***

The parameters and results of the current selected plane are highlighted in blue. When the measuring signal only exceeds the zero level by a little bit, the measuring results are not shown in black, but rather in gray. In this case, check to see if the measuring values are reliable or need to be thrown out and the measurement repeated with different settings.

The entries for power, focal length, and wavelength as well as any comments can also be changed after the fact. For this purpose there is the button ***Apply*** in the menu item ***Measurement*** > ***Environment***.

12.5.6 Caustic (menu *Presentation > Caustic)*

The results of the caustic measurement can be displayed by means of the menu item ***Presentation > Caustic***. On the left Fig. 12.22 on page 63 shows the measured beam parameter either on the basis of the 86%-radii or the 2. moment method evaluation according to ISO 11146. In the middle of the picture the graphic shows the caustic profile. The beam radii are depicted on the beam spread direction. On the right is a false color presentation of the measurement plane selected with the mouse shown together with numerical results of this corresponding plane.

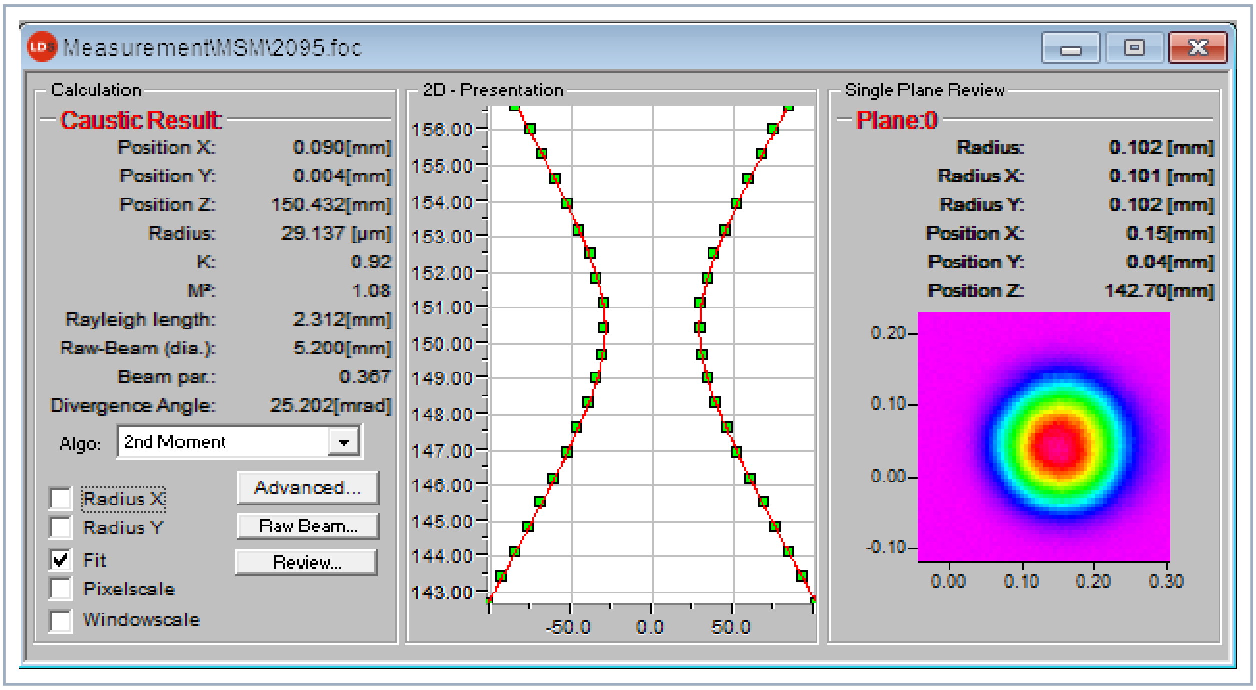


Fig. 12.22: Dialogue window ***Caustic***

The red line depicts a compensation curve according to the calculated fits which can be displayed via the check box ***Fit*** in the 2D presentation.

Compensating curve

In order to evaluate the caustic, a hyperbolic compensating curve (ISO 11146) is adapted to the measuring values. This compensating curve describes the propagation of an ideal laser beam mathematically. The development of the compensating curve is theoretically determined by means of the following parameters:

- Standardized beam quality factor M² or respectively beam propagation ratio K
- z-position
- focus radius
- rayleigh length

Standardized beam quality factor M² (or respectively the beam propagation ratio K= $\frac{1}{M^2}$)

The normed beam quality factor describes how well the affected laser beam can be focused in relation to the dominant mode. The basic mode represents the theoretically best possible beam and has a beam quality factor M² of 1. All other beams have higher M² values.

Z-position

This value provides the position of the focus points in the z-position. As the compensation curve takes the measurement points into consideration, the calculated z-position is not necessarily located at the position, which has measured the smallest radius.

Focus radius

The focus radius is the smallest beam radius in the caustic. Generally, this value is similar to the smallest value measured, but not necessarily.
Due to different reasons it may occur that the adaption to the measurement values was not carried out. This is the case if the compensation curve does not lie close to the measurement values. In this case the parameters of the adapted compensation curve are to be discarded.

Rayleigh length

The Rayleigh length is a derived parameter and describes the distance in z-direction with regard to which the beam radius has increased by the factor √2 (=1.41) and concerning which the beam area has increased by the factor 2. The Rayleigh length increases with the focal length of the focusing optics and the beam quality. The doubled Rayleigh length is an approximate point of reference, up to which material thickness (metal) a procession is possible with the optic employed.

In order to make sure that the adapted values have a high significance, the measurement is to be carried out in a z-range of at least ±2 Rayleigh-lengths. As demanded in the ISO 11146 5 to 6 Rayleigh-lengths would be ideal. However, this demand is often confronted with the problem of quickly sinking power densities of the laser beam which is to be measured. In case of a distance of 2 Rayleigh-lengths from the focus the power density has sunk to just a quarter.

In this case the caustic measurement consists of a compromise between the desired measurement range in z-direction and the power density (signal-to-noise ratio) necessary for a perfect measurement.

Cyclic caustic measurements

When performing cyclic caustic measurements, it is useful to store settings for various display parameters in a data file. This data is available anytime and can be reloaded for a new measurement. For a quick check of the beam or when it is necessary to measure only part of the caustic.

Cyclic measurements are normally performed over a period of 2 to 3 minutes; by Ethernet communication much quicker. For measurements after laser or system servicing, you should use more planes to achieve greater accuracy in the results.

To start a measurement, saved caustic data is loaded from the settings file. This is done through the menu item ***File > Load Settings***. The data is loaded after entering the desired file name.

Advanced (menu *Presentation* > *Caustic* > *Advanced)*

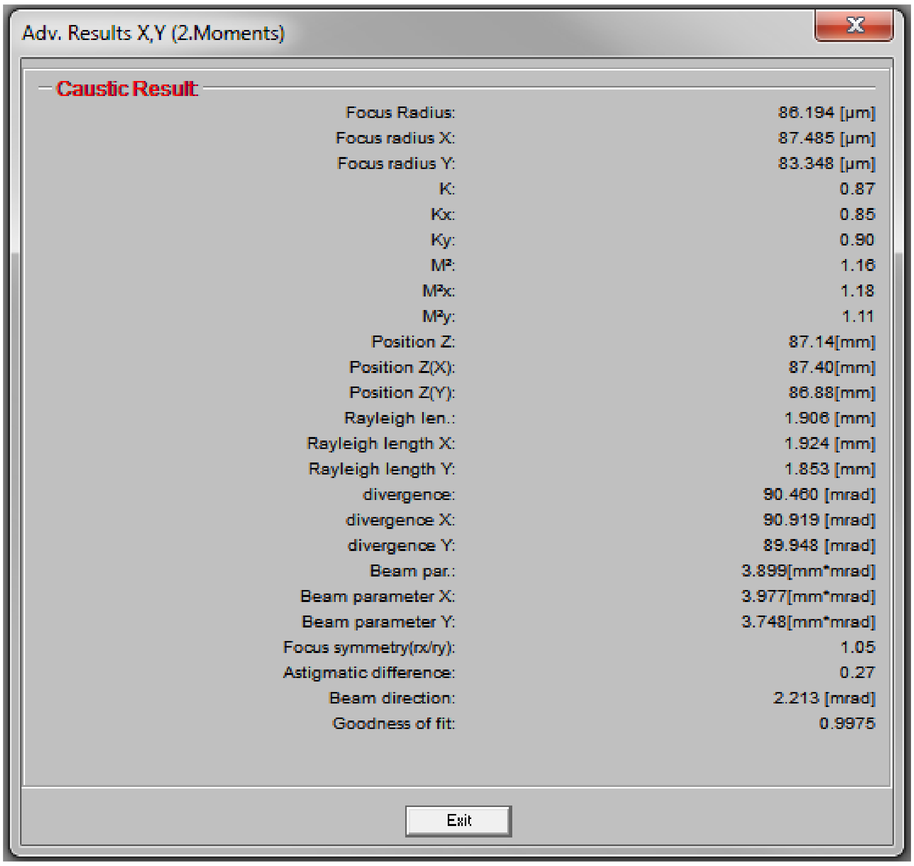


Fig. 12.23: Result window ***Results X,Y (2. moment)***

For the examination of asymmetric beams the dimensions of the main axes of the beam can be determined. On the basis of these values the program also calculates direction dependent beam propagation factors as well as beam position values. The related curves are shown via the two check boxes radius x, y while the numerical values are provided by the result window.

Raw beam (menu *Presentation* > *Caustic* > *Raw Beam)*

Not relevant for MicrosSpotMonitor MSM.

Review (menu *Presentation* > *Caustic* > *Review)*

This function checks whether the results and settings of the caustic measurement are within the reliable range.

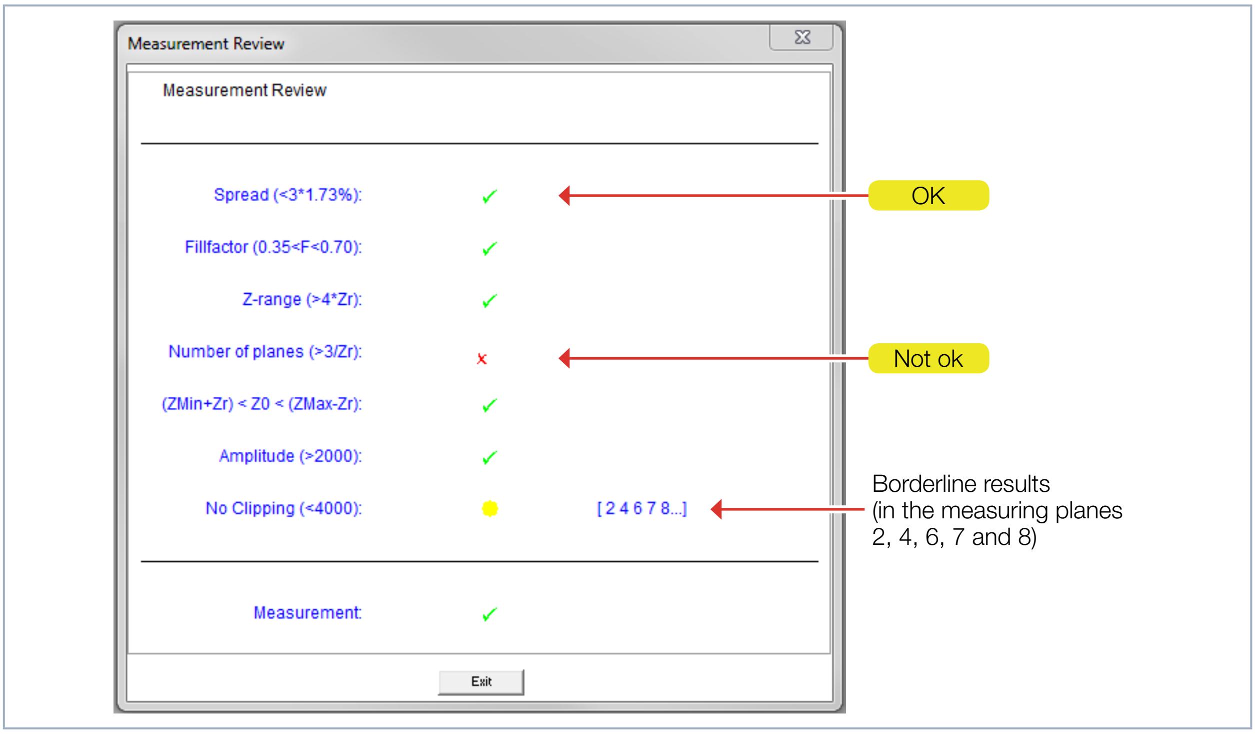


Fig. 12.24: Result window ***Measurement Review***

Under “spread” the average standard deviation of the caustic fit according to the 2. moment method radii is stated. A “tick” (✓) is set if the standard deviation is smaller than 3.5 % and if all of the measuring values lie within a range of ± 3 % standard deviation.
When the divergence receives a negative assessment (×) the affected measuring planes are also displayed. The displayed planes are arranged from left to right, starting with the greatest divergence and working its way down. This means that the plane with the greatest divergence (see Fig. 12.24 on page 66 Plane 2) will be the first one in front.

Valued functions	Test criterion	Positive evaluation ✓
Spread	Average relative standard deviation of the caustic fit according to the 2. moment method	Standard deviation < 3.5 %, all measurement values within a range of ± 3 % standard deviation
Fill factor	Describes the ratio of the beam diameter to the lengths of the sides of the measuring window	In the range 0.35 – 0.7
Z-range	Measuring range in z-direction	At least 4 Rayleigh-lengths
Measurement planes	Number of measurement planes per Rayleigh length	At least 3 measurement planes per Rayleigh length
$(Z_{Min}+Z_r) < Z_0 < (Z_{Max}-Z_r)$	Minimum measurement range above and below the focusing plane	The focus lies within the minimum measurement range and this range accounts for at least one Rayleigh length in every z-direction
Amplitude (>2 000)	Signal control	Above 2 000 counts
No Clipping (<4 000)	Signal control	Below 4 000 counts

Tab. 12.6: Criteria for the evaluation

If all criteria are fulfilled, the measuring results have a high reliability. The absolute accuracy can not be stated from the standard deviation from the fits as all the systematic measuring errors as well as the accuracy of the calibration are additionally taken into account when it comes to the absolute error.

12.5.7 Raw beam (menu *Presentation* > *Raw-beam)*

Not relevant for MicrosSpotMonitor MSM.

12.5.8 Symmetry check (menu *Presentation > SymmetryCheck*)

This display menu checks the rotational symmetry of the power density distribution of a laser beam. It can, for instance in connection with the monitoring operation (***Measurement > Single > Monitor***), be used for the alignment of laser resonators.
In the following, the figures Fig. 12.25 on page 68 and Fig. 12.26 on page 68 show two examples for the possible results of a symmetry check at an elliptic beam and a circular beam.

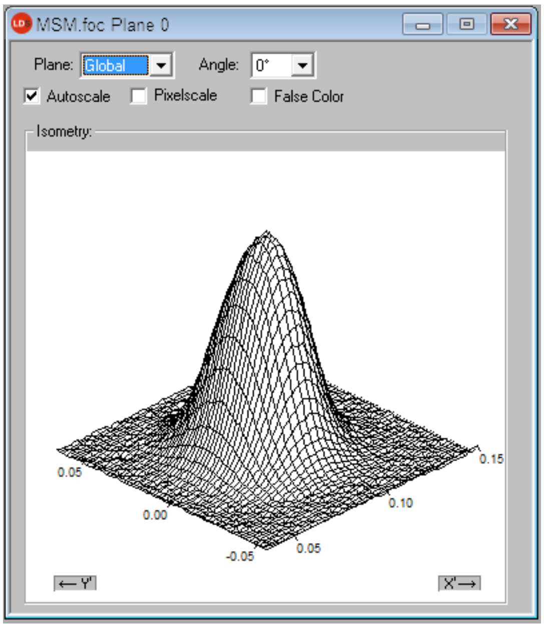


Fig. 12.25: Dialogue window (menu ***Presentation > Isometry***) power density distribution of an elliptic beam

The power density distribution of an elliptical beam as shown in Fig. 12.26 on page 68 together with the ***Symmetry check*** comes to the following results.

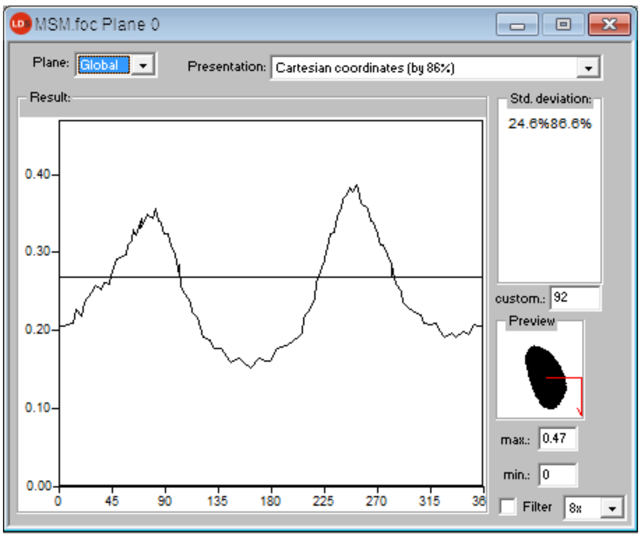


Fig. 12.26: Dialoque window ***Symmetry check*** in cartesian coordinates of an elliptic beam

The abscissa in Fig. 12.26 on page 68 shows the angle and the ordinate shows the beam radius with the intersection line at 86 % of the total power.

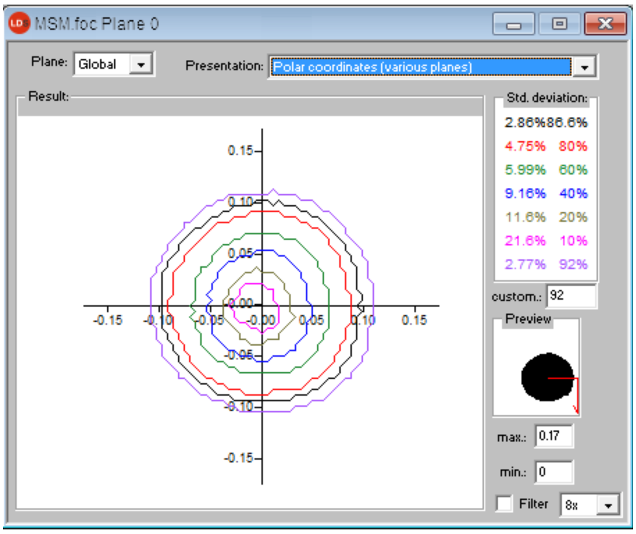


Fig. 12.27: Dialoque window ***Symmetry check*** in polar coordinates of an elliptic beam

On the screen the curves appear in different colors. The radius is indicated in pixel coordinates. The minimum as well as the maximum of the radius values can be chosen. On the right side the standard deviation of the different radius values are indicated. These values give detailed information on the symmetry of the beam distribution.

Well aligned resonators reach standard deviations in the range of 3 % to 5 %. Partially, values in a 1 % and 2 % range are possible.
A presentation in polar coordinates is also possible (Fig. 12.27 on page 69). The drawn in lines contain 86 % up to 10 % of the detected power. On the screen the graphs have different colors. X- and y-axis scale in pixel values.

12.5.9 Fixed contour lines (menu *Presentation* > *Fixed Contour Lines*)

The contour lines are displayed with different power levels. Intersection lines are selected with: 86 %, 80 %, 60 %, 40 %, 20 % and 10 % of the total power.
In this presentation it is also possible to measure distances by clicking the start and end points with the mouse.

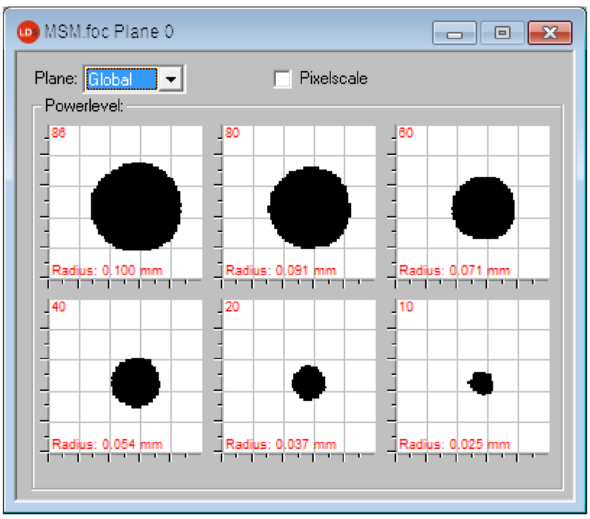


Fig. 12.28: Dialoque window ***Fixed contour lines***

12.5.10 Variable contour lines (menu *Presentation* > *Variable Contour Lines*)

Here the spatial power density distribution is displayed by means of freely selectable contour lines. Not only intersections in x- and y- direction but also in power density coordinates (A/D-converter-counts) can be carried out. The position of the intersections is settable by means of a slide control or the keyboard.

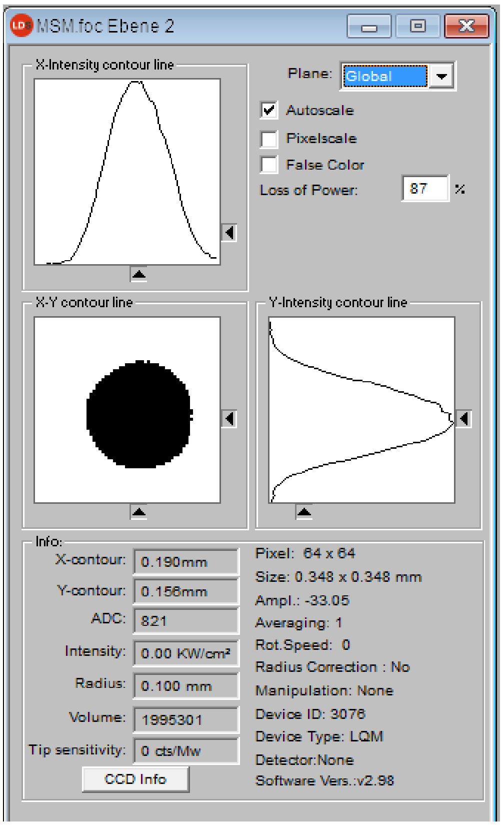


Fig. 12.29: Dialoque window ***Variable contour lines***

Setting by means of the keyboard:

- For the x-direction by means of the key ***x*** in order to increase the value and ***<shift> x*** in order to decrease it.
- For the y-direction by means of the key ***y*** in order to increase the value and ***<shift> y*** in order to decrease it.
- For the power density (intensity) by means of the key **i** in order to increase the value and ***<shift> i*** in order to decrease it.

In the range of the left hand lower corner the current intersection coordinates, the power densities, the radius generated by the intersection as well as the relative volume are displayed. The values are calculated basing on the correctly entered laser power.

In the right hand upper corner it is possible to switch the scaling. Below it, there is an input field where the desired power loss (-inclusion) can be entered. This value correlates to the given power levels in the window.

In addition to these functions, this window also offers plenty of additional information on the conditions under which measurements are taken. The amplification, resolution number, and the software version used for measuring are all displayed while measuring as well.

One click on the ***CCD Info*** button will open a window with additional information on the device parameters such as trigger mode, trigger delay, integration duration, magnification, and focussing optic type.

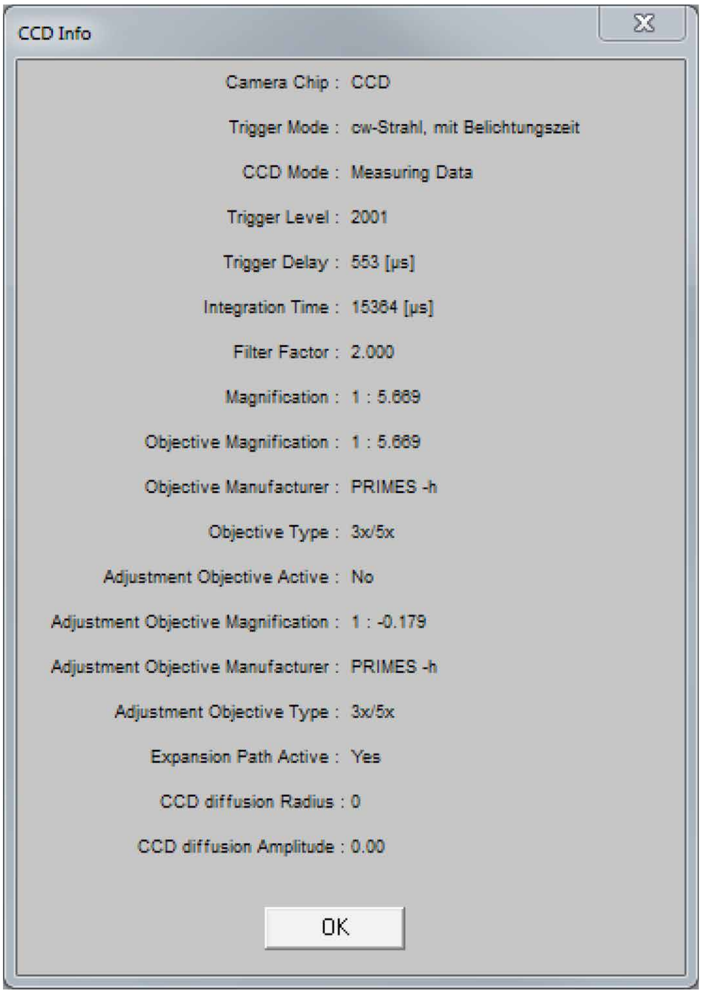


Fig. 12.30: Display window ***CCD Info***

12.5.11 Graphical review (menu *Presentation* > *Graphical Review*)

The display window ***Graphical review*** offers many possibilities to display the measurement values of the single measurement planes. In total this window can present 20 different graphs. The possible selections for the x- and y-coordinates are shown in the Tab. 12.7 on page 72.

y-axis	x-axis
Radius	Power
x-position	Time
y-position	Plane
Angle	Position
Ellipticity	

Tab. 12.7: Selections for the x/y coordinates

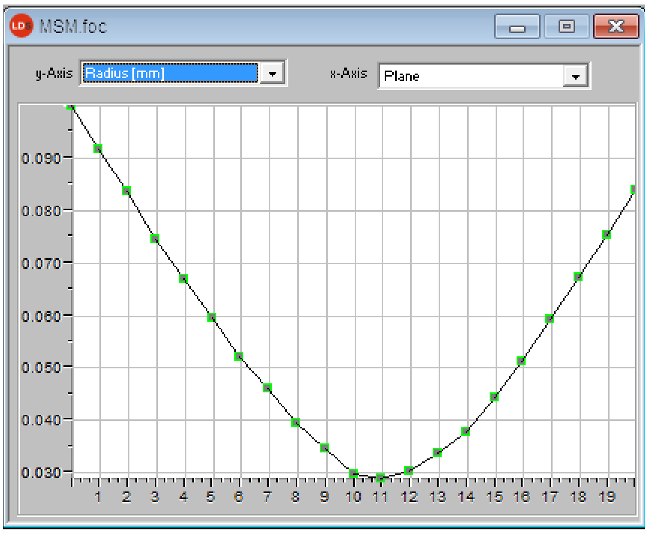


Fig. 12.31: Display window ***Graphical review*** – Example for assessment of a time series - radius/time

See chapter 12.4.9 on page 54, Section „Manual caustic measurement as time series (menu Measurement > Caustic > Manually adjusted)“.

12.5.12 Systemstate (menu *Presentation* > *Systemstate*)

Not relevant for MicrosSpotMonitor MSM.

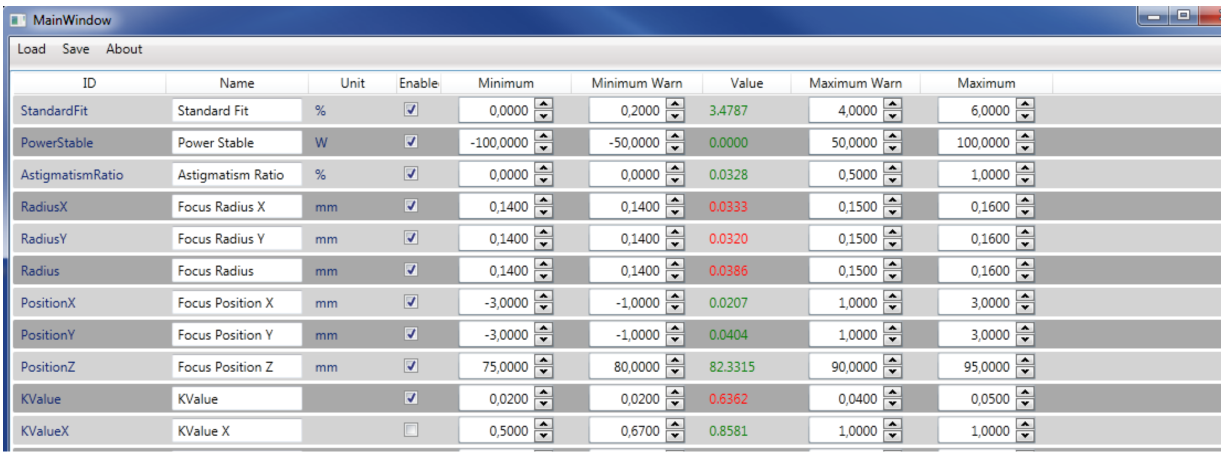
12.5.13 Evalution parameter view (menu *Presentation* > *Evalution Parameter View*)

In the directory “System“ in the LDS installation file (C:\Program\Primes\LDS2.98\System) you can find predefined parameter files for the raw beam retrograde calculation (RawBeamParams.eval) and the caustic evaluation (beamparams.eval). These can be pulled up under the menu point ***Presentation > Evaluation Parameter View***.

	Min	Warn	Actual	Warn	Max
Standard Fit [%]	0.00	0.50	3.48	3.00	5.00
Power Stable [W]	-100	-50	0	50	100
Astigmatism Ratio [%]	0.00	0.00	0.03	0.50	1.00
Focus Radius X [mm]	0.0100	0.0300	0.0333	0.0500	0.1000
Focus Radius Y [mm]	0.0100	0.0300	0.0320	0.0500	0.1000
Focus Radius [mm]	0.0100	0.0300	0.0386	0.0500	0.1000
Focus Position X [mm]	-0.200	-0.100	0.021	0.100	0.200
Focus Position Y [mm]	-0.200	-0.100	0.040	0.100	0.200
Focus Position Z [mm]	80.000	82.000	82.332	85.000	90.000
KValue	0.50	0.67	0.64	1.00	1.00
KValue X	0.50	0.67	0.86	1.00	1.00
KValue Y	0.50	0.67	0.90	1.00	1.00
Caustic Min Power [W]	50	100	0	10000	10000
Caustic Max Power [W]	0	0	0	7500	8000
Caustic Mean Power [W]	0	50	0	7500	8000
BPP	0.200	0.250	0.532	0.750	1.000
M²	1.00	1.00	1.57	1.50	2.00
M² X	1.00	1.00	1.57	1.50	2.00
M² Y	1.00	1.00	1.57	1.50	2.00
BeamDirection [°]	0.00	0.00	0.36	2.00	3.00
BeamDirection X [°]	0.00	0.00	0.36	2.00	3.00
BeamDirection Y [°]	0.00	0.00	0.36	2.00	3.00
Rayleigh Length [mm]	0.01	0.03	2.80	10.00	30.00
Divergence [mrad]	0.05	0.10	10.00	0.35	0.40

Fig. 12.32: Display window ***Evalution Parameter View*** with opened parameter file

The desired parameters and their limit values can be stipulated by means of the program PRIMES-EvalEditor and can then be saved in the evaluation parameter file (*.eval). The program is automatically installed when the LDS-setup is carried out.



ID	Name	Unit	Enable	Minimum	Minimum Warn	Value	Maximum Warn	Maximum
StandardFit	Standard Fit	%	☑	0,0000	0,2000	3.4787	4,0000	6,0000
PowerStable	Power Stable	W	☑	-100,0000	-50,0000	0.0000	50,0000	100,0000
AstigmatismRatio	Astigmatism Ratio	%	☑	0,0000	0,0000	0.0328	0,5000	1,0000
RadiusX	Focus Radius X	mm	☑	0,1400	0,1400	0.0333	0,1500	0,1600
RadiusY	Focus Radius Y	mm	☑	0,1400	0,1400	0.0320	0,1500	0,1600
Radius	Focus Radius	mm	☑	0,1400	0,1400	0.0386	0,1500	0,1600
PositionX	Focus Position X	mm	☑	-3,0000	-1,0000	0.0207	1,0000	3,0000
PositionY	Focus Position Y	mm	☑	-3,0000	-1,0000	0.0404	1,0000	3,0000
PositionZ	Focus Position Z	mm	☑	75,0000	80,0000	82.3315	90,0000	95,0000
KValue	KValue		☑	0,0200	0,0200	0.6362	0,0400	0,0500
KValueX	KValue X		☐	0,5000	0,6700	0.8581	1,0000	1,0000

Fig. 12.33: Dialoque window EvalEditor with loaded *.eval-file

The evaluation parameter file can only be displayed if the file **BeamControls.xsd** is located in the same directory (C:\Program\Primes\LDS2.98\System)!

12.5.14 Evaluate document (menu *Presentation* > *Evaluate doc*)

The evaluation function compares selectable beam parameters and their adjustable limit values with the results of a current or a saved measurement.
Under the menu point ***Presentation > Evaluate doc*** of the LDS, the following dialog window is opened:

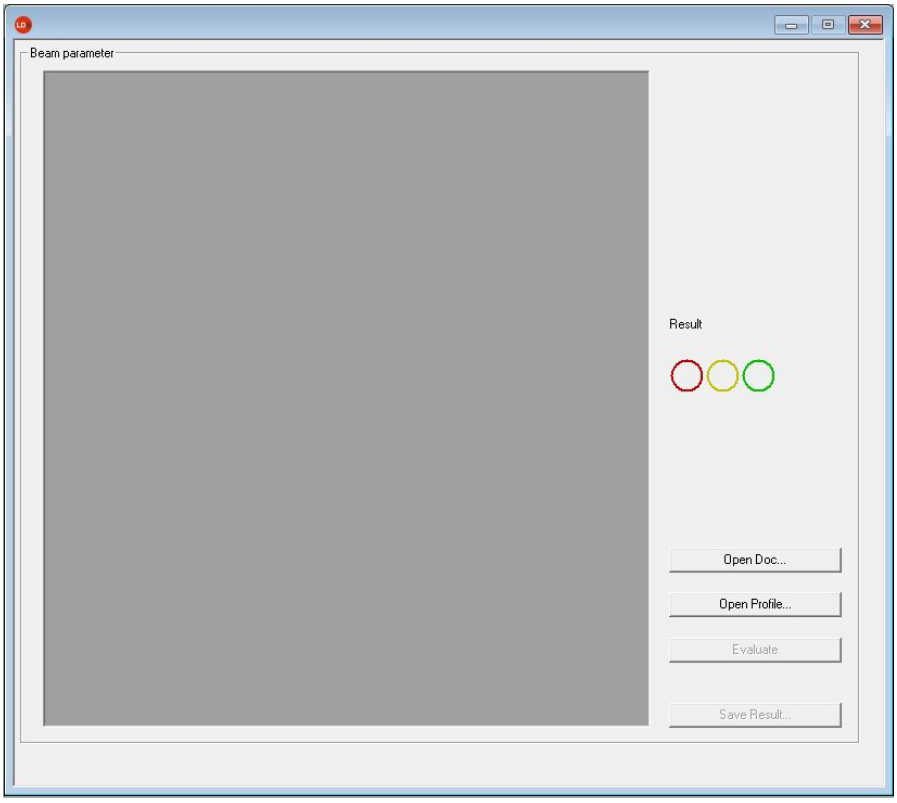


Fig. 12.34: Dialoque window ***Evaluate Document*** for loading an evaluation file

The button ***Open Doc*** opens a file selection window that allows to choose a saved measuring file (*.foc).

The button ***Open Profile*** opens a file selection window for choosing an evaluation parameter file (*.eval).

The button ***Evaluate*** triggers an evaluation (see Fig. 12.35 on page 75). The single evaluation parameters and the result of the evaluation are displayed. The overall evaluation (Result) of all results is displayed by means of a traffic light symbol.

Evaluation Criteria: Only if all single evaluations are ok, the overall evaluation is displayed in green in the traffic light symbol.

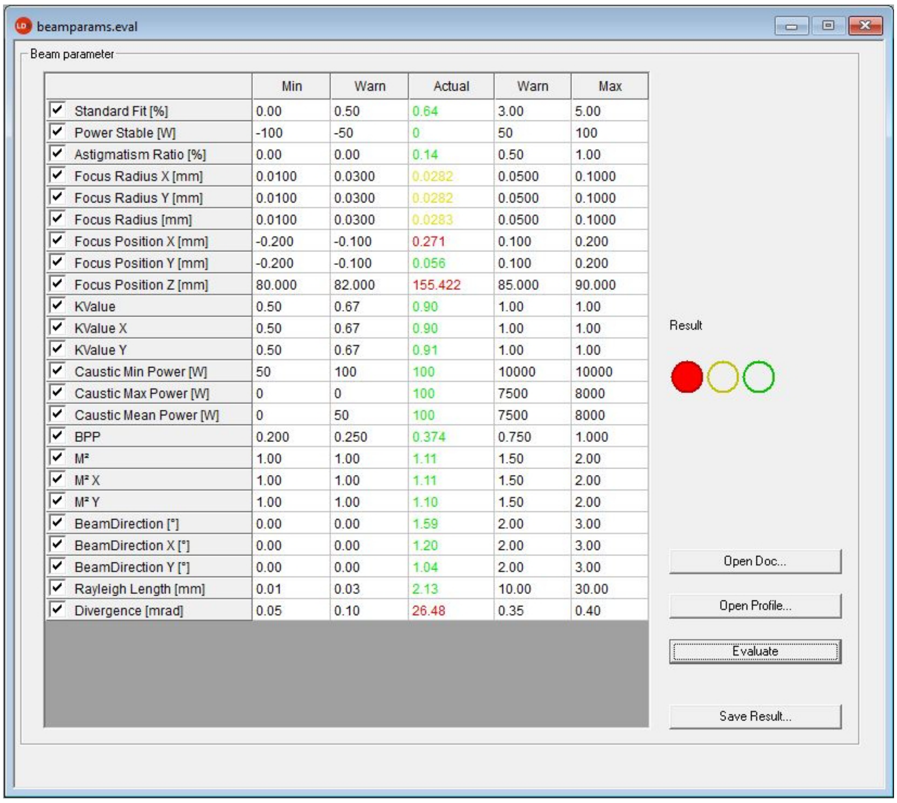


Fig. 12.35: Dialoque window ***Evaluate***

In case the warning or limit values are exceeded, this has an influence on the color display of the traffic light symbol. As soon as a warning value is exceeded or fallen short of, the yellow circle is filled. If the limit values (min/max) are exceeded or fallen short of, the red circle is filled. The actual values in the table of the evaluation window are marked in color as well.

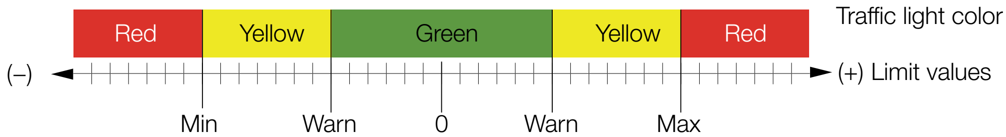


Fig. 12.36: Traffic light colors when warn- and limit values are exceeded

The overall result of the evaluation can be saved by means of the button ***Save***.

12.5.15 Color tables (menu *Presentation* > *Color Tables*)

Different color charts are available. It is possible to switch back and forth between the color charts. Thus the assignment of A/D converter values and different color scales can be varied. This is important for the false color presentation.

Three settings are possible:

- Linear color table (basic setting)
- Color table analogue to the root function
- Color table analogue to the fourth root function

These functions can especially be helpful as far as the analysis of slight variations near the zero level are concerned; e.g. the analysis of diffraction phenomena.

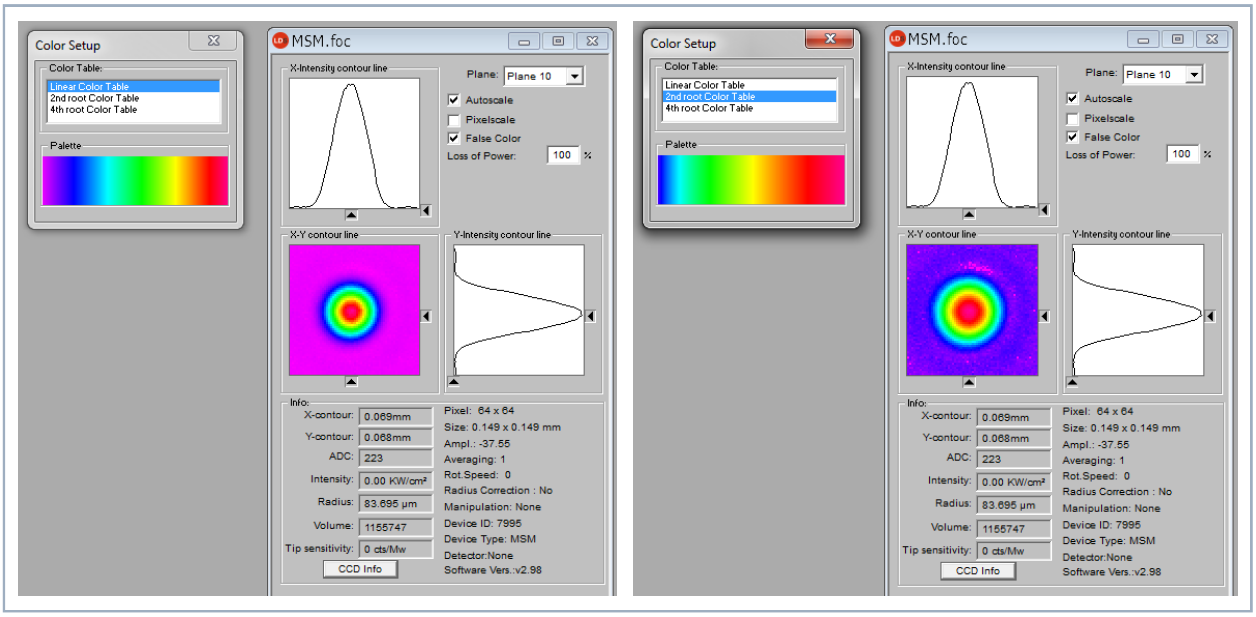


Fig. 12.37: Dialoque window ***Color Setup*** – Linear color table and 2nd root color table

12.5.16 Toolbar (Menu *Presentation* > *Toolbar*)

The toolbar can be shown or hidden by clicking ***Presentation*** **>** ***Toolbar*** in the menu.

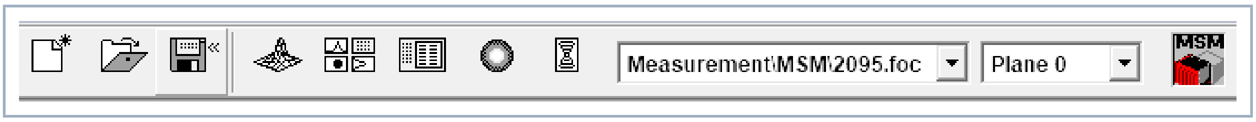


Fig. 12.38: Showing or hiding the toolbar

12.5.17 Position (menu *Presentation* > *Position*)

This menu can be used to move the device to its parked position.

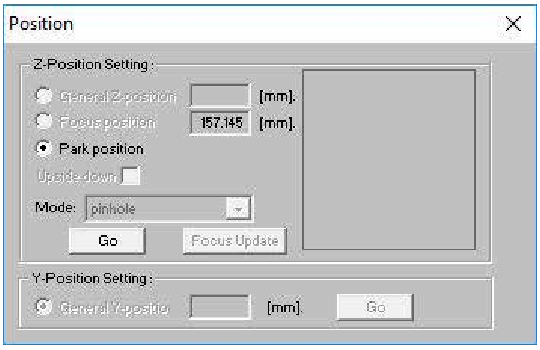


Fig. 12.39: Dialoque window ***Postition***

12.5.18 Evaluation (option) (menu *Presentation* > *Evaluation*)

By means of this evaluation function, you can compare and evaluate different parameters of the measured caustic (.foc-file) with specified limit values (.pro-file). The evaluation result is displayed optically with an LED symbol (red=bad, green=good). The overall result (field Conclusion) is only considered as good provided that all results are within the critical parameters ( ).

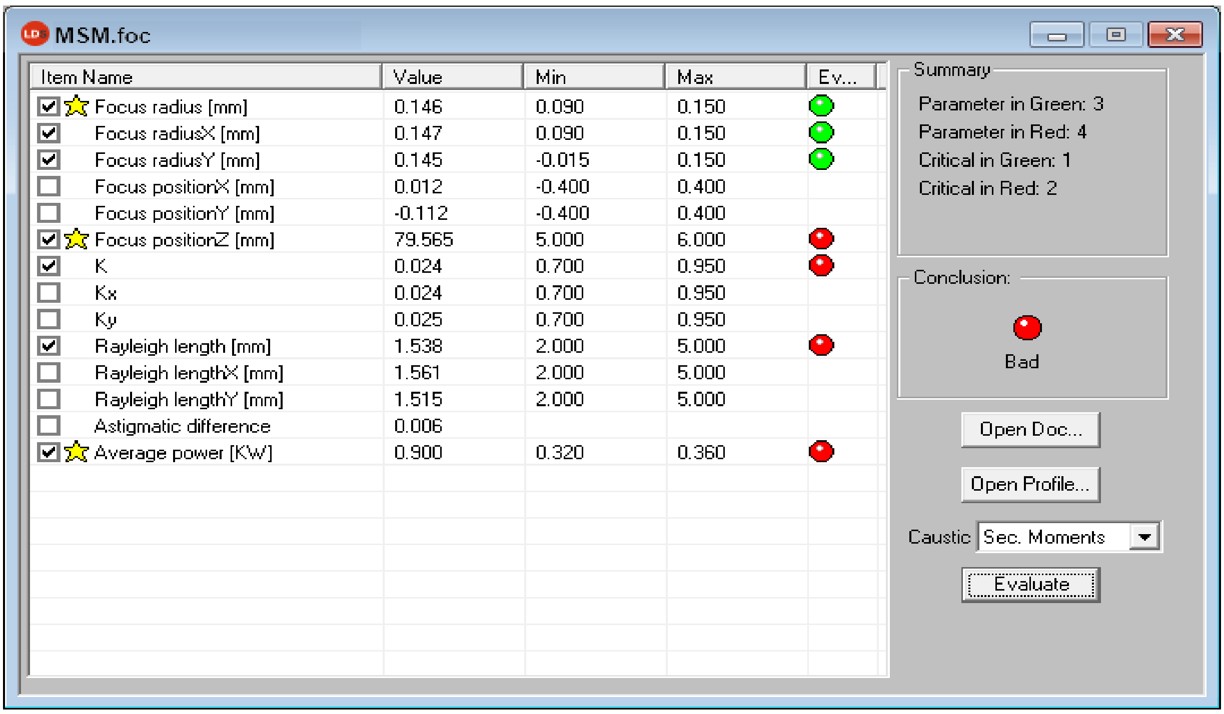
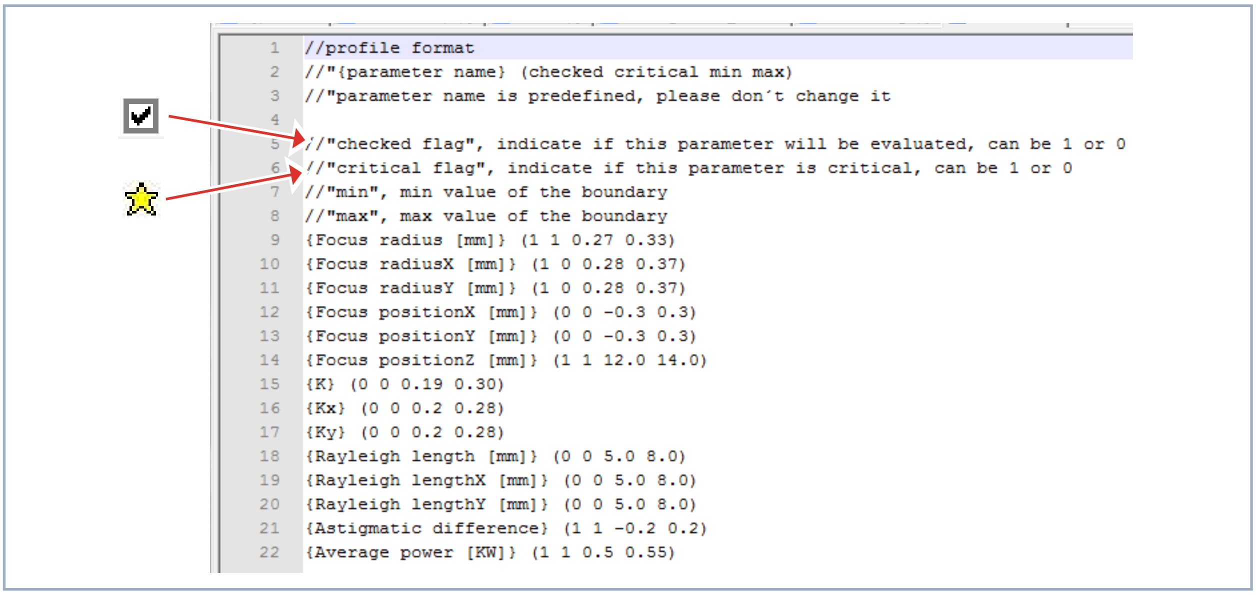


Fig. 12.40: Dialoque window ***Evaluation***

The parameters, the limit values and the identification of critical values are purported in a profile file (text file, please see the example file in Fig. 12.41 on page 78).



```
//profile format
//"{parameter name} (checked critical min max)
//"parameter name is predefined, please don´t change it

//"checked flag", indicate if this parameter will be evaluated, can be 1 or 0
//"critical flag", indicate if this parameter is critical, can be 1 or 0
//"min", min value of the boundary
//"max", max value of the boundary
{Focus radius [mm]} (1 1 0.27 0.33)
{Focus radiusX [mm]} (1 0 0.28 0.37)
{Focus radiusY [mm]} (1 0 0.28 0.37)
{Focus positionX [mm]} (0 0 -0.3 0.3)
{Focus positionY [mm]} (0 0 -0.3 0.3)
{Focus positionZ [mm]} (1 1 12.0 14.0)
{K} (0 0 0.19 0.30)
{Kx} (0 0 0.2 0.28)
{Ky} (0 0 0.2 0.28)
{Rayleigh length [mm]} (0 0 5.0 8.0)
{Rayleigh lengthX [mm]} (0 0 5.0 8.0)
{Rayleigh lengthY [mm]} (0 0 5.0 8.0)
{Astigmatic difference} (1 1 -0.2 0.2)
{Average power [KW]} (1 1 0.5 0.55)
```

Fig. 12.41: Example for a profile file

An evaluation is carried out as follows:

1. Click the button ***Open Doc*** and choose your measuring file (.foc-file).
2. Click the button ***Open Profile*** and choose your profile file (.pro-file).
3. Choose the desired radius definition in the selection ***Caustic***.
4. Click on the button ***Evaluate***.

12.6 Communication

12.6.1 Rescan bus (menu *Communication* > *Rescan bus*)

This menu can be used to reconnect a device that was connected previously.

12.6.2 Free communication (menu *Communication* > *Free Communication*)

By means of this menu you can control the communication via the PRIMES bus. Moreover, the settings for the communication are made here (see chapter 11.3.2 on page 31).

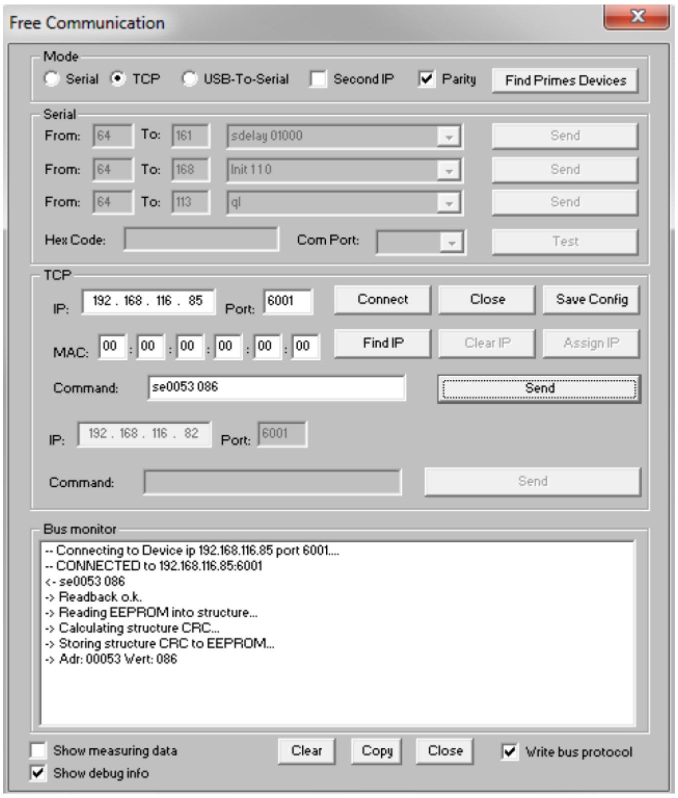


Fig. 12.42: Dialoque window ***Communication* > *Free Communication***

12.6.3 Scan device list (menu *Communication* > *Scan device list*)

Every PRIMES device has a certain bus address. If a device is supposed to be controlled by means of the LaserDiagnosticsSoftware LDS, the address has to be entered here. Moreover addresses can also be added or deleted in this menu.

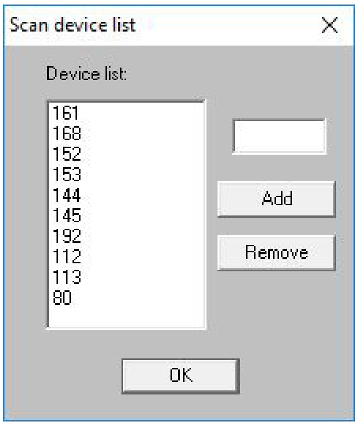


Fig. 12.43: Dialoque window ***Scan device list***

The following addresses for all PRIMES devices may be listed in the device list:
80, 92, 112, 113, 114, 144, 145, 152, 161, 168
For the MicroSpotMonitor MSM, the address 161 must be entered.

12.7 Script *(menu Script)*

By means of scripts complex measurement procedures can be controlled automatically. Scripts are programs which are written in several script languages. Scripts are almost exclusively provided as source files in order to enable an easy editing and adjustment of the program.

12.7.1 Editor (menu *Script > Editor)*

By means of the script editor you can draw up scripts which can control, for example, complex measuring procedures automatically. An example is given in Fig. 12.44 on page 81 – the beam find procedure with the MicroSpotMonitor MSM.
In order to open the script, the Open symbol has to be clicked, then a file can be chosen and played by using the button ▶. The button ⏸ stops and ■ ends the script.

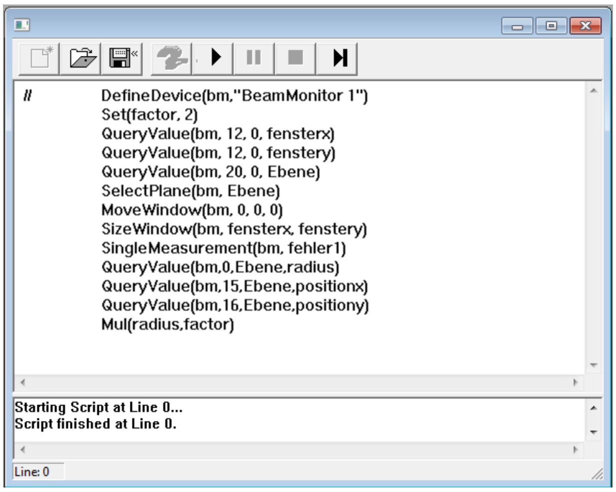


Fig. 12.44: Dialoque window ***Script*** – Script for the beam find procedure of the MicrosSpotMonitorMSM

12.7.2 List (menu *Script > List)*

Here all available scripts are listed.

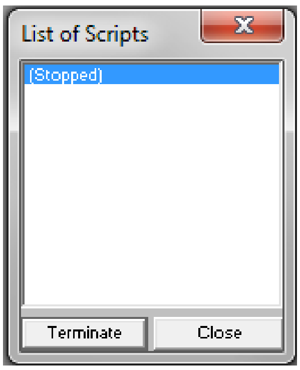


Fig. 12.45: Display window ***List of Scripts***

12.7.3 Python (menu *Script > Python)*

Starts the Python editor. The graphical user interface is identical to the one depicted in Fig. 12.44 on page 81. Python is a programming language with efficient abstract data structures and a simple but effective approach for an object-oriented programming. Python is not only suitable for scripts but also for a fast application development. For programming with Python a separate PRIMES documentation is available.

13 Measurement

13.1 Safety instructions

DANGER

Serious eye or skin injury due to laser radiation

During the measurement the laser beam is guided on the device, which causes scattered or directed reflection of the laser beam (laser class 4). The reflected beam is usually not visible.

The MicroSpotMonitor MSM must not be operated in any of the available configurations without taking the following precautions.

- ▶ Please wear safety goggles adapted to the power, power density, laser wave length and operating mode of the laser beam source in use.
- ▶ Wear suitable protective clothing and protective gloves.
- ▶ Protect yourself from laser radiation by separating protective devices (e.g. by using appropriate shielding).

DANGER

Serious eye or skin injury due to laser radiation

If the device is moved from its calibrated position, increased reflected radiation (laser class 4) may result during measuring operation.

- ▶ When mounting the device, please ensure that it cannot be moved, neither due to an unintended push or a pull on the cables.

NOTICE

Damaging/destroying the device

Contamination and fingerprints on the protective window can lead to damage or shattering or splintering of the protective window during measuring operation.

- ▶ Do not touch the protective window.
- ▶ Regularly check the condition of the protective window and exchange it in case of pollution (see chapter 15.1, „Exchanging the protective window“, on page 109).
- ▶ Only operate the device with a clean protective window.

NOTICE

Damaging/destroying the device

Obstacles in the movement range of the MicroSpotMonitor MSM can lead to collisions and damage the device.

- ▶ Keep the movement range free of obstacles (cutting nozzle, pressure rolls, etc.).

NOTICE

Damaging/destroying the device

Contamination can damage or destroy the optical components.

▶ **Only open the device in a dust-free environment.**

13.2 Selection and change of measuring objectives

13.2.1 Selection of the measuring objective

The selection of the right measuring objective is of crucial importance when it comes to the quality of the measurement with the MicroSpotMonitor MSM.

The measuring objective must be optimally matched to the wavelength, the numerical aperture and the focus size to be measured. Furthermore, the possible fields of application are limited by the sensor- and pixel size (see chapter 21.4.1 on page 121).

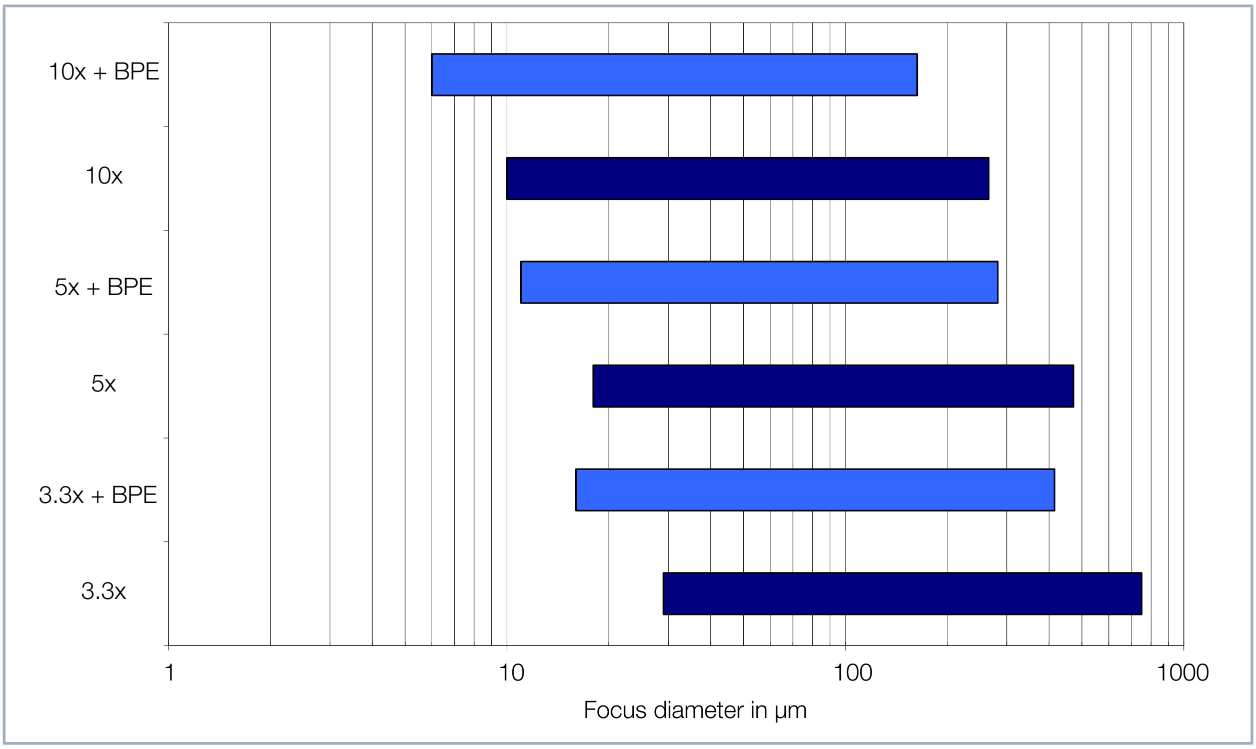


Fig. 13.1: Fields of application of the measuring objectives

In Fig. 13.1 on page 83 the field of application of different measuring objectives is depicted. The figure allows a quick first selection of the correct measuring objective.

The following table contains the limits that have to be observed when it comes to standard objectives as well as further objective data.

Standard						
Objective	NA	F	Max. measuring window	Min. resolution	Min. beam diameter	Max. beam diameter
3.3x	0.1	5	1.4 mm	1.4 µm	30 µm	1 mm
5x	0.2		910 µm	0.9 µm	20 µm	650 µm
10x	0.2	2	510 µm	0.5 µm	11 µm	350 µm

With beam path extension (BPE)						
Objective	NA	F	Max. measuring window	Min. resolution	Min. beam diameter	Max. beam diameter
3.3x	0.1	5	800 µm	0.8 µm	17.5 µm	550 µm
5x	0.2		550 µm	0.5 µm	12 µm	380 µm
10x	0.2	2	320 µm	0.3 µm	7 µm	220 µm

With alignment objective (AO)						
Objective	NA	F	Max. measuring window	Min. resolution	Min. beam diameter	Max. beam diameter
3.3x	0.1	5	4 mm	3.9 µm	90 µm	2.8 mm
5x	0.2		2.75 mm	2.7 µm	60 µm	2 mm
10x	0.2	2	1.6 mm	1.6 µm	35 µm	1.1 mm

Tab. 13.1: Measuring objective data

NA = numerical aperture
F = focusing value (see Fig. 13.5 on page 87)

On the basis of this table, a suitable measuring objective can be selected. The values apply for a wavelength of 1 064 nm (the values slightly differ with other wavelengths).

13.2.2 Exchanging the measuring objective

1. Unscrew the two knurled screws (see Fig. 13.2 on page 85).
2. Remove the measuring objective upwards.
- Please note that the measuring objective is fixed by two dowel pins and does not tilt during removal.

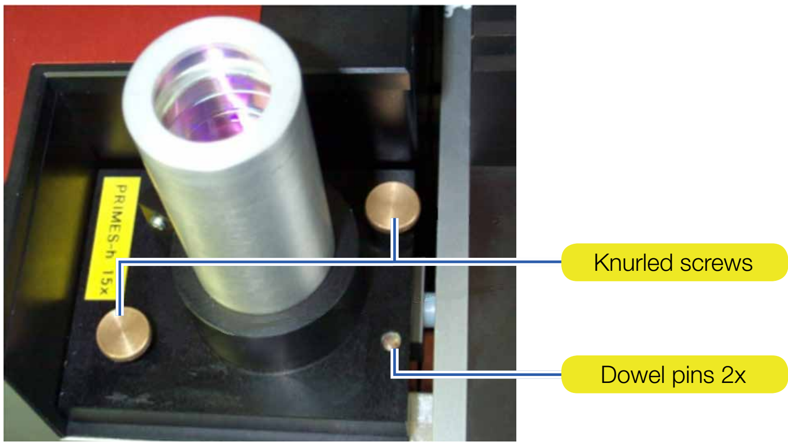


Fig. 13.2: Measuring objective

NOTICE

Component susceptible to electrostatic discharge

The EEPROM can be destroyed by an electrostatic discharge.

- ▶ **Do not touch the contacts of the EEPROM as well as the contact pins (see Fig. 13.3 on page 85).**
- ▶ **Put on an ESD armband before changing the measuring objective.**

There is an EEPROM in the mount of the measuring objectives, which contains all the objective data necessary.

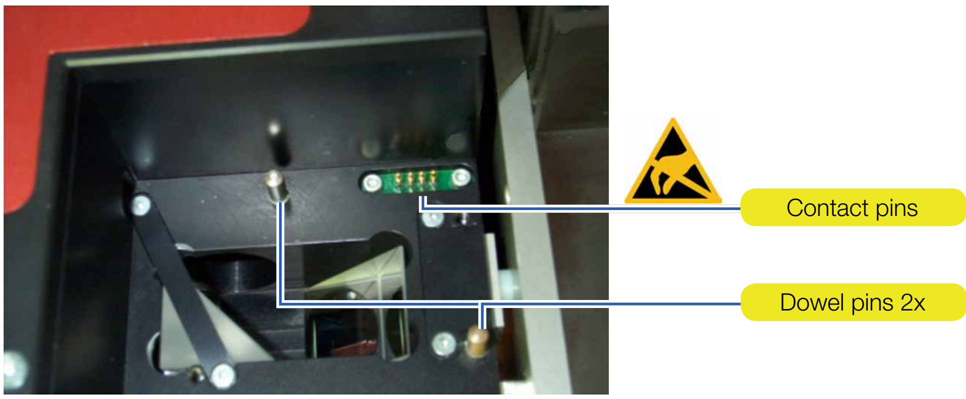


Fig. 13.3: Measuring objective – contacts and contact pins

3. Place the measuring objective from above on the two dowel pins (see Fig. 13.2 on page 85).
4. Press the measuring objective vertically down to its stop.
- When inserting, make sure that the measuring objective does not tilt.

13.2.3 Damage thresholds

The operating limits of the MicroSpotMonitor MSM are determined by the damage thresholds of the optical components. As described in chapter 21.4.1 on page 121, two different cases have to be considered.

NOTICE

Damaging/destroying the measuring objective

Power densities which are too high can destroy the measuring objective.

- ▶ **Please mind that the power density *I* is smaller on the first lens ~10 MWatt/cm² (cw) or ~100 MWatt/cm² (pulsed) respectively.**
- ▶ **The medium power should not exceed 250 Watt.**

The power density I is calculated according to the following formula:

$$I = \frac{P}{A} = \frac{P}{\pi \cdot r_{Spot}^{2}} \Rightarrow \qquad r_{Spot} \geq \sqrt{\frac{P}{\pi \cdot 10^{6\ bis\ 7} \frac{W}{cm^{2}}}}$$

Fig. 13.4: Formula for calculating the power density I

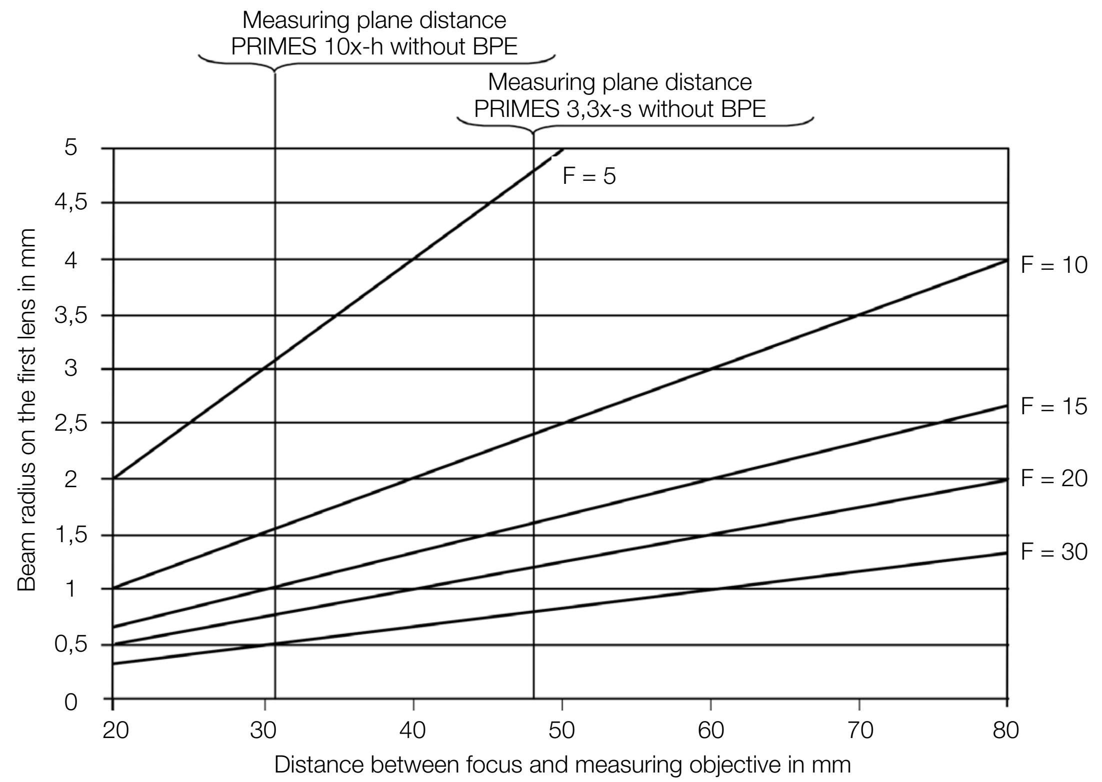
- If the focus is placed below the measuring plane (too close to the measuring objective), the power density rises at the first lens of the measuring objective.
- If the focus is above the measuring plane, an intermediate focus develops inside the device. If the laser beam focus is too far above the measuring plane, the intermediate focus can develop in areas in which the beam power has not been sufficiently decreased. This can damage the image-sided beam path.

The size and position of the range in which the focus is to be positioned before the first measurement depends on the measuring objecive selection, the used wavelength as well as on the type of focusing.

The diagram in Tab. 13.2 on page 87 shows that the upper limits for high-magnification measuring objectives are much narrower than those with a 3.3-fold magnification.

The lower limit for convergent beams depends on the power density of the laser beam on the first lens. This is a function of the laser power, the focusing, the M², as well as the raw beam diameter.

The graphs in Tab. 13.2 on page 87 and Tab. 13.3 on page 88 can be used to estimate the minimum distance.



Tab. 13.2: Estimatation by the focusing value F for 1 064 nm and 532 nm

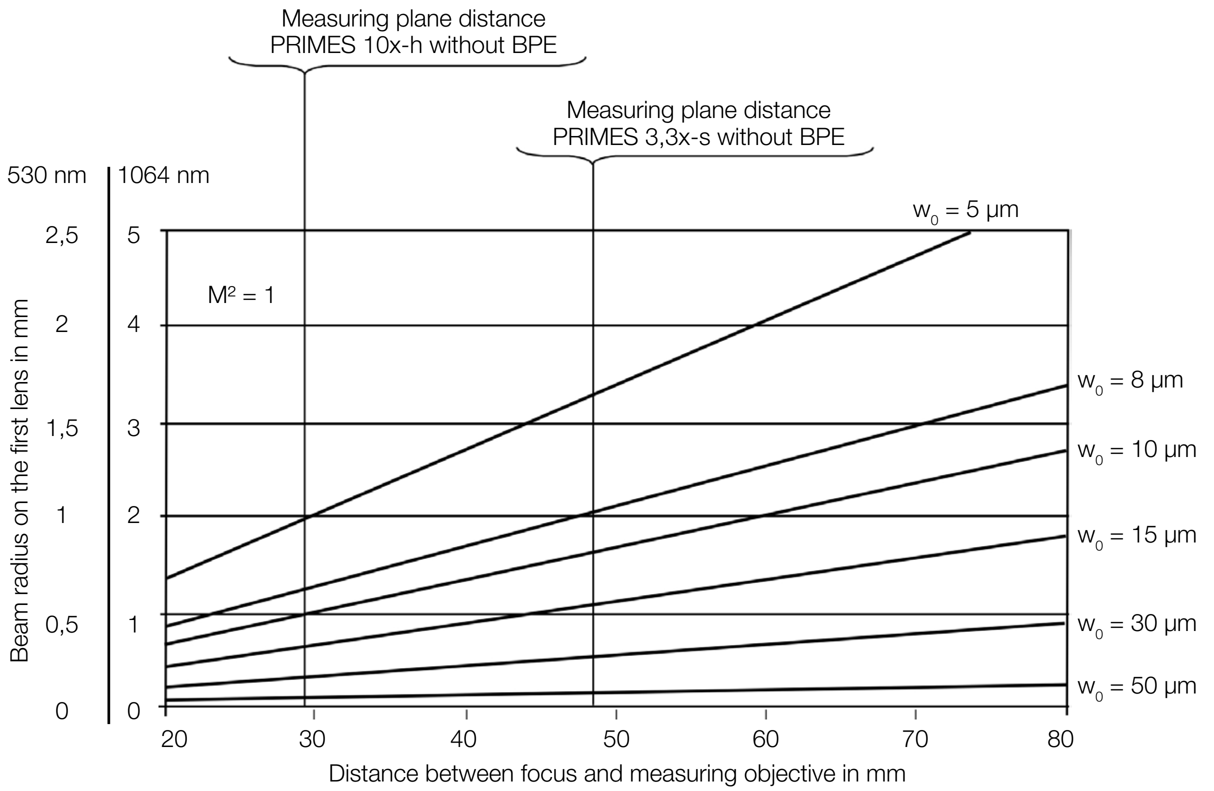
The diagram in Tab. 13.2 on page 87 shows the dependence of the beam radius on the first lens with the focusing value F and the distance of the focus from the first lens of the measuring objective.

The focusing value F can be determined by means of the following formula:

$$F = \frac{f}{d_s} = \frac{1}{2 \cdot \tan\left(\frac{\Theta}{2}\right)}$$

Fig. 13.5: Formula for calculating the focusing value F

f = Focal length of the focusing lens
d_s = Raw beam diameter
Θ = Full divergence angle



Tab. 13.3: Estimatation by the focus radius for 1 064 nm and 532 nm

The diagram in Tab. 13.3 on page 88 shows the dependence of the beam radius on the first lens with the wavelength, the focus radius, and the distance of the focus from the lens.

The beam radii are estimated by means of the beam parameter product BPP.

$$\frac{w_0 \cdot \Theta}{2} = \frac{\lambda}{\pi} \cdot M^2$$

Fig. 13.6: Formula for calculating the beam radii by the beam parameter product BPP

w_0 = Beam radius
Θ = Full divergence angle
λ = Wavelength
M^2 = Beam quality factor

In Tab. 13.3 on page 88, the beam quality factor M^2 was assumed to be 1.

The dependencies can be summarized as follows:

- When it comes to strongly divergent beams, e.g. with a focusing with small focal lengths, small focus radii develop. In order to be able to achieve a sufficient resolution on the camera chip, the 10-fold measuring objective is necessary. This objective also has a greater numerical aperture.
- When it comes to laser beams with a beam quality factor M^2 = 1-2, small focus radii also occur with small divergences. This may lead to damages of the entry lens when long focal length objectives are used.
- When it comes to laser beams with large beam quality factor M^2 values, high power values occur. They are, however, not so critical due to the large focus radii. The spot diameter on the entry lens should always be greater than 1 mm.

13.3 Prepare measurement

The following check lists should help you to realise the most important conditions for a measurement and to carry out all necessary settings of the LaserDiagnosticsSoftware LDS.

13.3.1 Check list measurement settings

❑	The device is stable and fixed.
❑	The movement range (z-axis) of the measuring device is free of obstacles.

Tab. 13.4: Check list safety precautions

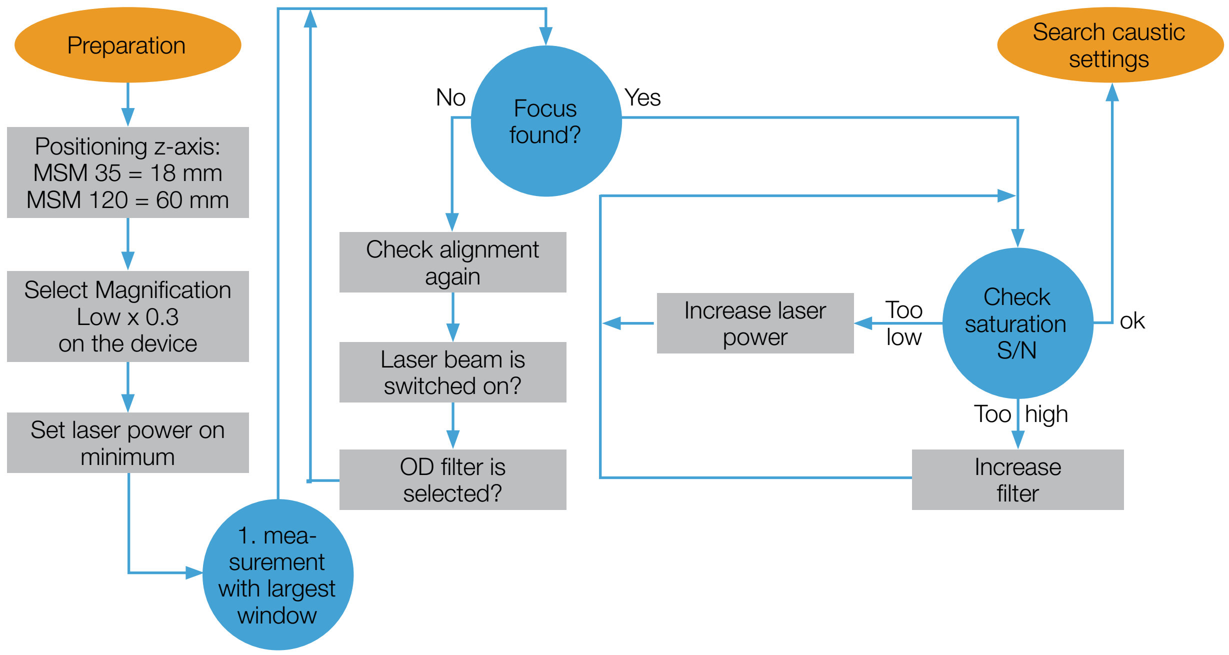
13.3.2 Check list measurement settings

LDS Menu Path	Action	
Measurement > Environment	❑	Enter the focal length
Measurement > Sensor param-eters	❑ ❑	Preset 64 pixel for the resolution x Preset 64 pixel for the resolution y
Measurement > CCD Settings	❑ ❑ ❑	Select the trigger mode Cw/Quasi-cw Measurement Select the CCD mode Measuring data Select the correct wave length
Measurement > Single	❑	Activate the checkbox Optim.
Measurement > Caustic	❑ ❑	Activate the mode Automatic Activate the checkbox Optim.
Measurement > Option	❑ ❑	Preset the fillfactor Max: 0.7 Min: 0.5 Ref: 0.6 Analyse Settings: Activate the checkbox Enable adjust nullevel

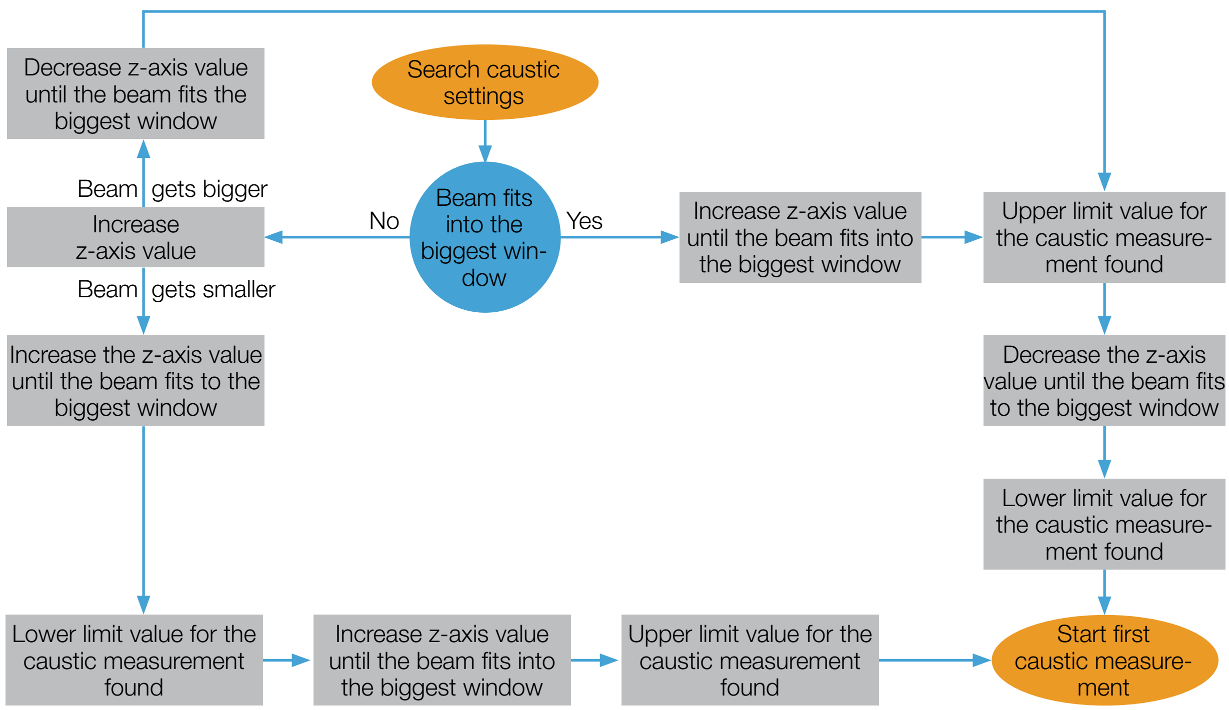
Tab. 13.5: Checkliste Messeinstellungen

13.4 Flowchart of a measurement

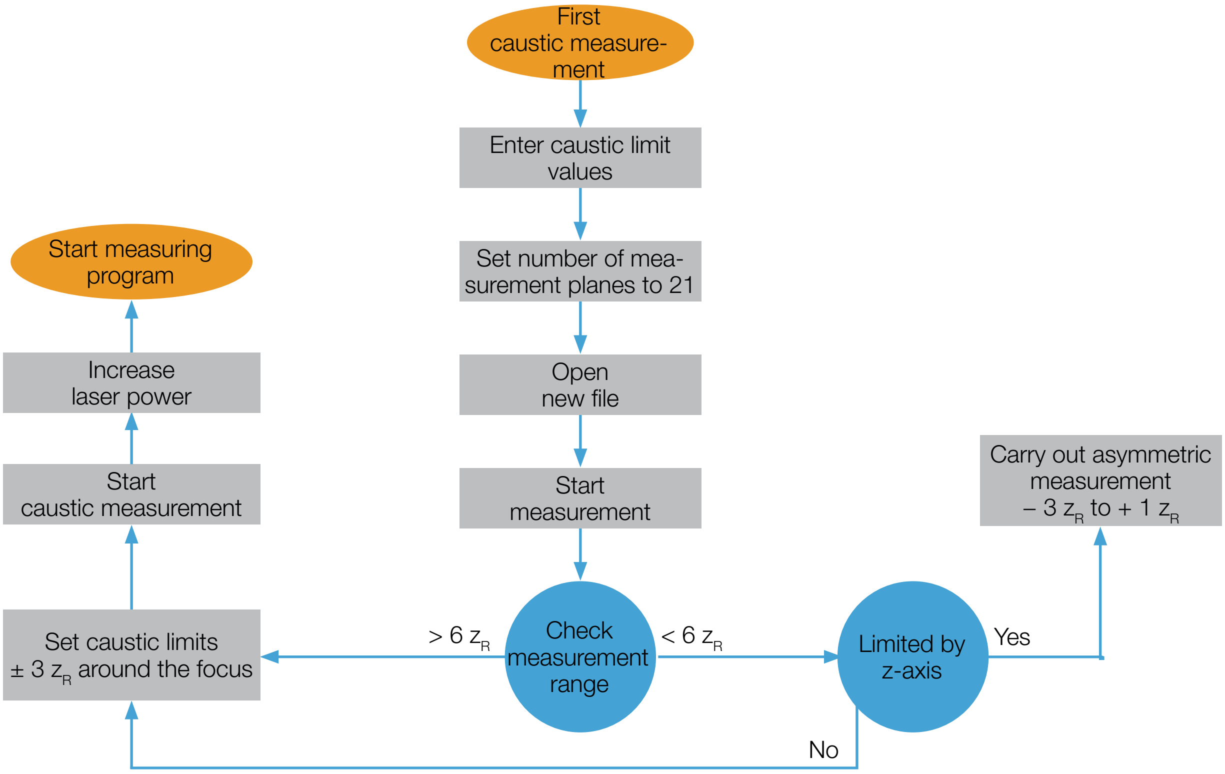
13.4.1 Prepare measurement



13.4.2 Set caustic limits



13.4.3 Perform caustic measurement



13.5 Perform measurement settings in the LaserDiagnosticsSoftware LDS

The following explanations of the configuration options should help you to make the right settings for the respective task.

The following chapters highlight important configuration options in color:

Color	Meaning
Red	This setting must always be set as shown.
Yellow	This setting is dependent from the desired operating mode (CW, pulse, single pulse, measurement series, etc.).
Green	This setting must be carried out before each measurement. The settings depend on the specific measurement task, such as the wavelength, the laser power or the geometry of the laser beam.

Tab. 13.6: Color meaning of the setting options

13.5.1 Sensor parameters (menu *Measurement* > *Sensor parameter*)

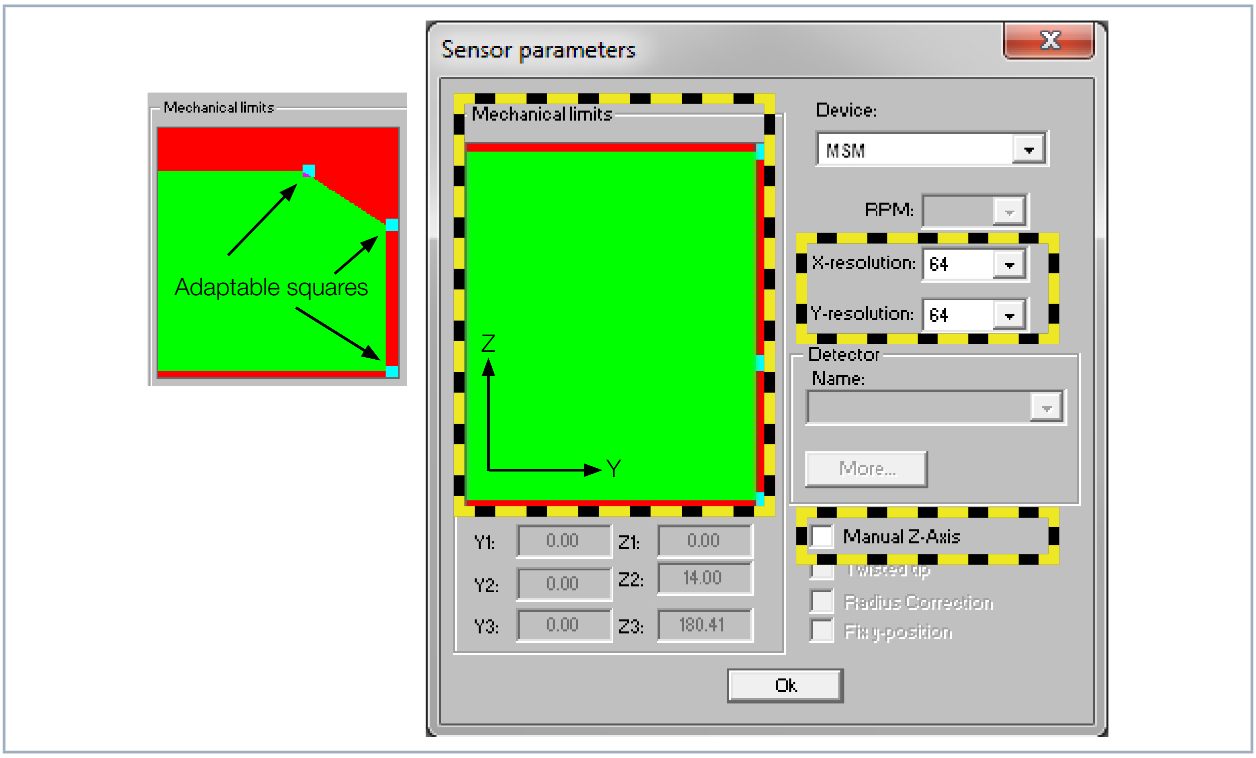


Fig. 13.7: Dialogue window ***Sensor parameters***

Mechanical limits

By pulling the turquoise square with the mouse pointer you can restrict the movement range of the y- and z-axis. Therewith you can prevent damages in case other components reach into the movement range of your device. The maximum value corresponds to the value Y3 and Z3.

Resolution

Here you can enter the number of pixels in the measuring window, ranging from 32 x 32 to 256 x 256 pixels. Generally, 64 pixels per line and a total of 64 lines is sufficient. Please keep in mind that the more pixels there are, the longer the measurement will take.

Manual z-axis

With this function you can deactivate the z-axes of the measuring system. This is useful if you want to use external movement axes. In this case you can manually assign a z-value to every measurement plane in the dialogue window ***Single measurement***.

Please find further information on the menu Menu *Measurement* > *Sensor paramter* in chapter 12.4.2 on page 45.

13.5.2 Measuring environment (menu *Measurement* > *Environment*)

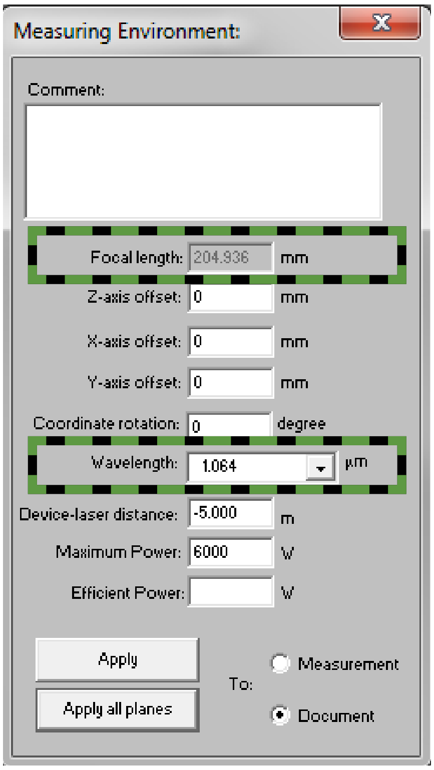


Fig. 13.8: Dialogue window ***Measuring Environment***

Focal length

Stating the focal length is relevant for the evaluation of the caustic measurements. From the caustic process and the entered focal length the raw beam diameter on the focussing optic can be calculated.

Wave length

The wave-length is the basis for a correct determination of the beam quality factor M². There are the following options:

- 1.064 µm for Nd:YAG laser
- 0.532 µm for Green laser
- 0.355 µm for UV laser

A wavelength can also be typed in numerically.

Please find further information on the menu menu *Measurement* > *Environment* in chapter 12.4.1 on page 44.

13.5.3 Measurement settings (menu *Measurement* > *Single*)

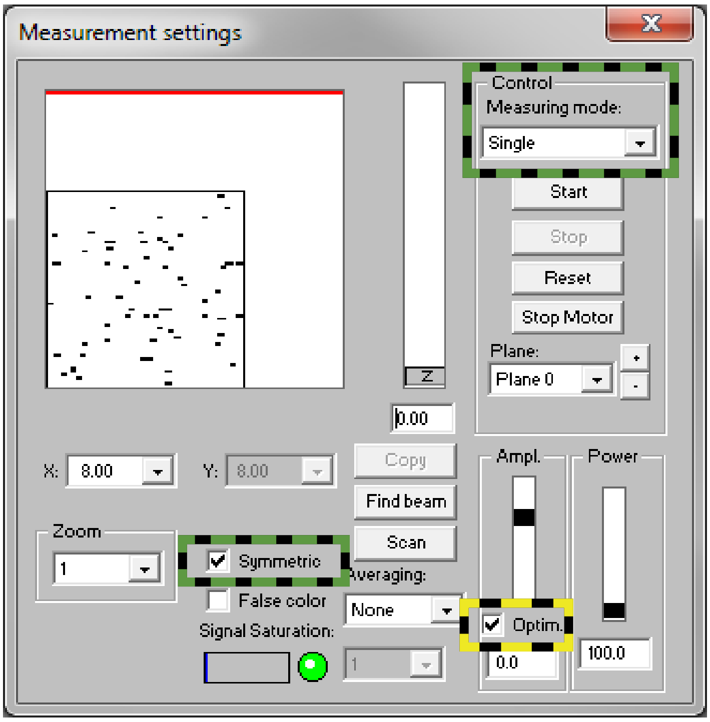


Fig. 13.9: Dialogfenster ***Messeinstellungen***

Controlling measuring modes (individual measurement, monitor, and video mode)

There is a total of three different measuring modes that can be selected here. In the ***Individual Measurement*** and ***Monitor*** measuring mode, all necessary compensations (smear effect, diffusion) and exposure time adjustments are performed every time a new measurement is carried out. Valid measuring data is generated in this mode.

The measuring mode ***VideoMode*** does not produce valid measurement data. Here the exposure time is carried over from the last measurement and does not vary. Compensation measurements are not performed, making it unnecessary to consider or compensate for measuring artifacts such as smear effects.
Due to the “high” measuring frequency of about 5 Hz, this operating mode is particularly suited for use when aligning the device. The numeric results should not be interpreted absolutely, but rather always relative to each other.

Optical amplification (opt. ampl.)

This function activates the automatic adjustment of the exposure time of the CCD for every measurement. The function must be activated in order to keep the signal/noise ratio consistently high for a caustic measurement.
For special measuring applications, however, it might make sense to deactivate this function and set the exposure time to a fixed value between 12 µs and 200 ms. Here it is important to ensure sufficient attenuation of the laser beam with the help of the fixed ND filter or the filter wheel.

Symmetrical

Once this function is activated, only rectangular measuring windows will be allowed. In cases where an elliptical or even a square laser beam is being measured, this function should be deactivated so that the measuring window can be optimally adjusted.

Please find further information on the menu *Measurement* > *Single* in chapter 12.4.8 on page 50.

13.5.4 Caustic settings (menu *Measurement* > *Caustic)*

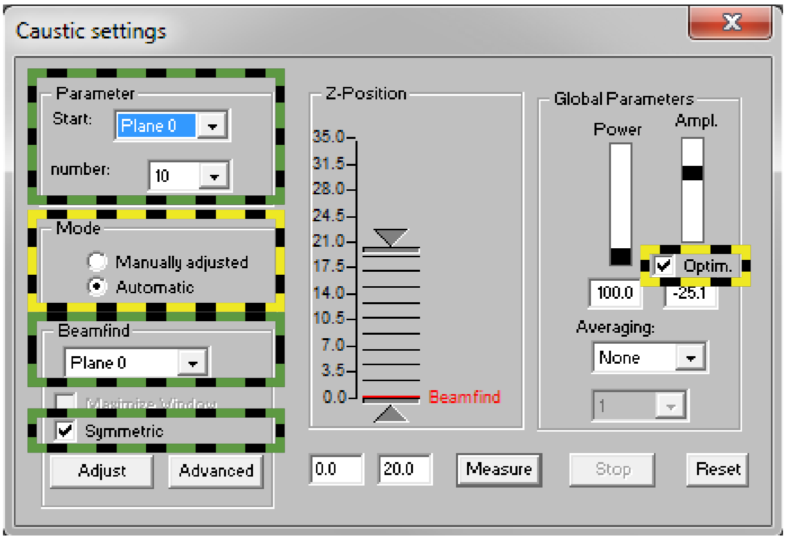


Fig. 13.10: Dialogue window ***Caustic settings***

Parameters (start number of the plane)

Under Start, the start number at which the measurement is initiated can be entered for the plane. By default, the start number is generally set to zero and should only be changed when you are measuring in an existing document and don't want the existing measurement data to be overwritten. If, for example, you have measured a caustic with 21 planes and want to magnify the measuring area to the smaller z-values, you can set the start plane to 21 and modify the measuring area appropriately. The new measuring values will then be written into the existing document starting with plane 21.

In the Quantity selection field, the number of planes to be measured in the specified z range is set. The following should be considered here:

- Since the LaserDiagnosticsSoftware LDS always sets the measuring plane distances so they are equidistant (equal spacing) and the measuring area is almost always situated symmetrically around the focal point, an odd number of measuring planes should be selected. The focus plane is calculated based on the measuring plane and displayed in the caustic illustration.
- Beam measurement norm DIN 11146 specifies that at least 10 measuring planes should be measured. Furthermore, five measurements should also be taken within a Rayleigh length and the other beyond 5 Rayleigh lengths. In order to meet all of the requirements with equidistant distribution, at least 17 measuring planes must be measured in a range of ± 3 Rayleigh lengths.

Mode (automatic and manual settings)

There are two different measuring modes for caustic measurement. In "Automatic" mode, the measuring system and the LDS determine the ideal measuring window position (x- and y-direction) for each measuring plane and the optimal measuring window size for the fill factor. Furthermore, the plane location in the z-direction is also calculated based on the specifications (number of measuring planes, measuring limits z-direction).

> **i** Especially when adjusting the measuring window size and the measuring window position in the x- and y-direction, the number of iterations (max. three per plane) can result in an extended measurement duration.

It is therefore possible to change the measuring mode to "Manual Settings" for recurring measuring tasks and for repeating measurements. In this case, the measuring system will take the measuring window positions and measuring window sizes from the previous measurement or from a .ptx file. This reduces the measurement duration considerably, but does require that the location and parameters of the laser beam change only minimally.

Beam search

This selection field specifies which plane the caustic measurement should be started in. If the optional ***Beam Find*** function is activated in the ***Options*** dialog window, that is also the plane in which this function will be performed. When the Beam Find function is deactivated, this plane must be manually measured ahead of time to make sure that the laser beam is found.

Please find further information on the menu *Measurement* > *Caustic* in chapter 12.4.9 on page 54.

13.5.5 CCD settings (menu *Measurement* > *CCD Settings*)

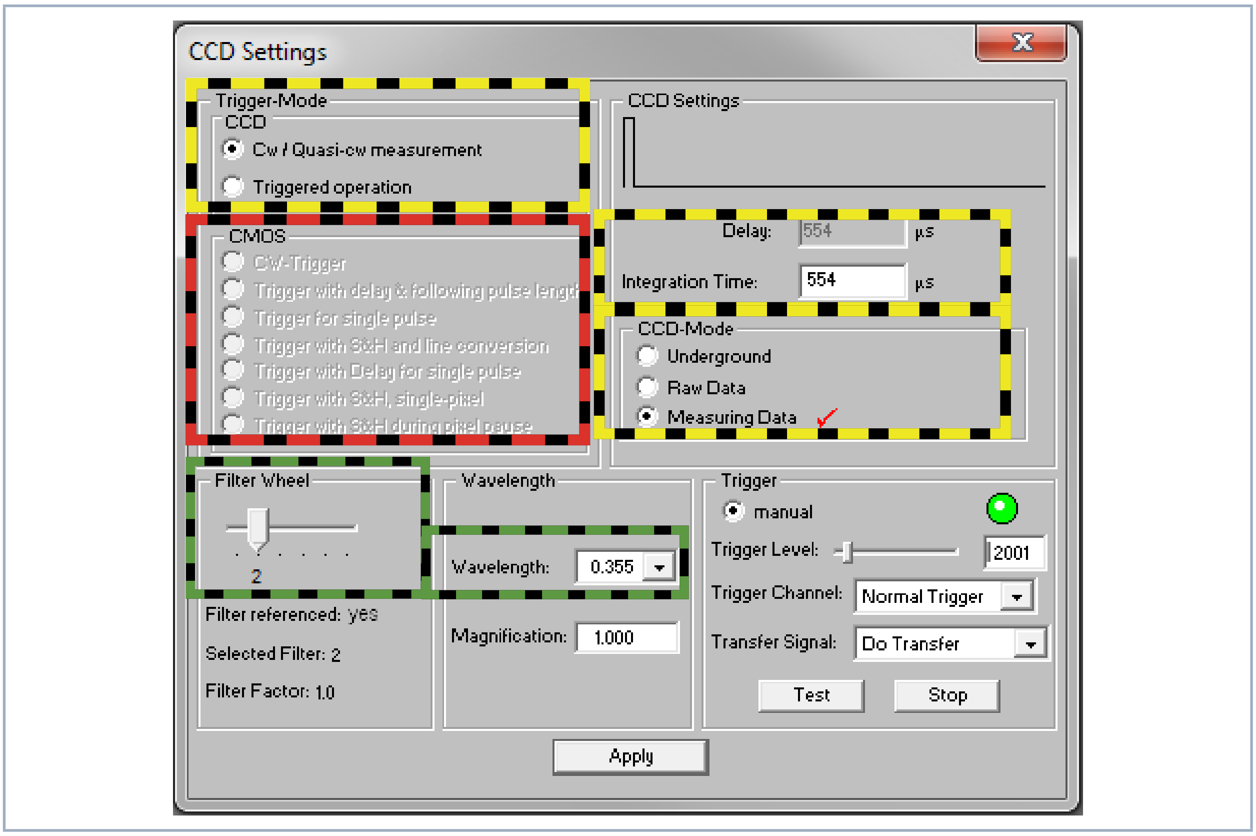


Fig. 13.11: Dialogue window ***CCD Settings***

The wavelength, attenuation, and operating mode are all set in the ***CCD Settings*** dialog window.

Trigger modes

The appropriate settings must be configured here in keeping with the operating mode of the laser to be measured. Here it is important to consider that pulsed lasers with a pulse frequency of more than 500 Hz can be measured in cw mode. If, however, the operating mode is set to pulsed and a cw laser system is involved, the measuring device will always display the error message “Error Black Pixel Measurement” or “Time Out During Measurement” in reaction to a measurement request.

Delay

This function can only be used with a “triggered operation” trigger mode. The time the measuring system should wait between when it detects the trigger pulse and the start of the measurement is set here. Together with the function “Integration Duration”, defined “Windows” from the plus cycles can be measured (e.g. exactly one pulse or parts of an ms pulse. The minimum delay is 12 µs.

CCD operating modes

Three different modes can be set here. If the ***Raw Data*** setting is activated, the measuring system will return the uncompensated data of the CCD when a measurement is requested. Especially with NIR irradiation, these can be riddled with measuring errors such as “smear effect” readout noise. Even the numeric beam data generated generated from this data will be affected by this.
If a ***Background*** is selected as the operating mode, only correction data will be returned while measuring. ***Measuring Data*** mode should always be the default setting here though. Only when this mode is turned on can the measuring system deliver reliable measuring values.

Integration duration

This function sets a defined integration duration. The optimizer must be deactivated before this can be accomplished, since otherwise the measuring device itself will optimize and thus change the integration duration. This function is also used mainly in measuring pulsed laser systems.

Filter wheel

Which filter is needed for measuring depends on the wavelength and the intensity of the laser beam being measured and the appropriate one must be chosen specifically for each measuring task.
A filter can be considered suitable when all measuring planes of a caustic measurement can be measured using an exposure time between 18 ms (-20 dB) and 0.18 ms (-60 dB). Outside of these limits, the S/N ratio of the CCD declines, thus reducing the accuracy.

Wavelength

Due to the wavelength-dependent overall magnification of the camera-based measuring system, it is important to check that the right selections have been made before each measurement. The wavelengths shown here represent the calibration points of the measuring objective. As a result of the achromatic properties of the measuring objective, a wavelength range between 1030 and 1100 can be achieved, for example, with a calibration point at 1064 nm without causing generating measuring errors.

General sequence control

- Empty the CCD register
- Aim for the holding point in line a (line in which photo transfer takes place); if the trigger is set off during sub-pulse, repeat line a (-> NLC = NoLineChange)
- Wait for the trigger if necessary and repeat line a (NLC)
- Wait out the delay if necessary and repeat line a (NLC)
- Aim for the holding point in line a through sub-pulse (-> delete the charge in the photo diodes)
- Integration – no cycles (sliding the charges through the register) of CCD
- Cycles start again, a few AD cycles later: Photo transfer
- Read out the CCD register; when the addresses match (= desired pixels), the measuring value is forwarded to the AD transformer.

The various signals going through the transfer output mark certain points in time during the sequence control:

Transfer signals	Meaning
Do transfer	Is high when the CCD is at the holding point in line a (referred to in this way, since photo transfer also takes place in this line – when it isn't being suppressed by the NLC).
Do transfer & Xend	A short high-pulse, when we reach the end of line a.
Sub	Is high as long as a sub-pulse is running.
Start done	Is high when the CCD is ready for integration (or when waiting for the trigger) so when it is at the holding point in line a. Is low again when the CCD is read out. You could use the positive side to light the laser.
Wait for trigger	Is high when the CCD is at the holding point in line a and is waiting for the trigger signal. Is low as soon as the trigger is activated and the delay begins. Only a short high pulse occurs in untriggered operation. Could be used in addition to the trigger out connector to check triggering.
Integration done	Is high as soon as integration is complete. Is low again when the CCD is read out.
Photo cycle	Is high when the CCD is ready for integration. Is low as soon as integration is complete. During untriggered operation, the high phase returns exactly the integration time.

Tab. 13.7: Signals that can be sent through the transfer outlet

Please find further information on the menu *Measurement* > *CCD Settings* in chapter 12.4.5 on page 48.

13.5.6 Option (advanced user only) (menu *Measurement* > *Option*)

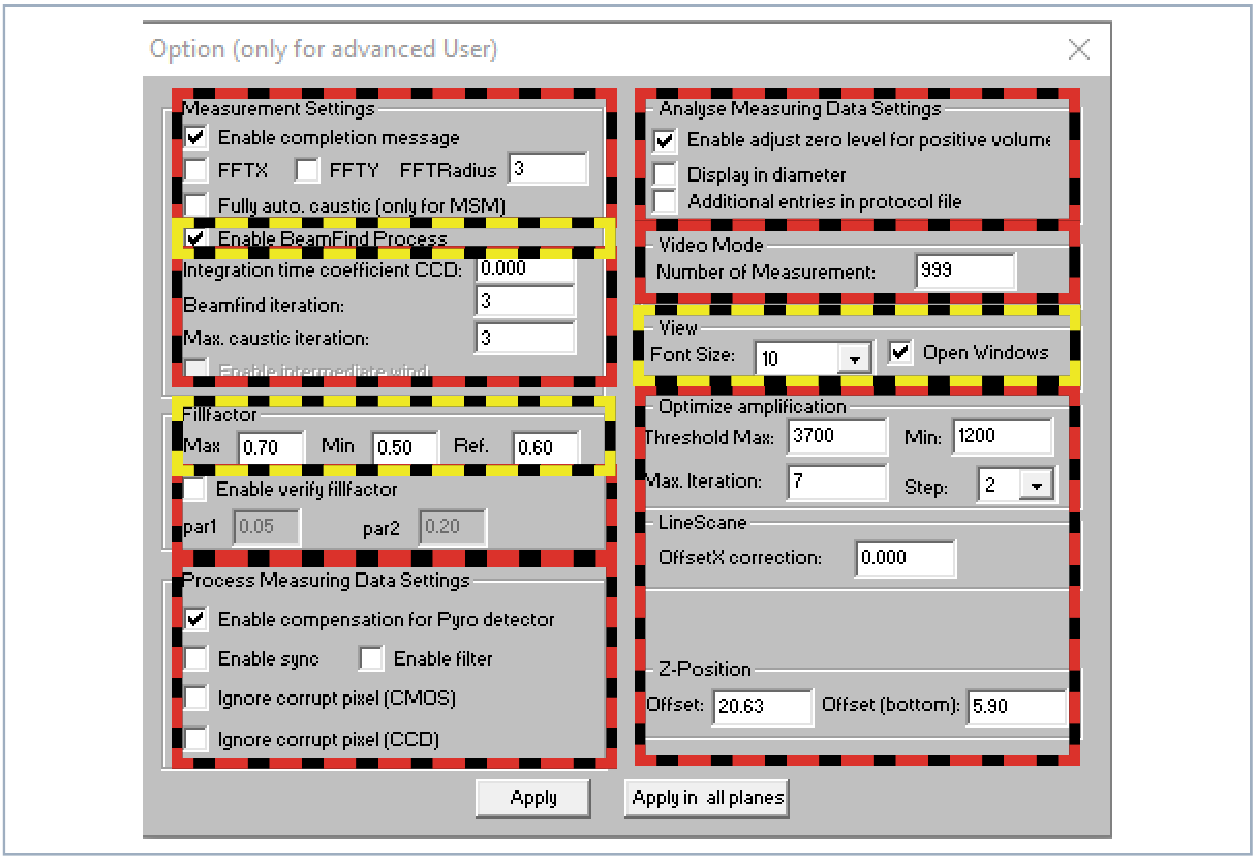


Fig. 13.12: Dialog window ***Option***

Enable beam find process

The Beam Find function must be used for caustic measurement. This involves an algorithm that separates the measuring signal from the measurement artifacts (e.g. noise) via an adjustable trigger threshold and adapts the size of the measuring window to this signal. This algorithm is only executed in the beam search plane (Dialog window ***Caustic***). On all other measuring planes, the measuring window size is determined using the fill factor.
If this function is deactivated, the beam search plane must be manually “premeasured” in the measuring system. Otherwise the measuring system might end up positioning the measuring window on the edge of the measuring area where there is no measuring signal. This makes it impossible to take a meaningful measurement.
If you turn the Beam Find function off and have the measuring measure the beam search plane system before each caustic measurement, you can save about 20 sec of measuring time per caustic measurement.

Summary: This function should be activated by default and only deactivated by experienced users. Turning off this function can shorten the time for caustic measurements by about 15 %.

Fillfactor

The fill factor is the quotient of the beam diameter and the length of the sides of the measuring window. As long as the measuring signal is not cut off and there are no noise components in the measuring result and now errors in the offset determination, the fill factor won’t influence the accuracy at all. But since every real measuring signal is tainted with noise and since the precision with which the zero level of a measuring signal can be determined is finite, very small fill factors can lead to a high level of accuracy. Depending on how substantial the RMS noise is and the errors in the zero level determination of a measuring plane, the optimal fill factor value to produce the best possible mathematical result will be different.

For TopHat and Gaussian beam shaped laser beams, the fill factor should range between 0.5 and 0.7. If the beam has diffraction rings, however, and if these are located completely within the measuring window, the optimal value for the fill factor can be between 0.5 and 0.6.

By default, the value should be set to: “Max 0.7 Min 0.5 Target 0.6”. For extremely deformed beams, the value may be changed to “Max 0.6 Min 0.4 Target 0.5”.

Font size

The font size for the most important display window can be changed here.
It is set to 10 points at the factory.

Open windows

When the window opening function is activated, some basic windows are opened when the LDS is started. If you don’t want this to happen, the function can be deactivated.

13.5.7 CCD info (menu *Measurement* > *CCD Info*)

The most important device data is shown in the menu ***Measurement*** > ***CCD Info***. Here you can see the magnification information for the measuring objective and also check which beam path is turned on.
If obvious default values (1:1) are shown instead of the actual magnification, then please check the mounting of the measurement objective.

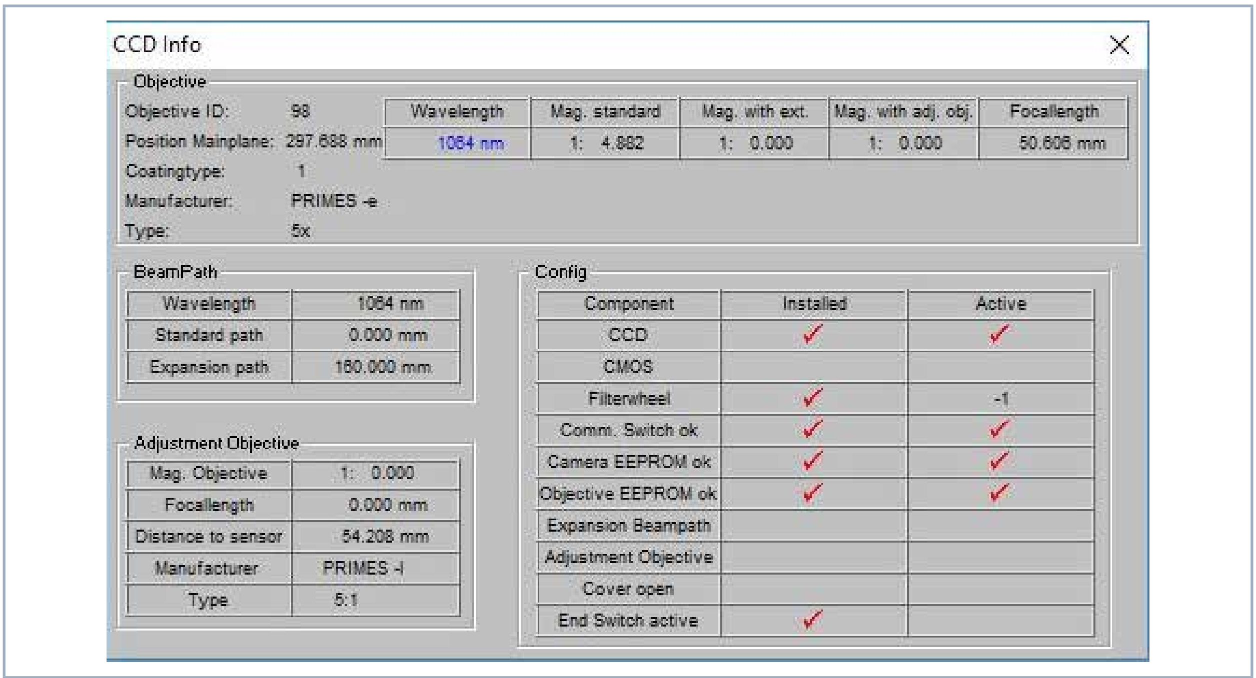


Fig. 13.13: Window ***CCD Info***

13.5.8 Single measurement (menu *Measurement* > *Single*)

This menu item is used for conducting single measurements. Settings for the measuring window position can be entered manually or automatically. The x- and y-axis measuring range of 2 mm x 2 mm at the device is much greater than the largest measuring window. It allows you to do a beam search manually or using the ***Scan*** function.

When a ***Scan*** is triggered, the MicroSpotMonitor MSM automatically tests the measuring range. When a point of maximum intensity is detected, the MicroSpotMonitor MSM automatically zooms to this point and adjusts the measuring window size. When the device has no x- or y-axis, the beam search function can be done automatically with item ***Find beam***.

The system only searches the area of the set-up window at the selected z-position. Afterwards, the ***Beam Search*** window appears. If the beam search is successful, a measurement window of appropriate size and position is displayed in the test panel of the "Single Measurement" window. The beam can then be recorded using the ***Measure*** button. The size of the measurement window depends on the magnification of the objective. Influencing factors are objective, wavelengths, and operating mode (standard, beam path extension, and calibration mode).

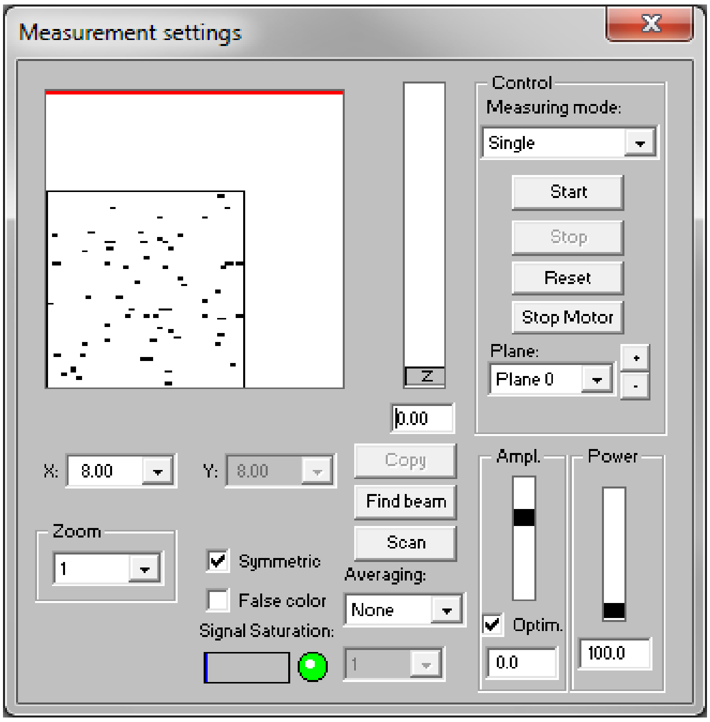


Fig. 13.14: Dialogue window ***Measurement settings***

During a manual beam search, the user can set the position and size of the measuring window within the mechanical limits himself. The selection is found in a pop-up menu, where you enter an x value for quadratic and/or x and y values for a rectangular measuring window. The position of the measuring window can be changed by clicking and dragging the frame using the mouse. The position of the window in the z-direction (height) can be changed using the z-sliding bar or by entering numerical values. The ***Zoom*** function allows a detail magnification of the measuring range.

A measurement is started with the ***Start*** button. The ***Monitor*** button starts periodic measurements based on current settings. The repetition rate depends on the spatial resolution and type of communications between the PC and the MicroSpotMonitor MSM.

The ***video mode*** only functions when using ethernet communications. The MicroSpotMonitor MSM provides 4 frames per second in ***video mode***. Unlike the monitoring operation, only raw data is transmitted in ***video mode***.
If the detector is overdriven during a measurement (the appearance of red in the representation and/or an A/D-Converter value of 4 095 in a clear section indicates ***signal saturation***), you should reduce the amplification using the Amplitude slider ***Ampl.*** and repeat the measurement. Amplification is automatically regulated when optimization is activated. If necessary, filtering must also be increased using a neutral glass density filter.

The radiated power can be configured using the ***Power*** scroll bar. The reference value for the scroll bar is entered in the ***Measurement > Environment*** menu. The power density is calculated in relation to the power values set here. Up to 50 individual measurements can be recorded in a measurement file. This is relevant when measuring the beam caustic and for time or power series. It is possible to switch back and forth between the individual measuring planes.

With the button ***Copy*** the measurement settings (window size and position, power and amplification) can be copied from the previous measuring plane.

By means of the option ***Averaging*** the average of the results of up to 50 single measurements per each plane is determined. There are different analysis algorithms available:

- ***Average*** determines the average value of the distributions measured
- ***Max. pixel*** determines the pointwise maxima of the distributions measured
- ***Max. trace*** determines the maximum traces of the distributions measured

During a measurement, the status of the measurement system is constantly displayed. These are:

- the current measuring plane
- the run of the reference cycle
- positioning the measuring head
- the measurement
- the data transmission – the progress is shown by means of the bar display

Fig. 13.15: Display window ***Monitor***

By means of the button ***Stop*** you can cancel a running measurement (this does not disrupt movement along the z-axis). We recommend triggering a ***Reset*** cycle afterwards. Canceling will also end ***monitor*** operation. The ***Stop*** button can be used to stop the measurement. A ***Reset*** cycle should then be triggered before further measuring.

13.5.9 Caustic measurement (menu *Measurement* > *Caustic*)

The caustic measurement is a serial measurement where the z position is varied. The goal is to examine propagation in the propagation direction. The results are stored in different planes. A different z position is assigned to every measuring plane. As the beam radius as well as the power density change in every z position, the position as well as the size of the window and the signal strength can vary from plane to plane. These parameters are therefore individually adjustable in every measuring plane.

The caustic measurement itself can be carried out either manually or automatically. For the automatic caustic measurement the following has to be entered:

- the minimum and maximum z-position
- the number of planes that are to be measured
- the starting plane for the beam search

After finding the beam, the system then measures the beam at equidistant intervals and determines the focus length, focus radius, and beam parameter product. During manual measurement, all parameters are configured by hand following individual measurements. The caustic can then be manually measured. The measuring parameters can be stored by means of the menu item ***File* > *Save measurement preferences*** and can be loaded again upon request.

Prepare a caustic measurement

When positioning the MicroSpotMonitor MSM, the beam focus should be in the middle of the z-axis working area. Depending on device accessories or fittings, this is approximately 17 mm above the null position (35 mm for a standard device) of the integrated z-axis. The following values can be set globally:

- power
- magnification
- the value and averaging mode

There should be a minimum of ten measuring planes within the range of ±2 Rayleigh Lengths around focus point. There should be at least five with the range of ±1 Rayleigh Length around the focus point.

To conform with ISO 11146 standards, one should measure, at a minimum, over four Rayleigh Lengths. We recommend measuring over ± 3 Rayleigh lengths in 21 planes.

Automatic caustic measurement (menu *Measurement* > *Caustic* > *Automatic)*

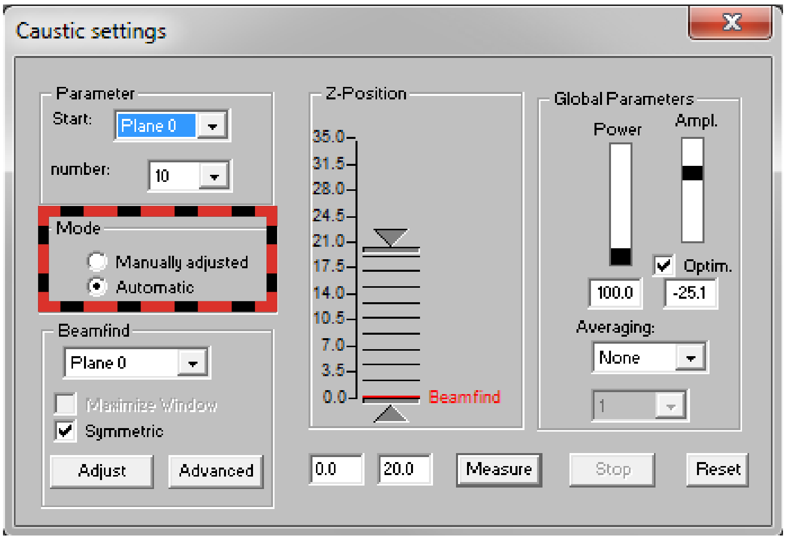


Fig. 13.16: Dialogue window ***Caustic settings***

During automatic caustic measurement, the minimum and maximum z-position is selected together with the number of measuring planes. The measurement cycle begins with an automatic beam search in the specified starting plane. The beam search only occurs within the area of the starting plane's measurement window.

If you don't want the search window size to take up the maximum space (depending on the lens), the window size can be adjusted, once the control box ***Maximize Window*** has been deactivated, by selecting ***Adjust*** in the menu. The ***Details*** menu point allows the user to configure the beam search parameters by changing the spacial resolution, threshold value, and minimum signal.

If automatic find beam needs to be left out to save time, it can be deactivated in the ***Options*** dialog window (**Menu *Measurement* > *Option***) (activate check box ***Beamfind***).

Manual caustic measurement (menu *Measurement > Caustic) and* (menu *Measurement > Single*)

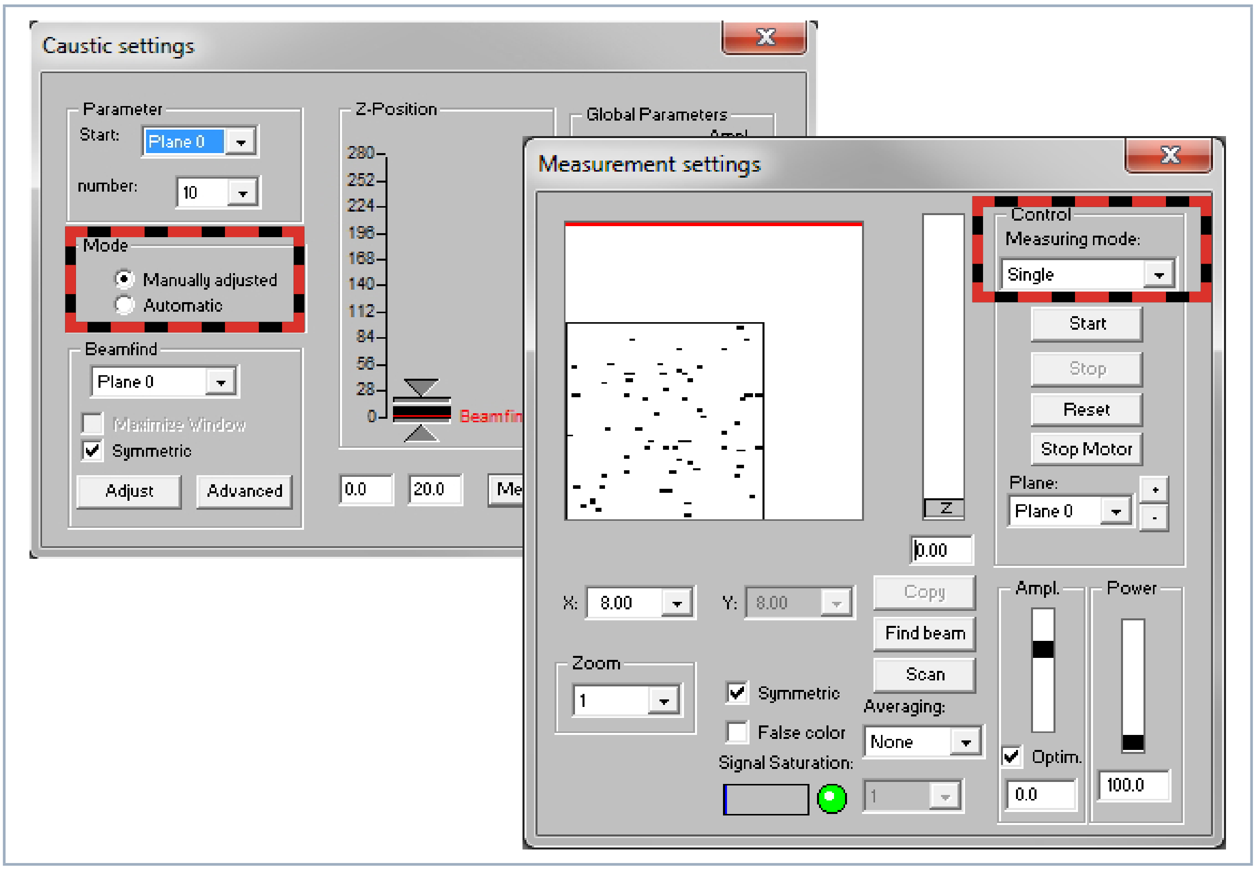


Fig. 13.17: Dialogue window ***Caustic settings*** and ***Measurement settings***

The manual caustic measurement consists of a series of individual measurements at various z-positions, with the results being stored in their own planes.

The z-distance for the individual planes should be about 1/200th of the focal length of the lens. For a lens with a focal length of 127 mm, this means a distance of about 0.5 mm to 0.6 mm. For a caustic measurement with fifteen planes, the range on the z-axis should be about 8 mm.

> The start plane and number of measuring planes must match the settings in the settings window- ***Measurement > Single > Measurement settings*** .

To conduct a manual caustic measurement, follow these steps:

1. Delete the old data in the ***Edit > Clear all planes*** dialog window or create a new document ***File > New***.
2. In the ***Caustic settings*** dialog window, click on ***Manually adjusted (menu Measurement > Caustic)***.
3. Select the first plane in the ***Measurement settings dialog window (men Measurement > Single)***.
4. Configure the z-position in the ***Measurement settings*** dialog window.
5. Configure the measurement window size and position in the ***Measurement settings*** dialog window.
6. Perform a measurement in the configured pane.
7. Select the next plane and start again at Point 3.

Steps 3 through 6 can be repeated ten to fifteen times.

Record a time series (menu *Measurement* > *Single*)

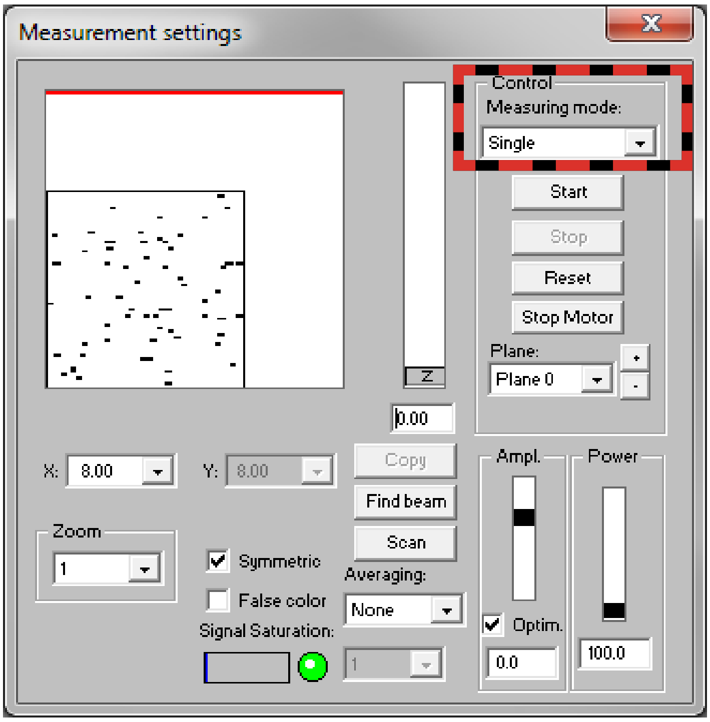


Fig. 13.18: Dialogue window ***Measurement settings***

Recording a time series corresponds to manual caustic measurement, but with the z-position staying the same on all planes.

1. Delete the old data in the ***Edit*** > ***Clear all planes*** dialog window or create a new document ***File*** > ***New***.
2. Select the first plane in the ***Measurement settings dialog window (men Measurement*** > ***Single)***.
3. Configure the z-position in the ***Measurement settings*** dialog window.
4. Configure the measurement window size and position in the ***Measurement settings*** dialog window.
5. Perform a measurement in the configured pane.
6. Select the next plane and use the old settings by clicking the ***Copy*** button.

14 Troubleshooting

14.1 Error during a measurement

When there is an error during data transfer, a processor in the measuring system failed or there was an error during program execution. Attempt to restart the system with the ***Reset*** button in the LaserDiagnoseSoftware LDS. If this does not help, turn off and on the 24 V power supply for the bus system and start another “Reset Cycle”. If necessary, restart the computer.

14.2 No measurement signal at the MicroSpotMonitor MSM

When there is no measurement signal detected, except for noise which is typically 270 - 300 counts at the MicroSpotMonitor MSM (the current number of counts can be found under the menu item ***Display > Variable Contour Lines***, recheck the device position. Besides wrong positioning a too high attenuation can cause the same problem.

15 Maintenance and service

The operator is responsible for determining the maintenance intervals for the measuring device. PRIMES recommends a maintenance interval of 12 months for inspection and validation or calibration. If the device is used only sporadically, the maintenance interval can also be extended up to 24 months.

15.1 Exchanging the protective window

The measuring objective of the MicroSpotMonitor MSM can be optionally delivered with a protective window or a protective window with cyclone. The protective window in the beam entrance is a wearing part and can be replaced if necessary. Low levels of contamination of the protective window can be carefully removed when cooled with Isopropanol (observe the manufacturer's safety instructions). In case of heavy, non-removable contamination or damage, the protective window must be replaced with a new one.

The protective window is coated with an antireflex coating and has low reflection values of less than 1%. To avoid increased reflection values, use only original PRIMES protective windows.

Protective window diameter	30 mm
Glass thickness	1.5 mm
Order number	801-004-054

15.1.1 Safety instructions

DANGER

Severe eye or skin injury due to laser radiation

If the protective window is not correctly positioned, reflections can cause directional laser radiation.

- **Make sure that the new protective window is settled flat in the groove of the protective window holder.**

CAUTION

Burns due to hot components

After a measurement the protective window is hot!

- **Do not replace the protective window directly after a measurement.**
- **Let the device cool down for an adequate period of time. The cooling ime varies depending on the laser power and the irradiation time.**

NOTICE

Damaging/destroying the device

Contamination and fingerprints on the protective window can lead to damage or shattering or splintering of the protective window during measuring operation.

- **Only replace the protective window in a dust-free environment.**
- **Do not touch the protective window.**
- **When exchanging the protective window wear powder-free latex gloves.**

The protective window is located in the protective window holder of the measuring objective below the retaining ring or cyclone. The retaining ring or the cyclone are attached to the protective window using a spring-loaded bayonet lock with three locking pegs.

15.1.2 Replacing the protective window

1. Follow the safety instructions in chapter “15.1.1 Safety instructions” on page 109.

2. Push the retaining ring down against the protective window holder, turn it counterclockwise until it stops and lift the retaining ring up and off.
3. Remove the old protective window from the protective window holder (e.g. with a suction cup) and dispose of it.

4. Carefully place the new protective window into the protective window holder.
5. Position the locking pegs of the retaining ring in the openings of the bayonet lock.
6. Push the retaining ring down and turn it clockwise until it stops.
- The bayonet lock is locked.

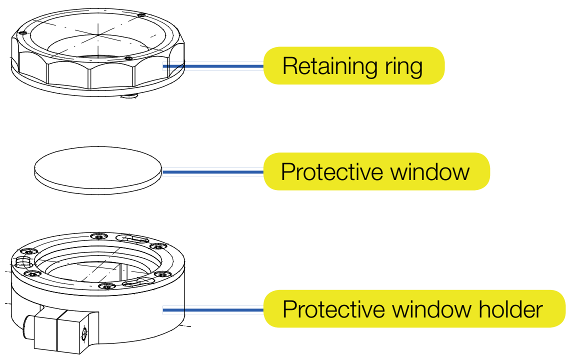


Fig. 15.1: Components of the protective window holder

15.1.3 Replacing the protective window for cyclone

1. Follow the safety instructions in chapter “15.1.1 Safety instructions” on page 109.

2. Remove the compressed air hoses around the cyclone if necessary.
3. Push the cyclone down against the protective window holder, turn it counterclockwise until it stops and lift it up and off.
4. Remove the old protective window from the protective window holder (e.g. with a piece of adhesive tape) and dispose of it.

5. Carefully place the new protective window into the protective window holder.
6. Position the locking pegs of the cyclone in the openings of the bayonet lock.
7. Push the cyclone down and turn it clockwise until it stops.
- The bayonet lock is locked.

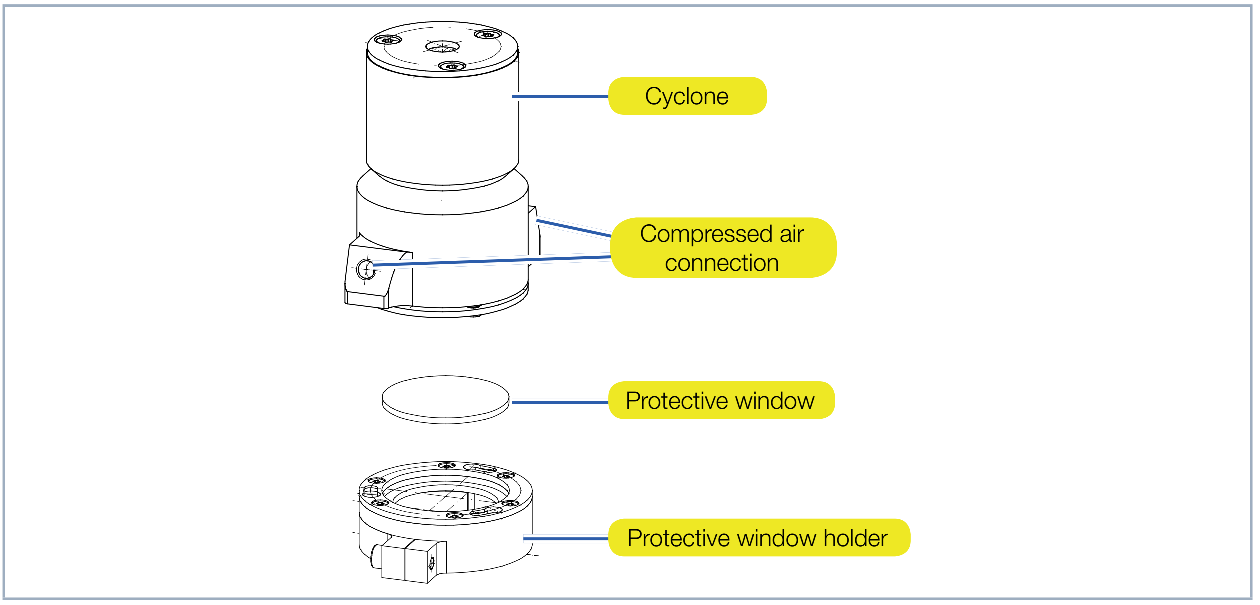


Fig. 15.2: Components of the protective window holder with cyclone

16 Storage

NOTICE

Beschädigung/Zerstörung der optischen Komponenten durch Verschmutzungen oder Stöße

Verschmutzungen können die optischen Bauteile beschädigen oder zerstören. Durch harte Stöße oder Fallenlassen können die optischen Bauteile beschädigt werden.

- ▶ **The device must only be transported with a mounted transport lock.**
- ▶ **To avoid contamination, please cover the aperture with the provided lid or optical tape.**
- ▶ **Store the device in the original PRIMES transport box (option).**

Please note before storing devices with water cooling circuit:

NOTICE

Damage/destruction of the device caused by leaking or freezing cooling water

Leaking cooling water can damage the device. Storing the device at temperatures near or below freezing and without emptying the cooling circuit completely can damage the device.

- ▶ **Empty the lines of the cooling circuit completely.**
- ▶ **Don’t use any compressed air to empty the cooling circuit.**
- ▶ **Even when the lines of the cooling circuit have been emptied, a small amount of residual water will remain in the device at all times. This may leak out and end up inside the device. Close the connector plug of the cooling circuit with the included sealing plug.**
- ▶ **Store the device in the original PRIMES transport box (option).**

17 Measures for the product disposal

Due to the Electrical and Electronic Equipment Act (“Elektro-G“) PRIMES is obliged to dispose PRIMES measuring devices manufactured after August, 2005, free of charge. PRIMES is a registered manufacturer in the German “Used Appliances Register“ (Elektro-Altgeräte-Register “EAR“) with the number WEEE-reg.-no. DE65549202.

Provided that you are located in the EU, you are welcome to send your PRIMES devices to the following address, where they will be disposed free of charge (this service does not include shipping costs):

PRIMES GmbH
Max-Planck-Str. 2
64319 Pfungstadt
Germany

18 Declaration of conformity

Original EG Declaration of Conformity

The manufacturer: PRIMES GmbH, Max-Planck-Straße 2, 64319 Pfungstadt, Germany,

hereby declares that the device with the designation:

MicroSpotMonitor (MSM)

Types: MSM 35; MSM 120; MSM-HP

is in conformity with the following relevant EC Directives:

- Machinery Directive 2006/42/EC
- EMC Directive EMC 2014/30/EU
- Low voltage Directive 2014/35/EU
- Directive 2011/65/EC on the restriction of the use of certain hazardous substances (RoHS) in electrical and electronic equipment
- Directive 2014/32/EC on measuring instruments

Authorized for the documentation:
PRIMES GmbH, Max-Planck-Straße 2, 64319 Pfungstadt, Germany

The manufacturer obligates himself to provide the national authority in charge with technical documents in response to a duly substantiated request within an adequate period of time.

Pfungstadt, November 19, 2019

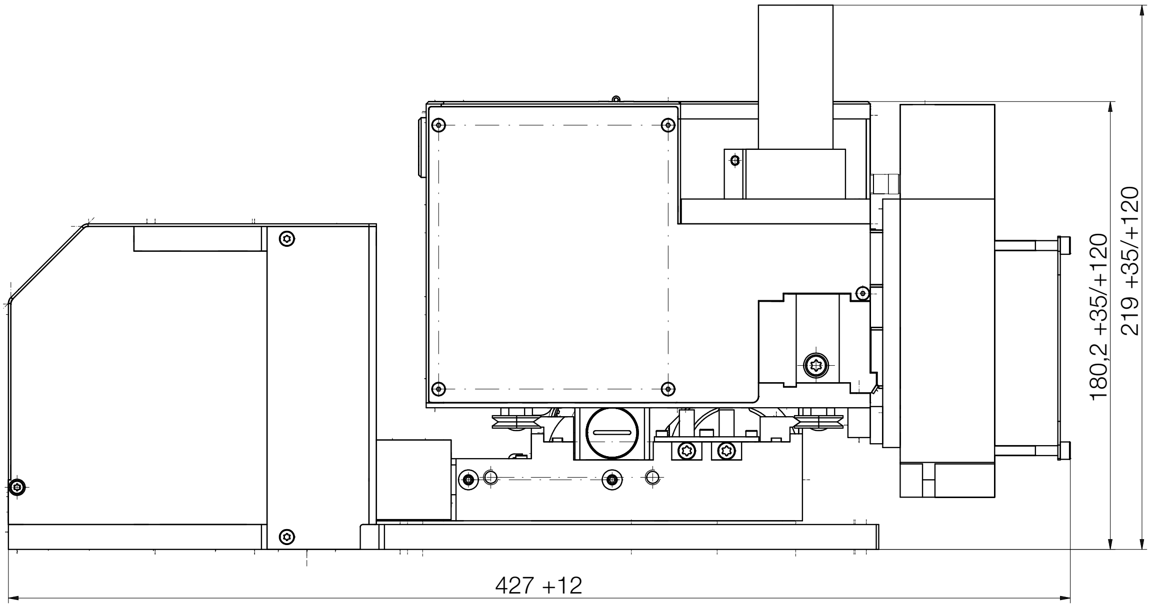
Dr. Reinhard Kramer, CEO

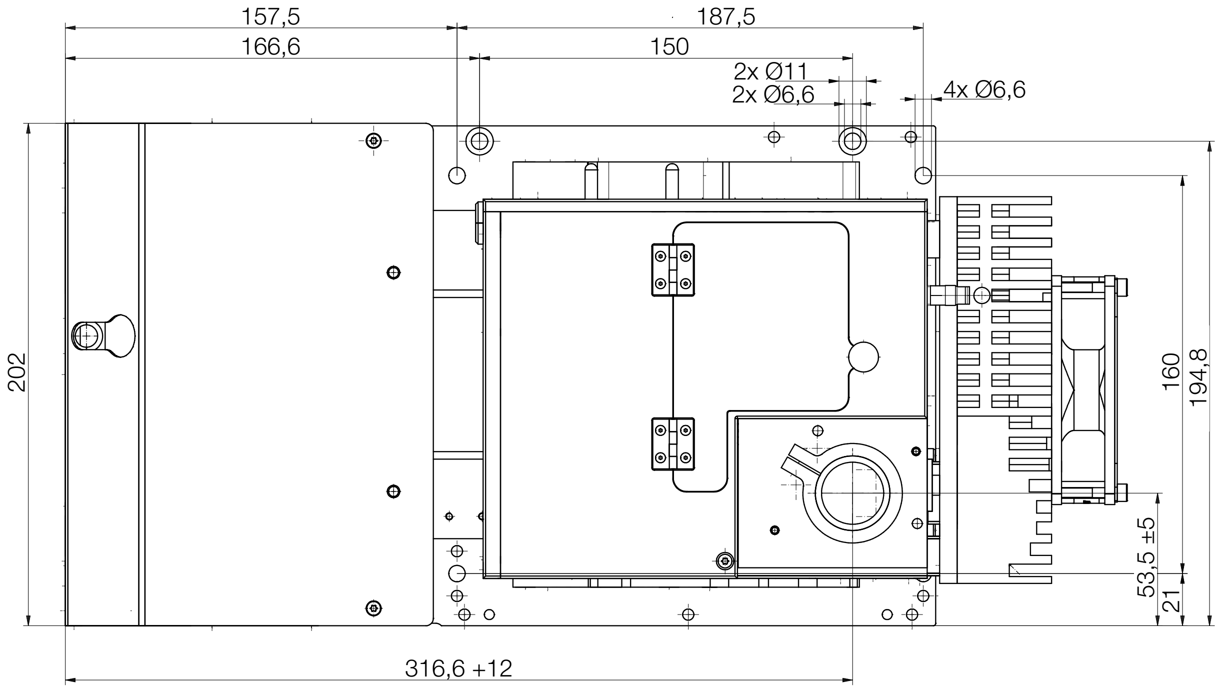
19 Technical data

Measurement parameters	
Power range	1 mW – 200 W (optional 500 W with water cooling)
Wavelength range	257 – 272 nm (on request)
	340 – 360 nm
	515 – 545 nm
	1 030 – 1 090 nm
Beam diameter	min. 20 µm – max. 1 mm (depending on the measuring objective)
Determined parameters	
Focus position x, y, z	yes
Focus radius x, y	yes
Beam quality factor M^2	yes
Raw beam diameter with focussing element	yes
Beam parameter product BPP	yes
Divergence angle	yes
Power density distribution	2D, 3D
Device parameters	
Measuring range x-, y-direction	0.02 – 2 mm (depending on the measuring objective)
Measuring range z-direction	35 mm or 120 mm
Integrated variable attenuation (option)	Filter wheel with 5 OD filter (OD 0 – 5)
Supply data	
Power supply	24 V DC ± 5 %, max. 1,8 A
Compressed air for cyclone (cleaned, free of water and oil)	0,5 bis 1 bar
Cooling water pressure	2 bar primary pressure with an unpressurized outflow, max. 4 bar
Min. Cooling water flow rate	1,5 l/min
Cooling water temperature T_{in} [1)]	Dew point temperatur < T_{in} < 30 °C
[1)] Please consult with PRIMES before doing anything that does not comply with this specification.	
Communication	
Interfaces	RS485/Ethernet
Dimensions and weight	
Dimensions (L x W x H)	Length: 427 mm +12 mm movement range + connector Width: 202 mm Height: 181 mm + 35/120 mm movement range + projection depending of the measuring objective used
Weight	15 kg

Environmental conditions	
Operating temperature range	10 – 40 °C
Storage temperature range	5 – 50 °C
Reference temperature	22 °C
Permissible relative humidity (non-condensing)	10 – 80 %

20 Dimensions





All dimensions in mm (general tolerance ISO 2768-v)

21 Appendix

21.1 Insert fixed OD filter (option) in the inspection chamber

1. Turn off the laser source.
2. Ensure that moving parts, e.g. robot arms, etc. are at a standstill and that they cannot be set in motion unintentionally.
3. Switch off the power supply of the MicroSpotMonitor MSM.

NOTICE

Damaging/destroying the optical components

Contamination can damage or destroy the optical components.

▶ **Only open the inspection chamber in a dust-free environment.**

4. Unscrew the knurled screw on the cover and open the cover.
5. Insert the fixed filter into the slot provided.
- The insert has different guides so that the fixed OD filter can only be inserted in one position.
6. Close the cover and screw in the knurled screw:
- Check the secure fit of the cover.
- The cover must fit flush with the housing, so that no dust or dirt can get into the inspection chamber.

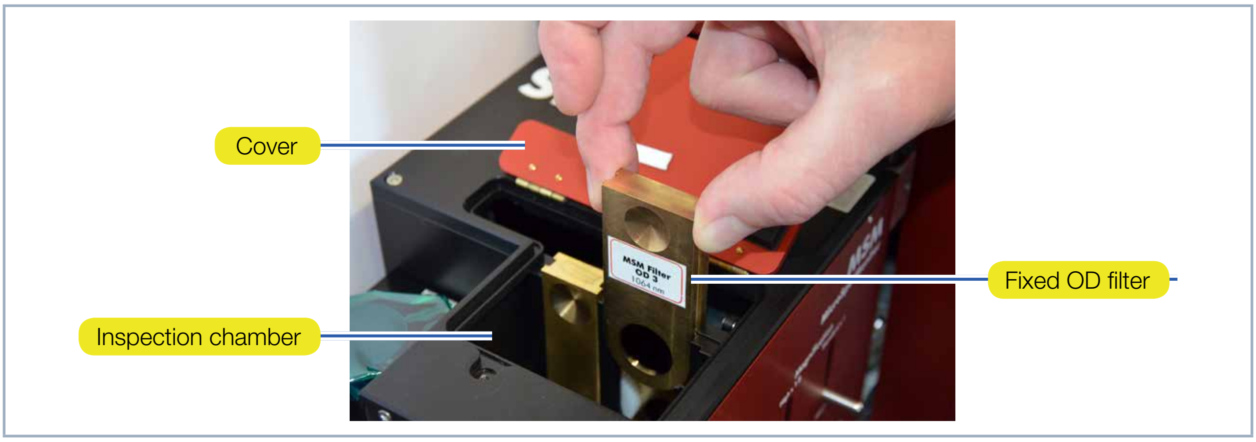


Fig. 21.1: Insert fixed OD filter into the inspection chamber

21.2 File “laserds.ini” – an Example

The contents of a laserds.ini file are shown below. Some information is gained regarding the startup settings for the system – such as:

- default serial interface.
- default settings for beam find, such as threshold and spatial resolution for the search.

The settings can be changed in a Windows® Editor. Close the LaserDiagnoseSoftware LDS before making changes in the laserds.ini file. Otherwise, the changes will not be activated and be reset when the program closes.

```
[Version]
No.=17

[Window]
left=10
top=10
right=1183
bottom=948

[Comm]
Data_Transfer_Mode=0
Port=
HighBaudrate=1
escan=161,168,152,144,145,
192,112,113,80

[Ethernet]
IP=0.0.0.0
Port=6001
MAC Address=00-00-00-00-00-00
[Device]
Type=
ID=-1

[Adresse]
Own=64

[Private]
Mode=0

Flag1=1111
Flag2=0
Flag3=0
[File]
Default=

[Laser]
Wellenlaenge=0.01060000
Drehzahlnr=0
Kamerachip=0
Laserleistung=6000.00000000
Brennweite=127.00000000
StrahlsucheTrigger=150
Strahlsuche Trigger für Pyro=150
Strahlsuche Trigger für Photo=50
StrahlsucheProzent=35
Funkvorhanden=1
Detektortyp=1
SperrbereichY0=8.00000000
...
...
Autoscaleon=1
Extern Z-Axis=0
Tip twisted=0

[Detectorparameter]
Detector 0 Tau1=10
Detector 0 Scale1=-0.1
Detector 0 Tau2=3500
Detector 0 Scale2=0.1
Detector 0 Tau3=0
Detector 0 Scale3=0
Detector 0 Name=Pyro-FM-1
Detector 1 Tau1=0
...
...

[TriggerModi]
TriggerMode 0=Dauer-Trigger
TriggerMode 1=Trigger mit Delay
und folgender Pulslänge
...
...
[Interface]
Startup=0
[Skript]
Startdatei=
[Output]
Out0=Port 0
Out1=Port 1
...
...

[Input]
In0=Port 0
In1=Port 1
In2=Port 2
...
...

[Multimon]
Rescan=32,33,128
Radius=1.

[Kaustik]
FuellMin=0.25
FuellMax=0.4
FuellSoll=0.35
[YAG-Kamera]
Trigger-Mode=0
Trigger-Level=0
Trigger-Delay=0
Pulslaenge=1
CCD-Mode=30
[Export]
Setting=0
[Service]
Firmenadresse=
Servicetechniker=

[BusProtokoll]
Befehl_Nr=0
Datei_Nr=1
Protokoll=0

[SchlittenKonstante]
Offset=1
OffsetFromBottom=5.9

[Process Data]
Mode=0

[View]
Font Size=10
Recent File1=
Recent File2=
Recent File3=
Single Window PositionX=0
Single Window PositionY=0
Caustic Window PositionX=0
Caustic Window PositionY=0
Sensor Window PositionX=0
Sensor Window PositionY=0
Envi Window PositionX=0
Envi Window PositionY=0
MSM Settings Window PositionX=0
MSM Settings Window PositionY=0
MSM Info Window PositionX=0
MSM Info Window PositionY=0
Free Window PositionX=0
Free Window PositionY=0
Power Window PositionX=0
Power Window PositionY=0
Show Measuring Windows=1
[Measurement]

Beamfind Iteration=3
```

21.3 Description of the MDF file format

The MDF file format is a simple ASCII-format which includes the main data of a beam measurement – the spatial power density distribution. MDF stands for “mailable data format”.
By means of this standardized format conversion problems between different evaluation programs are supposed to be reduced and a safe data transmission, e.g. per e-mail, is supposed to be ensured.

The files are arranged as follows:

1st line:	MDF 100 (file identifier)
2nd line:	Number of image points: in x-direction in y-direction
3rd line:	Size of the measurement range: length in x (mm) length in y (mm)
4th line:	Position along the beam axis: z-position (mm)
5th line:	Transversal position of the center of the measurement range: x-pos y-pos (mm)
6th line:	Amplification of the measuring signal: enhancement (dB)
7th line:	Number of averages: number
8th line:	Offset value displayed by the measuring device: offset-value
9th line:	Wavelength-value
10th line:	Power value
11th line:	Focal length value
12th line:	Date, time value

In the following lines the data can be found.
There is a maximum of 80 characters per line.

Comments

Comments are inserted as additional lines, into the lines after the file identifier.
The comment lines each start with a semicolon.

Example:

```
MDF100
;This is an example.
;These lines are a comment.
64   64
2   2
11
...
...
1
10
10 10 10 10 10 10 10 10 10 10
11 12 13 14 15 16 17 18 19 20
20 20 20 20 20 18 16 14 12 10
....
....
```

21.4 Optical components

The MicroSpotMonitor MSM is a camera-based measuring system. Depending on the application, up to 7 different optical components can be in the beam path.
The purpose and functioning of individual components is described in the following chapters.

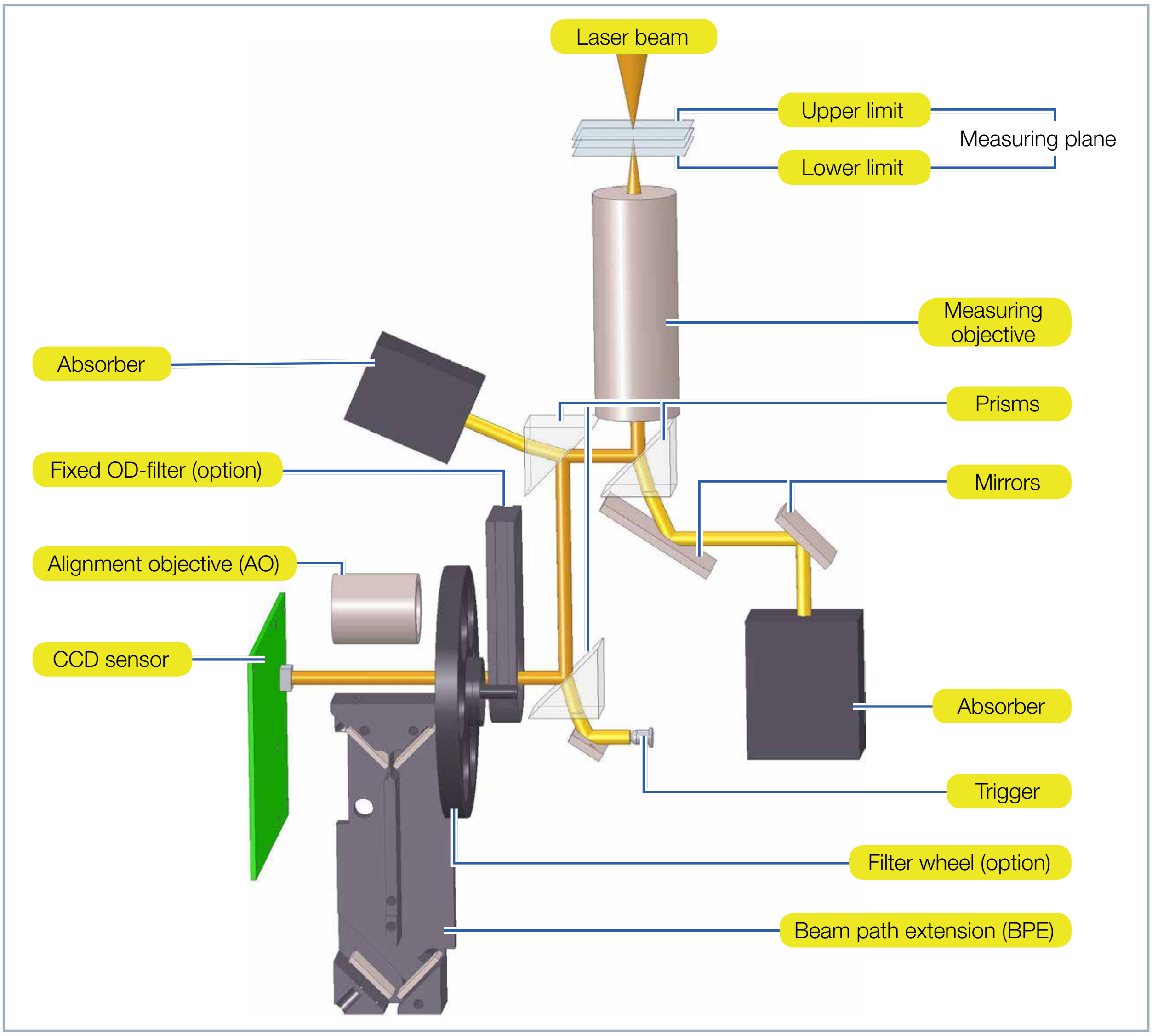


Fig. 21.2: Example of the optical design of the MicroSpotMonitor MSM

21.4.1 Measuring objective

The measuring objective is a lens system designed to reproduce a specific plane “above” the measuring objective onto the CCD sensor. “Above“ in this case, means that the plane is outside the MicroSpotMonitor MSM.
This non-contact measurement offers the advantage that even very high power densities (GW/cm²) can be detected. The measuring objective makes it possible to enlarge the beam and thus to image a sufficient resolution on the CCD sensor.

Fig. 21.3 on page 121 shows a diagram of the measuring objective. It includes all important parameters.

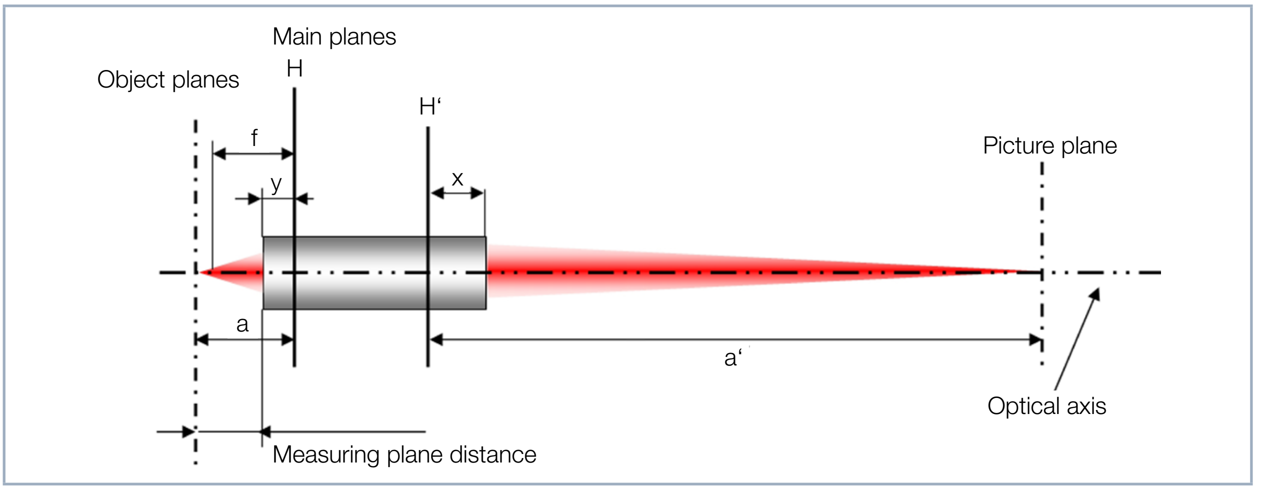


Fig. 21.3: Illustration of a defined plane with a measuring objective

The main planes H and H‘ in the measuring objective or image space are auxiliary quantities in order to combine any number of optical components into one unit. The focal length f, offset distance a, and image distance a‘ are measured from the intersection of the main planes with the optical axis (cardinal point).

The dimensions x, y and the measuring plane distance are important auxiliary quantities. They establish the relationship between the optics and their socket more exactly the socket edge.

The projection of the measuring objective is calculated according to the following formula:

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{a'} \qquad \textbf{(1.1)}$$

The focal length f is dependent on the wavelength and, as a result, the image distance a’ is dependent on the object distance a.

The magnification of the measuring lens is calculated from the quotient of a and a’:

$$\beta = \frac{a'}{a} \qquad \textbf{(1.2)}$$

The combination of the two formulas gives β a dependence on the image size a’ and the focal length f. The focal length is determined by selecting a measuring objective and the image distance is determined by the construction of the measuring device.

The choice of the measuring objective depends on the geometry and the beam parameters of the laser beam to be measured. The sensor area of the CCD sensor is 4.76 mm x 5.58 mm.
According to the ISO standard 11146, the measurement must be carried out for at least 4, more preferably 6 rayleigh lengths.

According to the following formula the sensor area must be at least 5 times larger than the expected focus diameter.

$$\omega_{\sigma(z)} = \omega_{a0} \cdot \sqrt{1+\left(\frac{z}{z_{Ra}}\right)^2} \qquad (1.3)$$

Once the appropriate measuring objective has been selected, the MicroSpotMonitor MSM recognizes the assembled measuring objective via an electronic coding on the holder of the measuring objective and adjusts the available measuring windows.
If, for example, the maximum square measurement window size in a 1:1 figure on the CCD sensor 4 mm x 4 mm, it should be reduced to 0.4 mm x 0.4 mm at a magnification of 10:1.

The inlet aperture of the MicrosSpotMonitor MSM can easily be aligned with the optical axis of the laser beam within a range of 2 mm x 2 mm using an alignment tool (see chapter 7.2.2 on page 19). The path of movement of the x and y axis of 2 mm makes it possible to position the laser beam precisely on the CCD sensor.

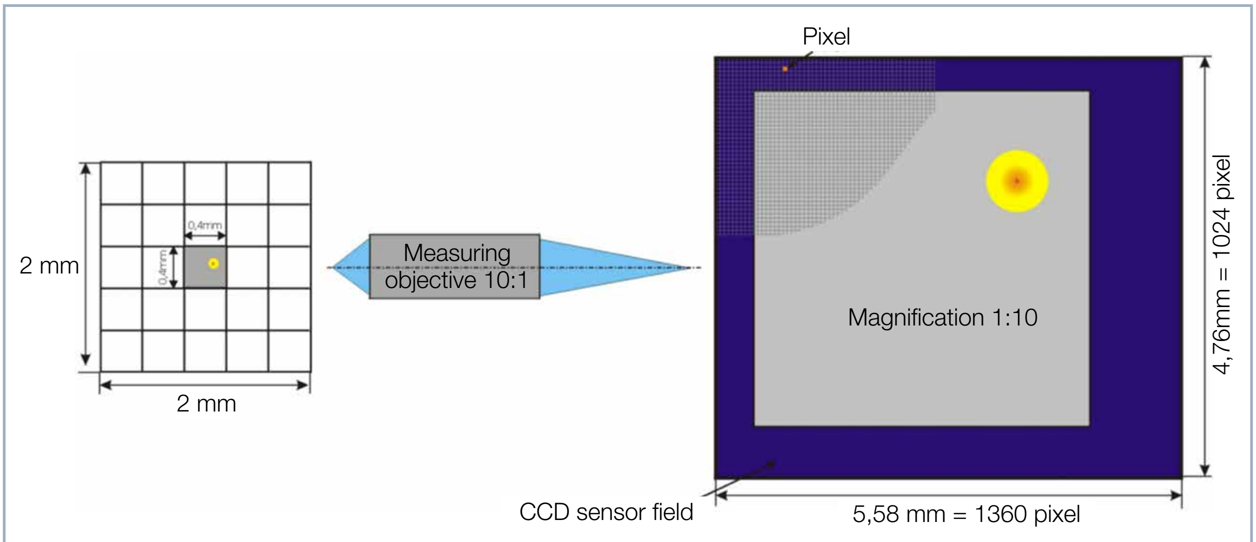


Fig. 21.4: Schematic illustration of a measuring plane on the CCD sensor

Fig. 21.4 on page 122 shows schematically the projection of a measuring plane onto the CCD sensor. The reticule on the left shows the measuring area, which can be measured with the x- and y-axis. This can also be done automatically with the help of the ***Scan*** command.
Within the measuring area, a measuring window can be positioned (size depending on measuring objective). On the right, the CCD sensor field is displayed. The measuring window, which has an edge length of 0,4 mm (in the object level), is projected to the chip with a 10-fold magnification.

Positioning the focused laser beam over the MicroSpotMonitor MSM

The image characteristics of the measuring objective make it necessary to position the laser beam focus in a specific range over the measuring objective.
Formula (1.1) shows, the further the focus is positioned over the measuring objective (afocus), the closer it is projected behind the measuring objective (a'focus).

Upper limit

If the focus is located too high above the measuring objective, a focus on the image-sided beam path can develop. Together with too high beam intensities, the optics might be damaged.

Measuring plane

The beam distribution of the measuring plane is displayed on the CCD sensor.

Lower limit

If the focus is too close to the measuring objective, it can – depending on the type of focusing and the power used – damage the entrance lens.

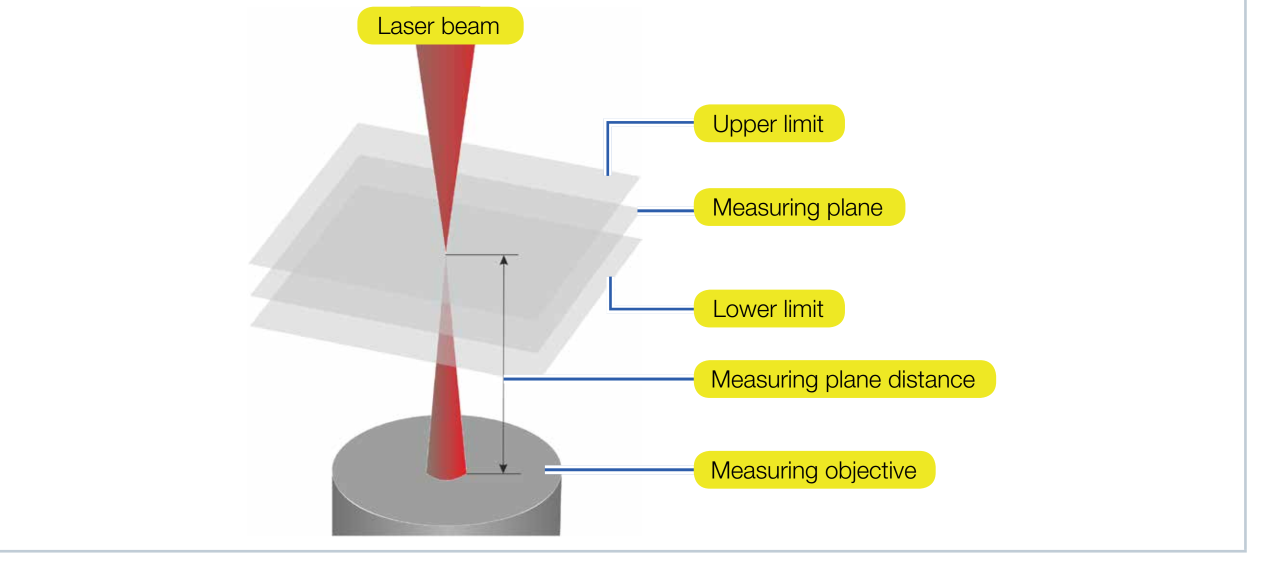


Fig. 21.5: Measuring range of the MicroSpotMonitor MSM

The size of the range in which the focus is to be positioned before the first measurement depends on the chosen objective, the used wavelength and the type of focusing. The measurement range lies within an upper and a lower limit.

Prisms

After the measuring objective, the laser beam strikes three uncoated quartz glass prisms which attenuate the laser beam.

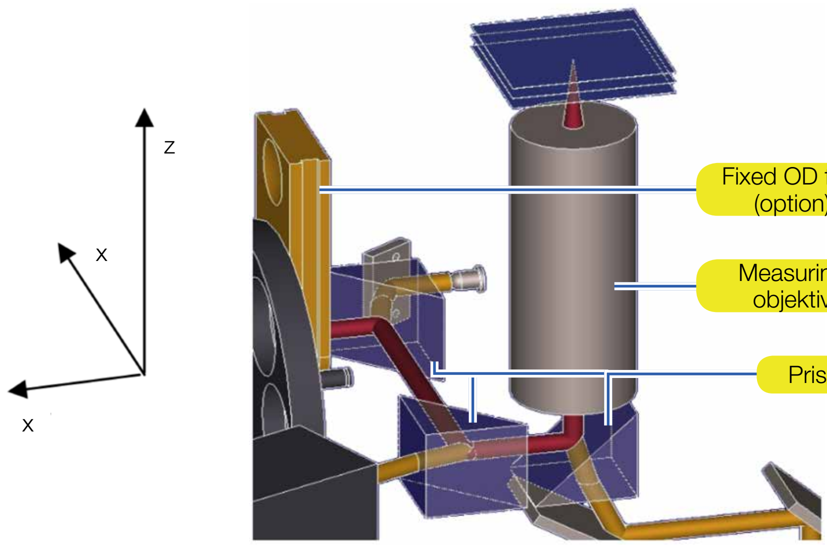


Fig. 21.6: Section of the beam path of the MicroSpotMonitor MSM

The reflection is described with the Fresnel formulas. They describe the so-called reflection respectively transmission ratio of light at surface boundaries.

$$\rho_{\perp} = \frac{-(\sqrt{n_{rel}{}^2 - \sin(\alpha)^2} - \cos(\alpha))^2}{n_{rel}{}^2 - 1} \quad (1.4)$$

$\rho_{\perp}$: Reflection ratio of vertically polarized light.

$$\sigma_{\perp} = \frac{2 \cdot \cos(\alpha) \cdot \sqrt{n_{rel}{}^2 - \sin(\alpha)^2} - 2 \cdot \cos(\alpha)^2}{n_{rel}{}^2 - 1} \quad (1.5)$$

$\sigma_{\perp}$: Transmission ratio of vertically polarized light.

$$\rho_{\parallel} = \frac{n_{rel}{}^2 \cdot \cos(\alpha) - \sqrt{n_{rel}{}^2 - \sin(\alpha)^2}}{n_{rel}{}^2 \cdot \cos(\alpha) + \sqrt{n_{rel}{}^2 - \sin(\alpha)^2}} \quad (1.6)$$

$\rho_{\parallel}$: Reflection ratio for parallel polarized light.

$$\sigma_{\parallel} = \frac{2 \cdot n_{rel} \cdot \cos(\alpha)}{n_{rel}{}^2 \cdot \cos(\alpha) + \sqrt{n_{rel}{}^2 - \sin(\alpha)^2}} \quad (1.7)$$

σ_{II} : Transmission ratio of parallel polarized light.

$$n_{rel} = \frac{n_2}{n_1} \qquad (1.8)$$

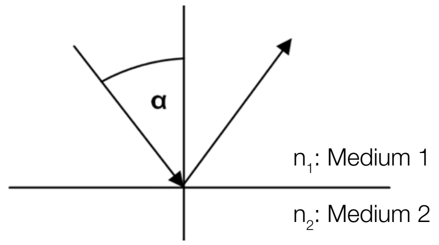


Fig. 21.7: Reflection of a beam at surface boundaries

The reflection respectively the translucence coefficients correspond to the squares of the respective ratios.

$$R_{[in\%]} = \rho^2 \cdot 100\,;\, T_{[in\%]} = \sigma^2 \cdot 100 \qquad (1.9)$$

In einem Diagramm aufgetragen ergeben sich folgende Kurven:

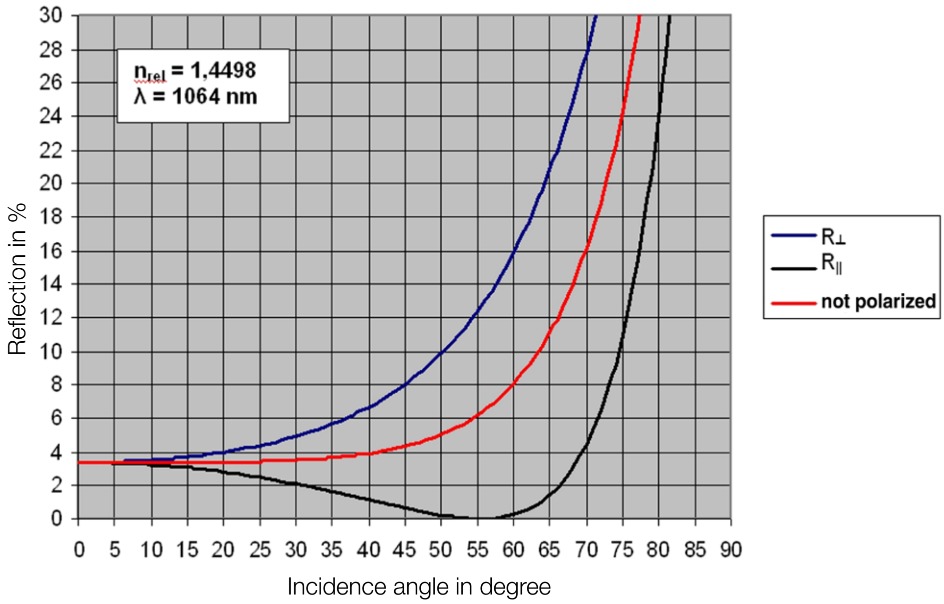


Fig. 21.8: Reflexion eines Laserstrahls in % in Abhängigkeit des Einfallswinkels

The curves in Fig. 21.8 on page 125 were calculated for a wavelength of 1 064 nm. The refractive index n of quartz glass is wavelength-dependent. It varies from 1.4498 to 1.4766 in the wavelength range of 350 to 1 064 nm.

It can be clearly seen that the reflection characteristics depend on polarization. Thisalso applies to an angle of incidence of 45°, the angle of incidence at which the beam passes in the MicroSpotMonitor MSM.

For this reason, the prisms are integrated in the MicroSpotMonitor MSM in such a way that the beam is diverted in all three spatial directions (see Fig. 21.6 on page 124). This ensures that always two of the three incidence planes of the prisms are perpendicular to each other and compensate the polarization effects.

Nevertheless, the attenuation of the prisms remains a function of the wavelength and polarization of the laser beam.

In the optimal case for reflection,
- the laser beam is attenuated by a factor of $1{,}7 \cdot 10^{-4}$ (λ = 350 nm; $\perp$ polarized),
- in the worst case by the factor of $6 \cdot 10^{-5}$ (λ = 1064 nm; || polarized).

For all other wavelengths (between 350 nm and 1 064 nm) and polarizations, the values interjacent.

However, this only affects the measurements if the polarization changes over the beam profile. In this case, an additional prism can be mounted above the measuring objective. The radiation transmitted by the prisms is guided via mirrors to the absorber resp. to a trigger diode.

21.4.2 Fixed filter and filter wheel

For further attenuation of the beam, an arbitrary fixed OD filter (option) can be inserted into the beam path (see chapter 21.1 on page 117). Behind the retractable OD filter is a filter wheel (option). The filter wheel has 6 positions. It can be operated during the measurement via software control. The filter wheel is equipped with five filters with an optical density between 1 and 5. The 6th position remains empty in order to allow the laser beam to pass unfiltered.

Neutral gas seal filters have approximately the same penetrability in a large wavelength range. The degree of weakening can be varied with the type of glass and the thickness of the filter.
However, the filters are only capable of handling 100 mW/cm², that‘s why they are not suitable to substitute for prisms.
The maximum average power which the MicroSpotMonitor MSM can handle is 250 watts (500 W version with water cooling only). Be sure to use the aperture of the measuring objective when operating in this power range.

The formula for converting the optical density into the transmission coefficient in % is:

$$D = \log\left(\frac{100}{T_{[in\%]}}\right) \qquad (1.10)$$

The Filter wheel can be selected to weaken the laser beam by a factor of 10 to 10^5. Taking both filter levels together results in a dynamic range of 200 dB.

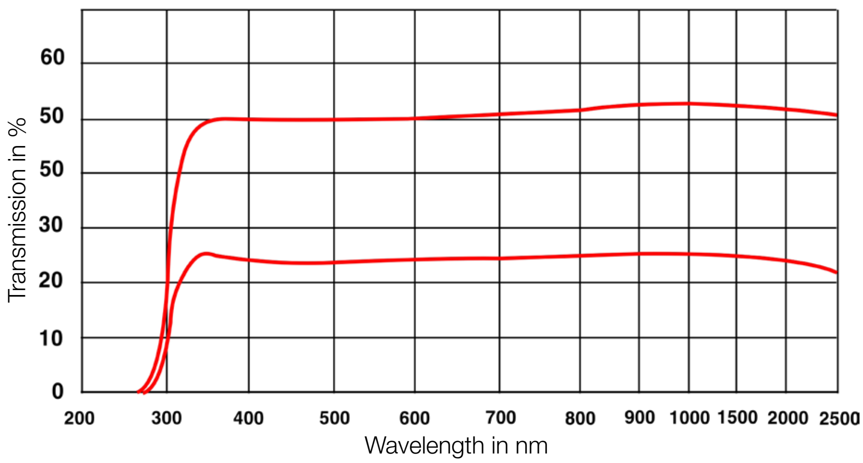


Fig. 21.9: Typical transmission curve of a neutral glass filter

21.4.3 Beam path extension (BPE)

The beam path extension allows the user to adjust the overall magnification of the system.

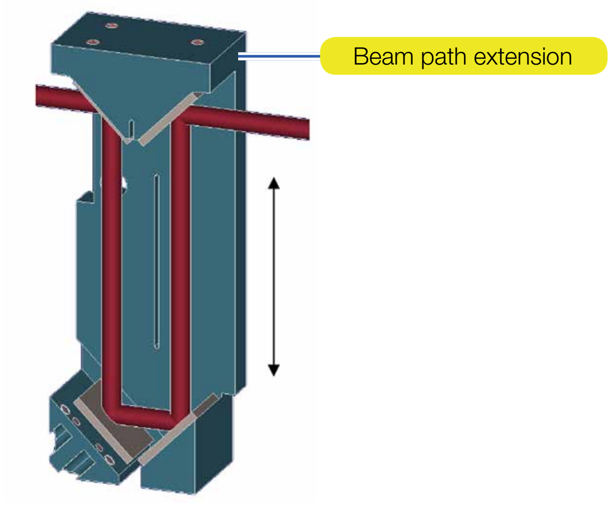


Fig. 21.10: Beam path extension of the MicroSpotMonitor MSM

The beam path extension consists of four mirrors. Using the levers to adjust the magnification (see Fig. 5.1 on page 13), it can be inserted in the beam path directly behind the filter wheel.

According to equation (***1.1***) for the measuring objective, this results in an enlargement of the overall image. The factor by which the magnification changes depends on the measuring objective and is approximately 1.5.

When a beam part extension is used, it is important that the object distance be changed as well. The z-axis position of the MicroSpotMonitor MSM needs to be adjusted after activating or deactivating the beam path extension.

21.4.4 Alignment objective (JO)

The beam search is simplified using the alignment objective. The alignment objective is another lens that is inserted in the image side beam path just like the beam path extension.

Depending on the wavelength and the measuring objective used, it results in a reduction factor of 2 to 3. As the name implies, the adjustment lens is particularly suitable for adjusting the MicroSpotMonitor MSM because the reduction reduces the required positioning accuracy of the MicroSpotMonitor MSM.

The reduced imaging of the measurement plane can also be seen as an enlargement of the active area of the camera chip. The sensor area of the CCD sensor is 4.76 mm x 5.58 mm. Using a 10x measuring objective means that in the standard case the MicroSpotMonitor MSM has to be positioned to approx. 0.5 mm in the x- and y-direction, for example in CCD mode. With the help of the adjustment lens, this range can be extended to 1.5 mm.

The adjustment lens can be validated at wavelengths of 1064 nm and 532 nm. At the wavelength of 355 nm, it can only be used for alignment.

21.4.5 Absorber

More than 99.8 % of the transmitted beam power is redirected by the first two prisms through a mirror system to an absorber.

The absorber is a channel in which the beam is completely absorbed by multiple reflections. There are several variants available, the air-cooled absorber (up to 200 watts of average power), the water-cooled 500 W version and the water-cooled versions of the HighPower MicroSpotMonitor (HP-MSM) and HighPower MicroSpotMonitor HighBrillance (HP-MSM-HB).

21.4.6 Trigger diode

With the aid of a sensor, the transmitted beam of the third prism is used as a triggering signal. The threshold at which the sensor sends a triggering signal can be set by the user or automatically. This signal can be used by the software to control delay and exposure time as well as better measure pulsated laser beams.

21.4.7 Charge-coupled device sensor (CCD sensor)

There are many different variants of CCD sensors. They differ in structure as well as read routines.

- Full Frame
- Frame Transfer (FT)
- Interline Transfer (IT)
- Frame Interline Transfer (FIT)

The variant used in the MicrosSpotMonitor MSM, Interline Transfer, is widespread in industry and offers the ability to control exposure time.
The CCD sensor used has a pixel pitch of 4.6 µm, at 1 024 × 1 360 photoactive pixels. The dynamic range of 55 dB is extended to more than 130 dB with the help of exposure time control. The exposure time can be set between 12 µs and 181 ms.

Structure of the CCD sensor

Die Fig. 21.11 on page 128 shows the schematic structure of the CCD sensor.

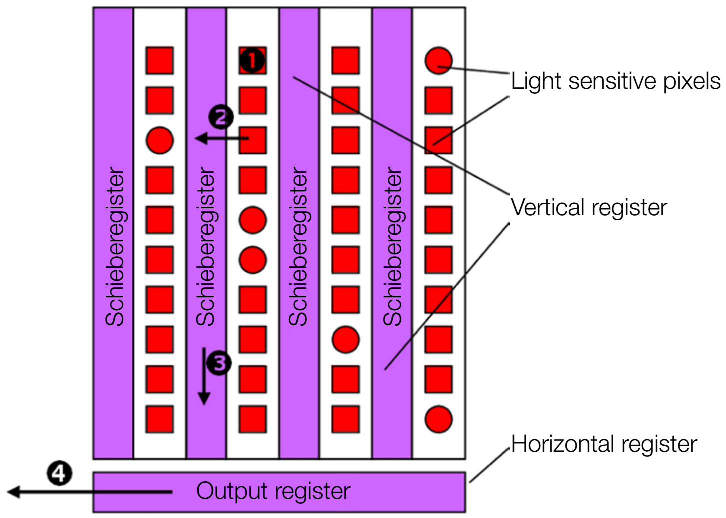


Fig. 21.11: Structure of an interline transfer CCD sensor

❶ Expose individual pixels: 12 µs – 181 ms
❷ Transfer to shift registers: 10 µs
❸ Transfer to output register: 10 µs (12 ms for 1 200 lines)
❹ Read the output register: 100 µs – 120 ms per line

The light-sensitive pixels are surrounded by vertical registers. During a photo transfer command, data from the active pixels is transferred to the shift registers. So that pixel offset is not too great, the vertical registers are not actually to the side, but behind the light sensitive pixels. They are called shift registers because they are not light-sensitive. The vertical registers transfer data to the horizontal register. Data is trasferred line by line.
Around the photoactive pixel array are additional lines and rows of non light sensitive cells. These cells store data for the CCD's internal control and are read along with the image information from the light sensitive pixels.

These processes are controlled by counters, whose values are assigned to specific actions. The most important counter, the line counter, controls the actual output. With every increment of this counter, a new pixel line is transferred to the horizontal register. In addition to timing output of image data to the output register, this counter also initiates all other important commands such as sub pulse or photo transfer. For example, each increment causes a sub pulse to be sent.

The line counter is controlled by the ouput counter. Using the line and output counters, it's possible to get the precise location of every individual pixel at any given time. When the output counter has reached its maximum value, all pixels are read, the counter resets to zero, the line counter increments, the next row is transferred to the ouput register and then read.

Other counters include the delay counter and exposure counter. These control the delay and exposure times respectively.

Fig. 21.11 on page 128 shows the sequence of steps as well as approximate timing. Reading the output register can take up to ten times as long as the other steps. After exposure, it takes about 132 ms to read all pixels in the sensor. The output register requires 120 ms of that time. In order to speed up output, the MicroSpotMonitor MSM can limit the amount of data to be transferred.

Since the MicroSpotMonitor MSM measures laser beams with a diameter of a few µm, a sensor size of 4.76 mm x 5.58 mm is sufficiently large. Even if the laser beam is expanded with the help of the measuring objective, only a small part fo the chip is illuminated. This area is limited with a measuring window which is regulated by the user through the software. For example, if the measuring window extends from line 800 to 1120 with a resolution of 32 x 32, then only every 10th line starting from line 800 is necessary to calculate the light distribution. Lines 0 through 799 and those above 1 120 are processed in fast scan mode. Only the first 50 values are read from the output register before the counter is incremented and the next line transferred to the output register.

In order to clear the output register, line 799 has to be completely read. Line 800 must also be completely read and the values processed. The fast scan mode is approximately 25 times faster than the normal output routine.

Within the measuring window, lines are read using the scan interleave mode. Since every 10th line is required within the measuring window, the 1st through 8th lines are only partially read while the 9th and 10th are fully read.

The total measuring time using this method is reduced by factor of 7.

Smear effect

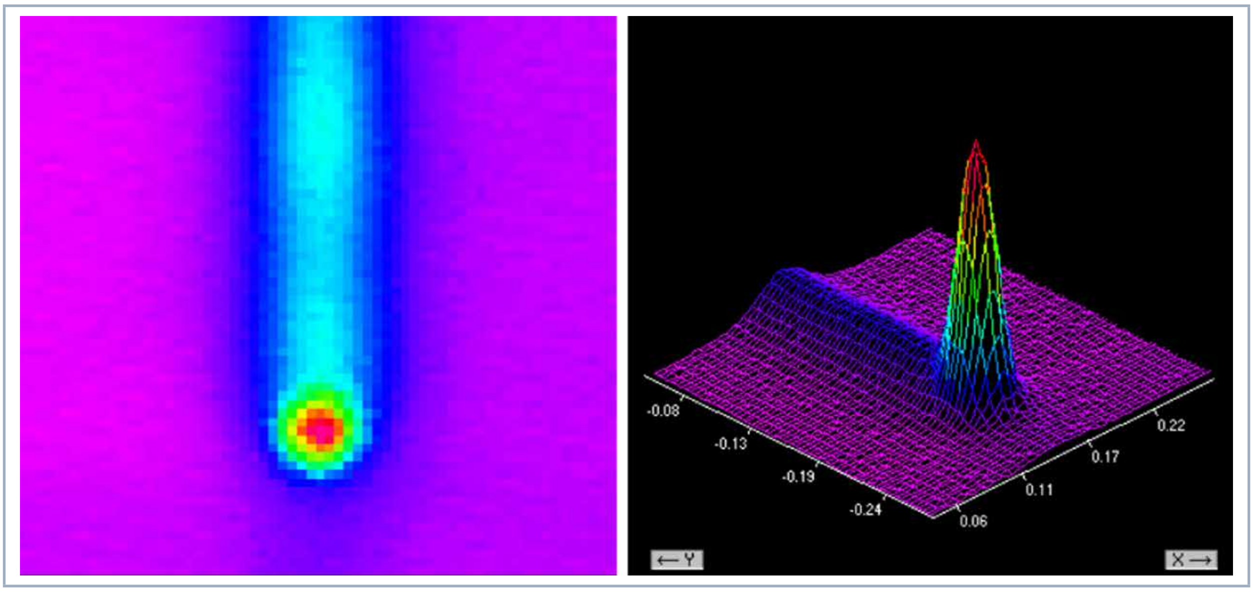


Fig. 21.12: Example of smear effect

During intense illuminations, it's possible to experience smear effect. Visualization of this effect is seen through a signal bar that starts from a bright location of the image and extends to the edge. This effect occurs because loads are generated in the shift registers by high intensity light. When the chip is read, all load packets above the bright beam are raised by a specific offset value.

A black measurement is done with the MicroSpotMonitor MSM before each measurement (even during triggered operation) to compensate for this effect. During a black measurement, registers are cleared, exposure time cycles, and the CCD is read without having made an image transfer. The black measurement produces data that corresponds to the smear effect. The black measurement data is removed from the normal image.

Dark current

During long exposures, a second effect can occur. Dark current occurs because power (thermal electrons) is generated in the light sensitive pixels. This effect is the same for each pixel, independent of exposure intensity, and increases linearly with exposure time. Dark current produces image offsets during long exposure times. There are integrated routines in the software to compensate for this effect.

Output

The line counter guarantees that the CCD sensor is read line-by-line as long as no measurement was started. At the start of a measurement, the line counter is reset to zero. It is stopped when it reaches a certain value, that is a certain line (x_0). The line counter triggers a command to clear the shift registers and pixel data. The delay period counter starts immediately after this.

During this time, sub pulses are generated at specific intervals to ensure that the pixels are totally clear before actual exposure (illumination). The exposure counter starts after the delay period. The line counter is reactivated after the exposure time has passed.

The shift registers are first read without an image transfer. This black measurement data is processed and the line counter is reset to zero. This process is immediately repeated after the exposure time has passed and the image transferred.

Image information is stored in the shift registers and available for output.

Trigger

One trigger mode is available to diagnose pulsated laser systems. The trigger signal comes from a photo diode below the fourth prism. The trigger threshold (signal strength at which a trigger signal is generated) can be set through a dialogue window in the software.

In trigger mode, a fixed delay and exposure time is set. Even during triggered operation, a black measurement is taken. This measurement starts like a normal operation in line x_0. The registers and sensor matrix are cleared.

If a trigger signal is received during clearing, the registers and pixels are cleared again. If no trigger signal is received, the sensor is ready for measurement. As soon as a trigger signal is received, the delay counter and then exposure counter is activated. During this time, sub pulses are repeatedly generated to prevent illumination before the actual exposure. Then, the shift registers are read without an image transfer. This process immediately repeats unless an image transfer command is received.

21.5 Measuring pulsed irradiation

The CCD sensor of the MicroSpotMonitor MSM has a dynamic of 55 dB. An integration time control has been implemented in order to expand this. The integration time can be freely chosen within the range of 12 µs to 186 ms.
If the ***Optm. (Optimize)*** function is activated in the ***Single*** or ***Caustic*** dialog window, then the LaserDiagnosticsSoftware LDS will automatically – using a series of pre-measurements – set the integration time at which the output signal of a pixel in the array is too high. The optimal integration time will then be a little below that.

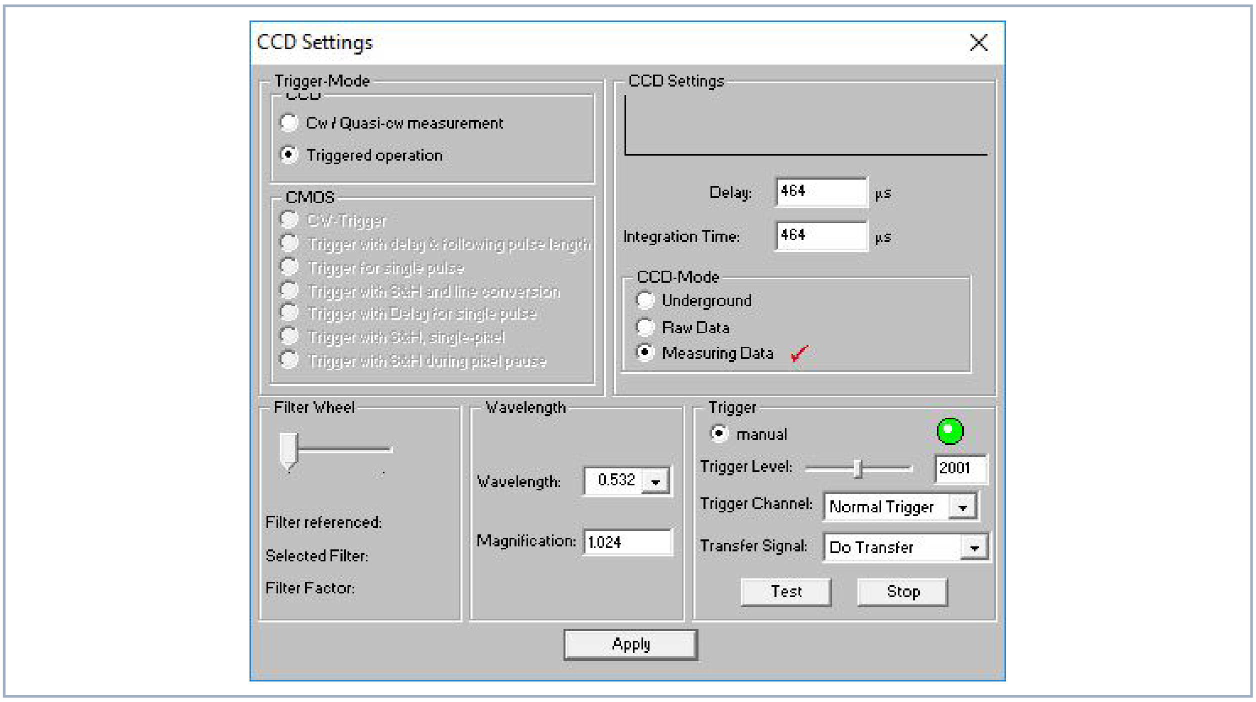


Fig. 21.13: CCD settings in the dialog window ***CCD Setting***

The integration time control magnifies the dynamics of the CCD sensor from 55 dB to over 130 dB. Once the ***Optim.*** Function is deactivated, a set integration time can be specified in the ***CCD Setting*** dialog window in the MicroSpotMonitor MSM (see Fig. 21.13 on page 132).

Integration time control alone isn't enough to be able to measure the full range of pulsed lasers. If, for example, it involves a pulsed laser with a very low pulse frequency (< 5 Hz), the maximum integration time of 186 ms will no longer be sufficient. This is why, in addition to the integration time control, a trigger option and delay time is also implemented.

In regards to triggering, there is an internal trigger and an external trigger.
A photo diode behind a prism functions as the internal trigger.
The user can determine the limit value of the trigger (0 ... 4 096).
The trigger is preset to the value 2001 This setting works well for the majority of all applications.

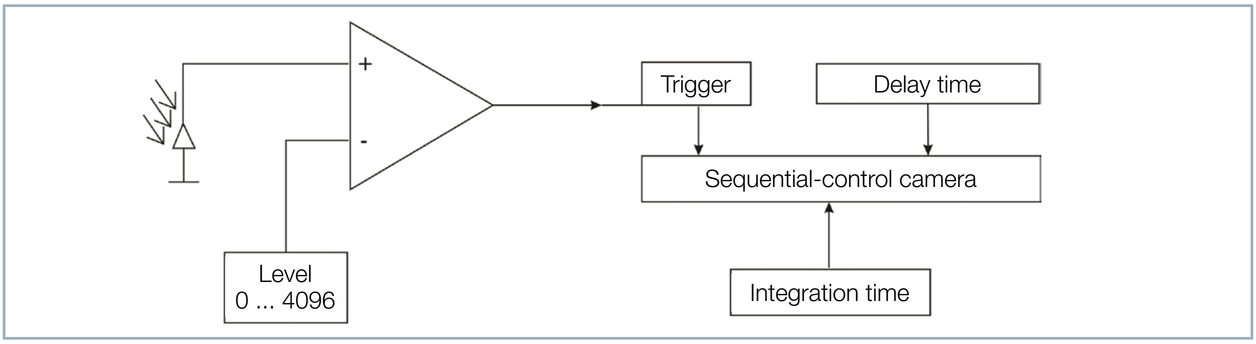


Fig. 21.14: Options for affecting the sequence control of the CCD sensor

Fig. 21.14 on page 133 Shows that the trigger, together with the adjustable delay and integration time, interferes with the sequence control of the CCD sensor. The user can now define discrete time frames in which the LQM is allowed to measure. The external trigger is connected via a BNC socket meant for this purpose. Similarly, it also interferes with the sequence control, meaning that it can be handled in the same way as the internal trigger.

The delay time and trigger type (external or internal trigger) settings are made in the ***CCD Settings*** dialog window of the LaserDiagnosticsSoftware LDS.
When you enter a delay or integration time, you must always be sure to confirm these entries with the ***Update*** button.

There are the following time constants:

Timeout:	20 sec (Standard)
Minimum integration time:	12 µs
Maximum integration time:	186 ms
Minimum delay:	12 µs
Maximum delay:	186 ms

The long timeout time (20 sec.) also helps to measure lasers with a pulse that is manually triggered. If this is the case, a measurement must first be taken. The MicroSpotMonitor MSM will move to the desired position and run through a certain routine internally. Once the MicroSpotMonitor MSM is ready for a trigger, notification of this will be displayed in the ***Free Communication*** dialog window. Right after the measurement is initiated, a communication flow will be visible.

If this stops with the indication ***Waiting for Trigger***, then the MicroSpotMonitor MSM is waiting for a trigger. Every measurement of the MicroSpotMonitor MSM consists of a dark measurement and a measurement with photo transfer. This applies for triggered as well as untriggered operation. This means that each measurement requires at least two trigger signals or two laser pulses.

21.5.1 Measuring configuration selection

There are various measuring options to differentiate between:

- Measuring a single plane or a complete caustic
- Measuring a complete pulse or just a single section
- Measuring with a fixed integration time or with integration time control
- Measuring with triggered or untriggered operation
- Variations of optimal integration time caused by changing the attenuation

If you combine these measuring options with the pulse parameters:

- Pulse duration: fs – ms
- Pulse frequency: 1 Hz – 1 kHz

There are several options. The following merely describes a rough structure that is intended to help in choosing measuring settings.

21.5.2 Influence of the pulse parameters on the integration time control

The software-operated integration time control always assumes that there is a continual laser beam.
This may cause quantization of the integration time for slow pulse lasers (< 500 Hz) or lasers with high pulse energy (integration time very short). Tab. 21.1 on page 134 And the diagram in Fig. 21.15 on page 135 makes this clear.

Pulse frequency	Number of pulses in	
in Hz	186 ms	1 ms
1	0	0 - 1
5	1	0 - 1
10	2	0 - 1
50	9	0 - 1
100	19	0 - 1
200	37	0 - 1
500	93	0 - 1
1 000	186	1 - 2
2 000	372	2 - 3
5 000	930	5,00
10 000	1860	10,00

Tab. 21.1: Number of detected pulses in correlation with the integration time and pulse frequency

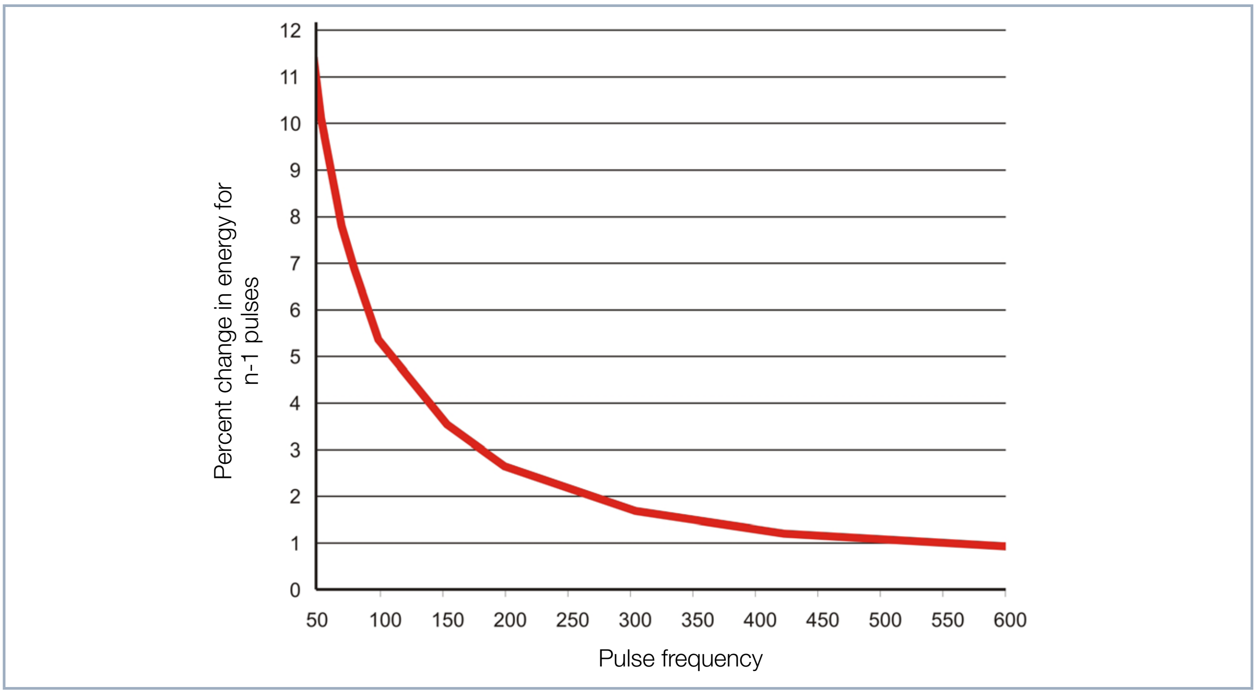


Fig. 21.15: Percentage of change in the detected energy when exactly one pulse is left out, in correlation with the pulse frequency

Tab. 21.1 on page 134 Shows the number of detected pulses during the maximum integration time (186 ms) and during an integration time of 1 ms for various pulse frequencies.
Quantization with low pulse frequencies is clearly illustrated in the column for the 186 ms integration time. While 1 860 pulses are detected at a pulse frequency of 10 kHz, at 10 Hz there is only one or no more than two.

If the signal level is too high during a measurement at 10 Hz pulse frequency and the software tries to adjust the integration time, there are only three possible results. The energy application for a measurement remains the same, it decreases by 50 %, or it drops to zero. These increments are less significant at a pulse frequency of 10 kHz. This correlation is shown in general terms in Fig. 21.15 on page 135. It is important to recognize that, starting from a pulse frequency of 500 Hz, the minimum jump when the integration time is shortened amounts to 1 %.

Small pulse frequencies aren't the only thing that will cause quantization though. If the pulse energy is very high and it isn't possible to further increase the attenuation, the integration times will be smaller. In Tab. 21.1 on page 134, an integration time of 1 ms is added to the maximum integration time. In this case, a pulse frequency of 500 Hz is not sufficient in order to pretty much continuously control the energy application for each measurement through integration time control.

A total of four states can always be differentiated on the way from low to high pulse frequencies or from short to long integration times. This is demonstrated by the following example for measuring pulsed irradiation during untriggered operation.

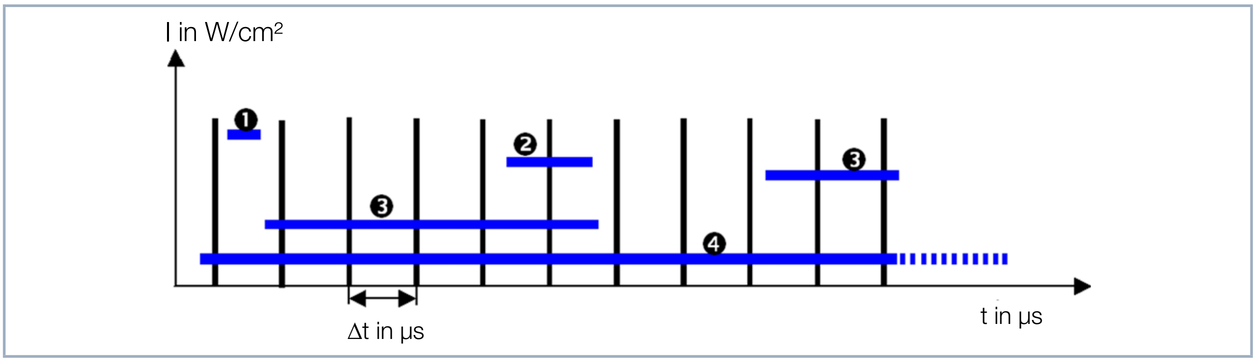


Fig. 21.16: Measuring with different integration times

❶	12 – 200 µs:	Sporadic measuring of pulses
❷	200 – 400 µs:	1 pulse
❸	200 – 2 ms:	Quantization noise cause by a varied number of pulses
❹	2 – 200 ms:	Virtually continual integration time control

Fig. 21.16 on page 136 shows pulsed irradiation. The pulse pauses amount to 200 µs. The required integration time of the sensor correlates directly with the intensity of the laser beam.

If it is smaller than the pulse pause as in Case 1, no more than one pulse will be in the measurement statistically speaking. The probability of there being one pulse during each measurement of integration time control as well as during the actual measurement is slim.

If the optimal integration time falls exactly between the simple and double duration of the pulse pause, there will always be just one pulse in each measurement (Case 1). This is the perfect state for measuring on one plane. The caustic can also be measured with this setup, since the dynamics of the CCD sensors is 55 dB for a single pulse, with the intensity only varying by a factor of 5 in the relevant caustic range. Here it is important to make sure that the signal saturation for the measurement in the beam waist is as high as possible. Only then is it possible to ensure that there is a sufficient S/N ratio when measuring a plane far outside of the focus.

Case 3 describes a situation where the integration time falls between the simple duration and the duration times ten of the pulse pause. Within this range, every pulse is more or less noticeable as a clear signal jump during the integration time. Integration time control is only possible with quantization. The measuring results often have a bad S/N ratio or the signal level is too high.
If the integration time increases even more, the signal jumps become flatter. Integration time control pretty much operates continuously (Case 4). The laser being measured can now be measured as a cw laser.

The neutral-density filters, which can be inserted into the optical path, make it possible to always work within the desired range 1 - 4.

Furthermore, as was mentioned in the initial consideration, the MicroSpotMonitor MSM is equipped with quite a few options for triggering. Combined with integration time control and delay time control, it is possible to take good measurements even in Case 1.

These four cases can generally be sorted into two groups. Case 1 and 2 must be measured in the triggered measuring mode. Case 4, however, is best measured in untriggered measuring mode cw. Case 3 should be avoided altogether by choosing a suitable filter.
The below diagram in Fig. 21.17 on page 137 should help with case classification for the laser beams to be measured.

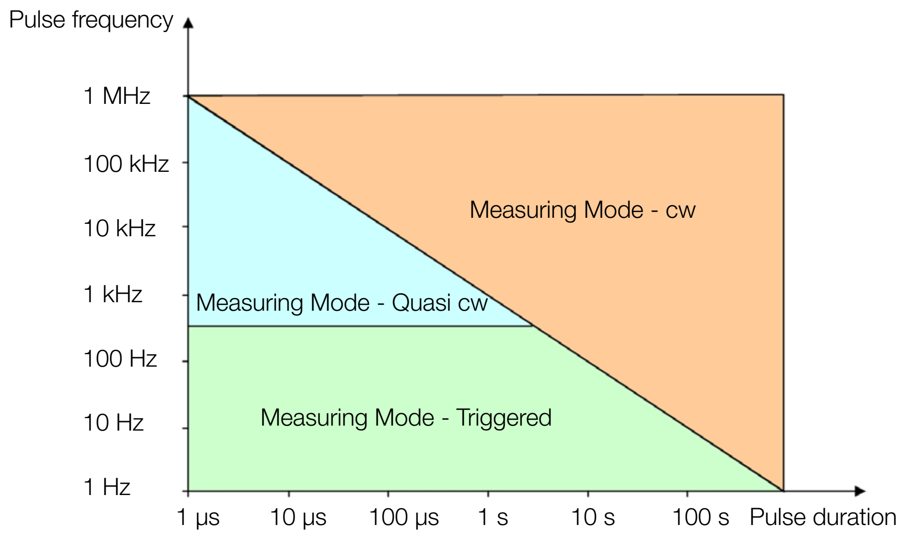


Fig. 21.17: Choosing the measuring mode through laser parameters

If the laser is in the blue range, it is best to choose measuring mode cw. It is, however, important to remember that the closer you get to the limit during triggered operation, the greater the integration time will be in order to achieve the virtual cw case. As a rule of thumb, the integration time within the focal point should amount roughly to the time for 35 pulses. If the laser being measured falls below the limit frequency of approx. 500 Hz, you should switch to triggered measuring mode.

While it is almost always possible to measure with the integration time control (optim. function) in the cw or virtual cw measuring mode, it only makes sense to use it for very long pulse durations (>1 ms) in triggered measuring mode. With the help of the attenuation filter, the integration time is thus set so that it only amounts to a fraction of the pulse duration. The trigger will then merely specify to the device the starting time for the measurement. The integration time may increase or decrease during the course of the caustic measurement without leaving the pulse path (see Fig. 21.18 on page 137 or Example 2).

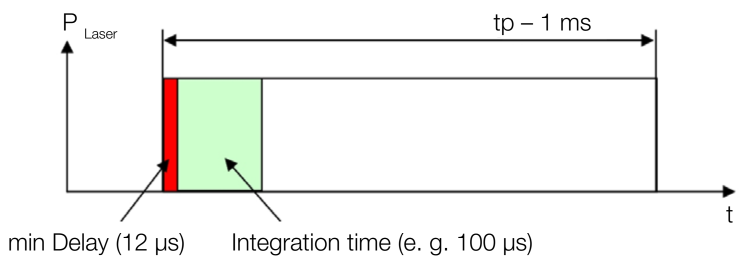


Fig. 21.18: Measuring parameters for pulsed laser systems with pulse duration greater than 1 ms

In all situations, it is advisable to specify a fixed integration time in order to, through the skilled selection of the filter as well as the delay and integration times, make sure that a fixed number of pulses is always measured (see Example 1).

21.5.3 Examples for triggered measuring mode

Example 1: Pulse duration 50 ns
Pulse frequency 1 kHz

MicroSpotMonitor MSM Settings:

Delay:	950 µs
Integration duration:	0.1 ms
Trigger channel:	External trigger

Depending on how precisely you are able to set off the trigger, you can also extend or shorten the integration time.

Measure:
Initiate a measurement. You now have 20 sec. to set off a trigger.
As a result of the delay value of 0.95 ms and the fixed integration time of 100 µs, the MicroSpotMonitor MSM detects the second laser pulse after setting off the trigger.

Example 2: Pulse duration 1 ms

MicroSpotMonitor MSM Settings:

Delay:	12 µs
Integration duration:	1 ms
Trigger channel:	Internal trigger

Measure:
Initiate a measurement. You now have 20 sec. to set off a laser pulse.
The MicroSpotMonitor MSM measures 12 µs after the trigger is set off.
In this example, the first 12 µs of the laser pulse are not measured:

Example 3: Measuring exactly one pulse
Trigger mode: Triggered operation

In the ***CCD Settings*** dialog window, there is a selection menu called ***CCD Operating Modes***. There you can choose between background, raw data, and measurement data.

When measuring in raw data mode, the CCD is read out quite normally. A second, dark measurement, is not performed though. Depending on the application case, wavelength, and integration time, there may be obvious errors in the background.

It makes sense to measure in this mode when exactly one pulse will be triggered. Since there won't be a second, dark, measurement, this single pulse is enough. Here the attenuation should be chosen so that the integration time is longer than the pulse duration. This makes it possible to avoid most background effects. If the integration time is too long though, more dark electrons will be generated.

If you would like to record the entire pulse, it must be triggered externally. In this case, the minimum delay between the trigger and start of the measurement should be 12 µs.

21.5.4 Summary

If the laser is pulsing at a high frequency (> 500 Hz) or if the pulses last a long time (> 1ms), it is best to measure with the ***Optim.*** option. This makes it possible to vary or optimize the integration time during a caustic measurement.
For the long pulse duration, choose the attenuation so that the integration time is smaller than the pulse duration even outside of the focal point.
When the pulse frequency is very high, however, the attenuation must be chosen so that enough laser pulses are integrated during the measuring cycle. If too few pulses come during an integration time, the number of photoelectrons will change too much with each pulse. The regulating routines of the LaserDiagnosticsSoftware LDS will then lead to measurements with signal levels that are statistically too high.

It is important to make sure that the integration time is never smaller than the pulse pauses. If this is the case, it will no longer be possible to perform an untriggered measurement properly with the MicroSpotMonitor MSM.

So it sometimes makes sense to set the attenuation so that exactly one pulse is enough to expose the sensor at the focal point. You can then measure a caustic with a fixed delay and an integration time set when the focus was measured. The dynamic of the CCD sensor (55 dB) is sufficient to measure the entire caustic with an acceptable S/N ratio.

22 Basis of laser beam diagnosis

22.1 Laser beam parameter

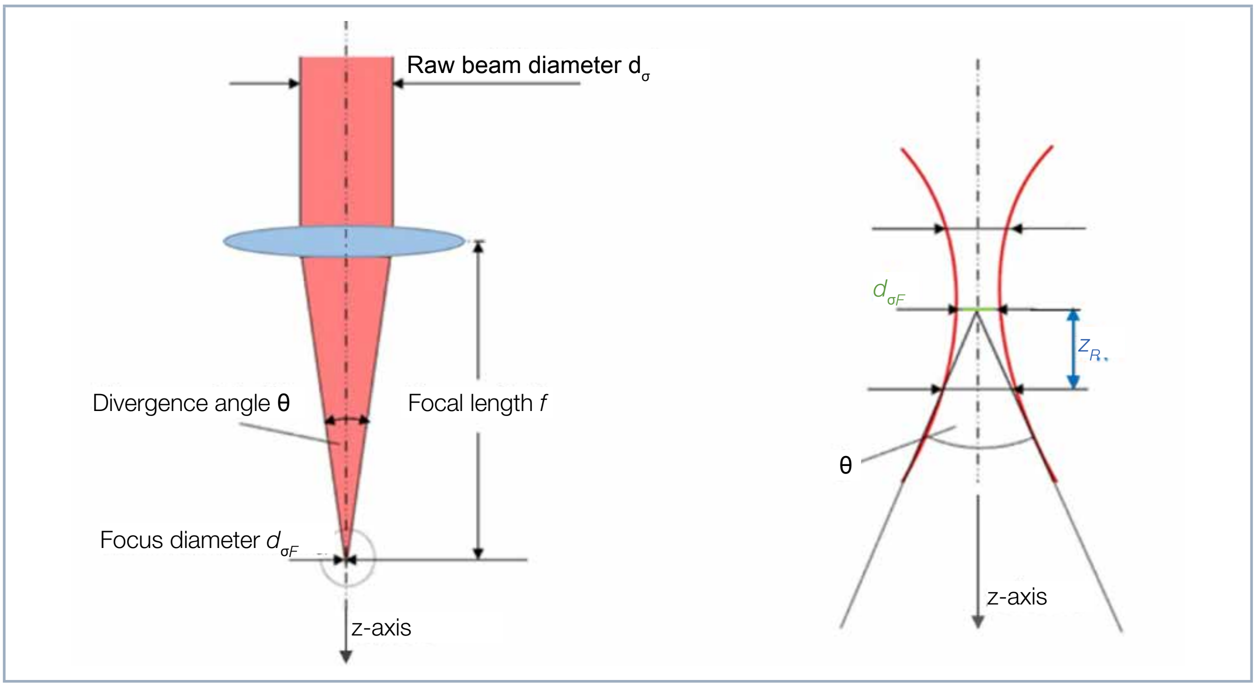


Fig. 22.1: Sketch for the definition of beam parameters

22.1.1 Rotationally symmetric beams

According to ISO 11145 as well as ISO 11146 three beam parameters are necessary for the characterization of a rotationally symmetric beam:

- the z-position of the beam waist (focus) z_0
- the diameter of the beam waist $d_{\sigma F}$
- the far field divergence angle Θ

By means of these three values it is possible to determine the beam diameter at every spot along the propagation direction. The following restriction is applicable: The divergence angle has to be smaller than 0.8 rad and the focus diameter and the divergence angle were determined with the 2. moment method.

$$d_\sigma(z)^2 = d_{\sigma 0}{}^2 + (z - z_0)^2 \cdot \Theta_\sigma^2 \quad \textit{(1.1)}$$

Furthermore, the beam propagation is described by means of the so called beam propagation ratio K.

$$K = \frac{1}{M^2} = \frac{4 \cdot \lambda}{\pi} \cdot \frac{1}{d_{\sigma 0} \cdot \Theta_\sigma} \quad \textit{(1.2)}$$

with:
K = beam propagation ratio
M^2 = beam propagation factor
λ = wave length in a medium with the refractive index n
Θ_σ = divergence angle
$d_{\sigma 0}$ = beam waist diameter

The derived beam parameter product, is a constant size as long as image defect free and aperture free components are used.

$$SPP = \frac{d_{\sigma 0} \cdot \theta}{4} = \frac{\lambda}{\pi \cdot k} = \frac{M^2 \cdot \lambda}{\pi} \quad \textit{(1.3)}$$

An important beam parameter is the Rayleigh length:

The rayleigh length is the distance towards the propagation in which the laser beam has increased by $\sqrt{2}$. It can be calculated by means of the following formula:

$$z_R = \frac{d_{\sigma 0}}{\Theta_\sigma} = \frac{\pi \cdot d_{\sigma 0}{}^2}{4 \cdot \lambda \cdot M^2} \quad \textit{(1.4)}$$

22.1.2 Non rotationally symmetric beams

In order to describe non rotationally symmetric beams, the following parameters are required:

- the z-position of the beam waist (focus) z_x and z_y
- the diameter of the beam waist $d_{\sigma0x}$ and $d_{\sigma0y}$
- the far field divergence angle $\Theta_{\sigma x}$ and $\Theta_{\sigma y}$
- the angle ϕ between the x´-axis of the measuring system and the x-axis of the beam (the x-axis of the beam is the one closest to the x-axis of the measuring system.)

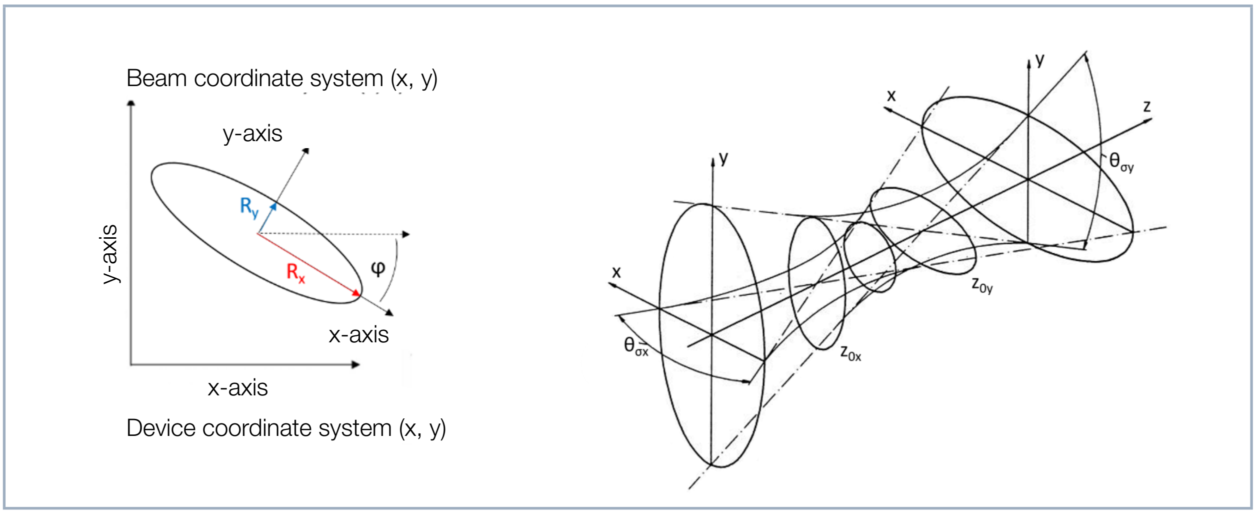


Fig. 22.2: Beam parameter of the not rotationally symmetric beam

All beams which can be characterized by two axes which are perpendicular to each other can be described by means of the above mentioned parameters.

Further beam parameter such as the K-figure or the beam propagation factor are calculated directionally by means of as the same equations as the rotationally symmetric beams. This always results in two parameters such as Kx and Ky.

22.2 Calculation of beam data

For the calculation of the beam data not only the algorithms for the 2. moment method are implemented as demanded by the ISO standard 11145 but also the 86 % method which is widely-spread within the industry. For the Gaussian TEM00-mode both methods offer similar results whereas in case of the majority of other laser beams the 2. moment method calculates bigger beam diameters than the 86 % method.
Laser radiation often is a mixture of different modes with different frequencies and coherent characteristics. All known measuring procedures only provide little information on the beam. Therefore the calculated beam parameters are always dependent on the measuring procedure. For the interpretation of the measuring results it is important to be aware of this fact.

The calculation of the beam radius requires the following to preparatory steps:

1. Measurement of the power density distribution
2. Determination of the zero level
3. Determination of the beam position

22.2.1 Determination of the zero level

The zero level can – for instance – be determined by means of a histogram by applying the frequency of the measured power density values (please see Fig. 22.3 on page 143).

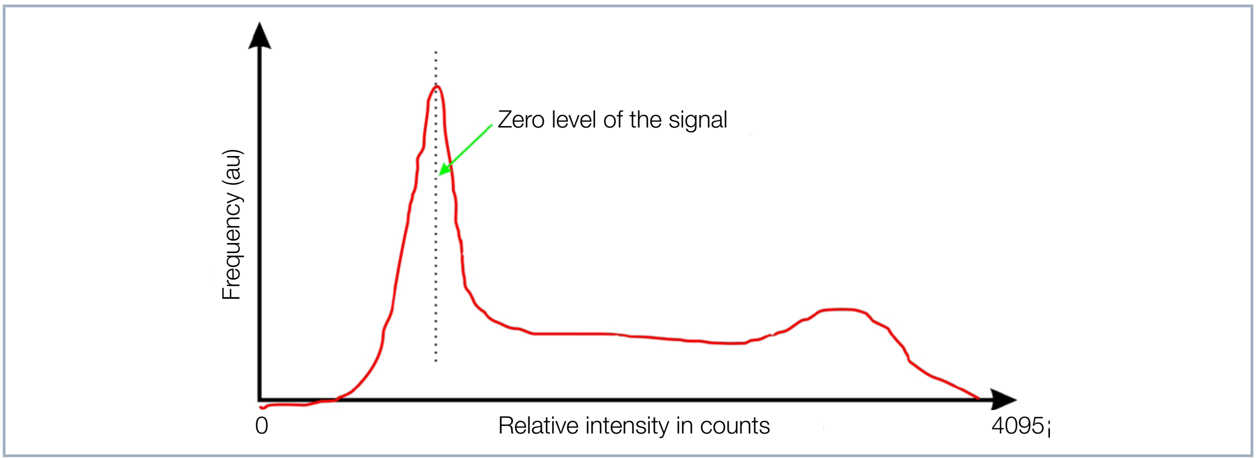


Fig. 22.3: Schematic histogram of the scanned measuring points

The histogram shows how frequently a certain power density was measured. The maximum of this curve indicates the power density of the zero level. The power density is deducted from all measured values of the power density distribution.

It is important to measure the zero level accurately because even the slightest error would lead to a drastic change as far as the volume is concerned. This in turn has a great impact on the measured beam radius.

22.2.2 Determination of the beam position

The beam position is determined by means of the 1. moment method. This means the moment of inertia of the power density distribution (E(x, y, z)) is determined.

$$\bar{x} = \frac{\int\int x \cdot E(x,y,z)dxdy}{\int\int E(x,y,z)dxdy} \qquad \bar{y} = \frac{\int\int y \cdot E(x,y,z)dxdy}{\int\int E(x,y,z)dxdy} \qquad (1.5)$$

As mentioned at the beginning of the chapter, there are two possibilities how to determine the beam radius after the determination of the beam position.

22.2.3 Radius determination with the 2. moment method of the power density distribution

The calculation of the beam radius according to the 2. moment method of the power density distribution is effected as shown in equation ***(1.6)***.

$$\sigma_x^2(z) = \frac{\iint (x-\bar{x})^2 \cdot E(x,y,z)\,dxdy}{\iint E(x,y,z)\,dxdy} \qquad \sigma_y^2(z) = \frac{\iint (y-\bar{y})^2 \cdot E(x,y,z)\,dxdy}{\iint E(x,y,z)\,dxdy} \qquad (1.6)$$

Based on equation ***(1.6)*** the beam diameter is determined as follows:

$$d_{\sigma x}(z) = 4 \cdot \sigma_x(z)$$
$$d_{\sigma y}(z) = 4 \cdot \sigma_y(z) \qquad (1.7)$$

This algorithm contains the product derived from the power density and the squared distance to the moment of inertia. It is only reliable when the zero level is determined correctly. The fill factor, the ratio of the beam diameter divided by the integration range/measuring window size is a further important quantity. It should always have a value between 0.35 and 0.7.

22.2.4 Radius determination with the method of the 86 % power inclusion

The first step is the determination of the volume of the power density distribution. It is proportional to the total power. The addition of all power density values and their multiplication with the pixel dimensions result in the volume and therefore the total power. A reliable zero level subtraction is the fundamental basis.
Based on this total power, the focus lies on the range which includes the 86 % of the total beam power. This beam power must lie within the beam radius.
The integration typically starts with the values of the maximum power density. Then the integration range is enlarged until 86 % of the total power lie within the radius. As far as the integration is concerned, the number of pixels is counted. By means of this the 86 % range which means the beam diameter can be determined. For circular beams similar to the fundamental mode beams the procedure works well.

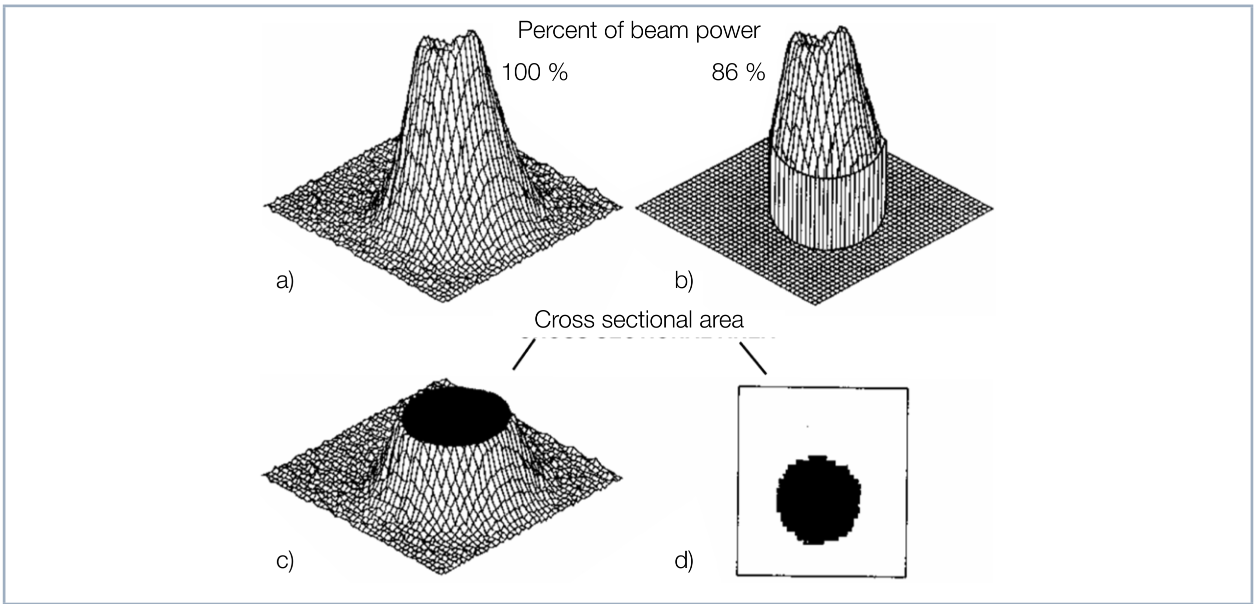


Fig. 22.4: Graphical presentation of the calculation of the 86% radius

a) Shows the power density distribution.
b) Shows the pixels which include 86 % of the power together.
As a clarification the pixels with a low power are set to zero.
c) Shows a section at the “86 % power density inclusion”.
The level lies at 14 % of the maximum power.
d) Shows the section through the distribution at 86 %.

22.2.5 Further radius definitions (option)

Not all measuring devices for the laser beam diagnosis come to the same measuring result when carrying out similar measurements with the same laser beam. Apart from a different validation of the measuring devices the measuring procedures and the used evaluation algorithms have an influence on the determined beam dimension.
Not all the processes used comply with the valid standards. However, they are the preferred choice for instance in the scientific area. For practical reasons, for instance for the design of the orifices or for the correlation with processing results, it can also be helpful to use alternative beam radius definitions.

As an option, we offer an extension to the following alternative radius definitions:

1. Knife edge method according to ISO 11146-3
2. Slit method according to ISO 11146-3
3. Gaussfit method
4. $1/e^2$ power density loss method
5. Power inclusion method with a freely definable 1st power value
6. Power inclusion method with a freely definable 2nd power value

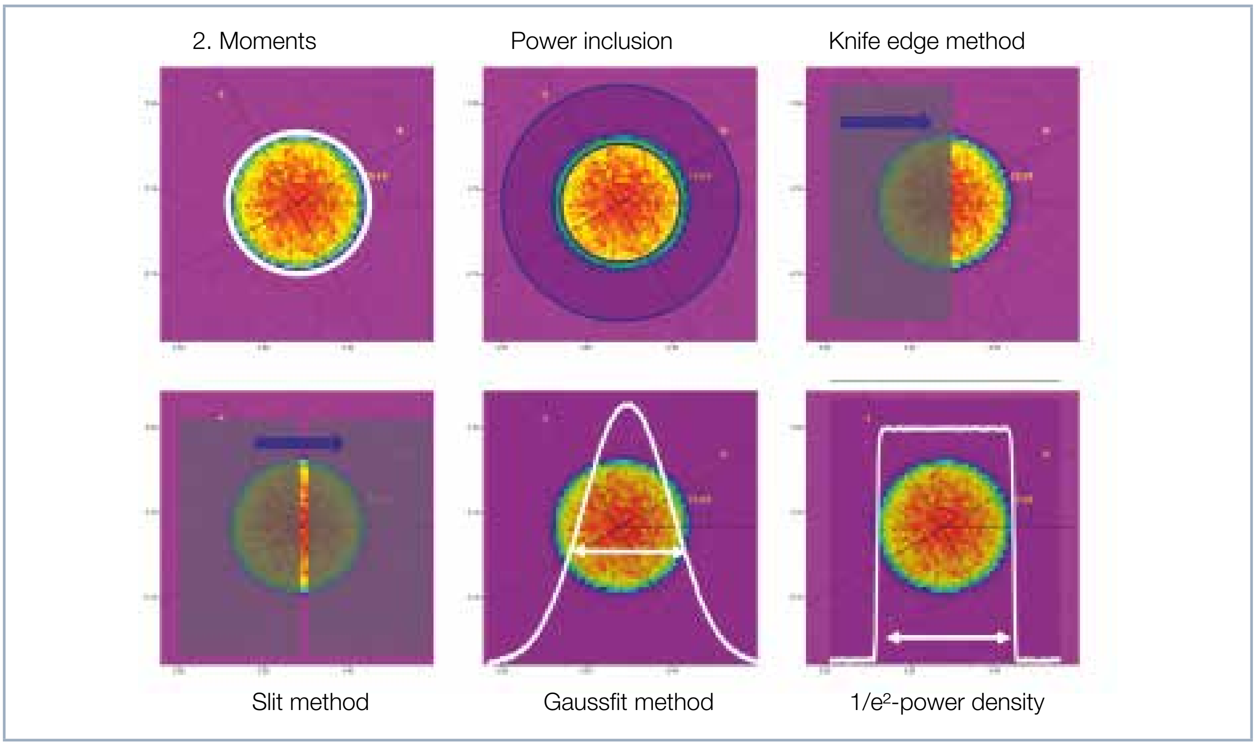


Fig. 22.5: Schematic illustration of the beam radius definitions that are offered optionally for the PRIMES LaserDiagnosticsSoftware LDS

22.3 Measurement errors

Regardless of the measuring principle, there are many sources of errors in determining beam radius.

- Determination of the zero level
- Finite size of the measurement window
- Resolution in x and y directions
- Intensity resolution

22.3.1 Error in determining zero level

Calculation of the beam waist radius is very strongly dependent on changes in the zero level. It doesn't matter if the 86% or 2. moment method is used.

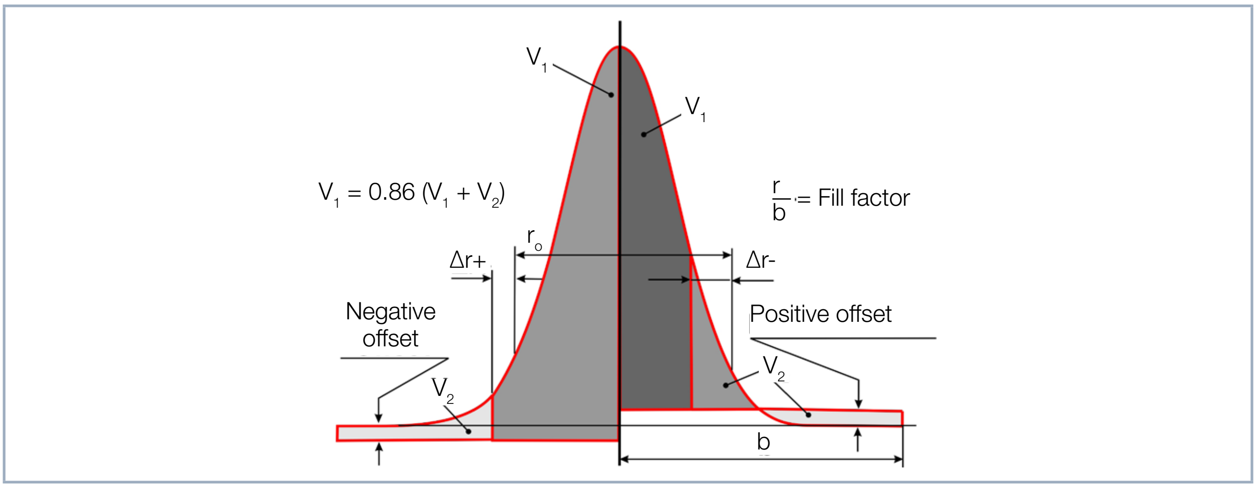


Fig. 22.6: Gaussian Intensity Distribution, zero level lowered (left) and raised (right)

Fig. 22.6 on page 147 illustrates this. When the zero level is lowered (left side), the total volume between the measurement values and the zero level increases. Because of this increase, a larger beam radius is calculated using the curve equation. Conversely, if the zero level is raised (right side), the volume decreases and the computed beam radius will be too small.

22.3.2 Saturating the signal

High signal amplitudes are clipped by the limited dynamics of the system. If the high power densities are missing from the calculation of beam geometry, the algorithm always computes a beam that is too large. This can be compensated for by increasing attenuation.

22.3.3 Errors from incorrect measurement window size

The entire laser beam must be within the measurement window for correct normalization of the volume of the measured distribution. Since the intensity distribution, in principle, extends infinitely, a fraction of the beam power is always outside the measuring range.
In the following, the normalization of beam radius is proportional by half to the window size. This size is defined as the Fill Factor (F).

$$F = \frac{2 \cdot r_s}{\textit{Width of the measuring window}} \tag{1.8}$$

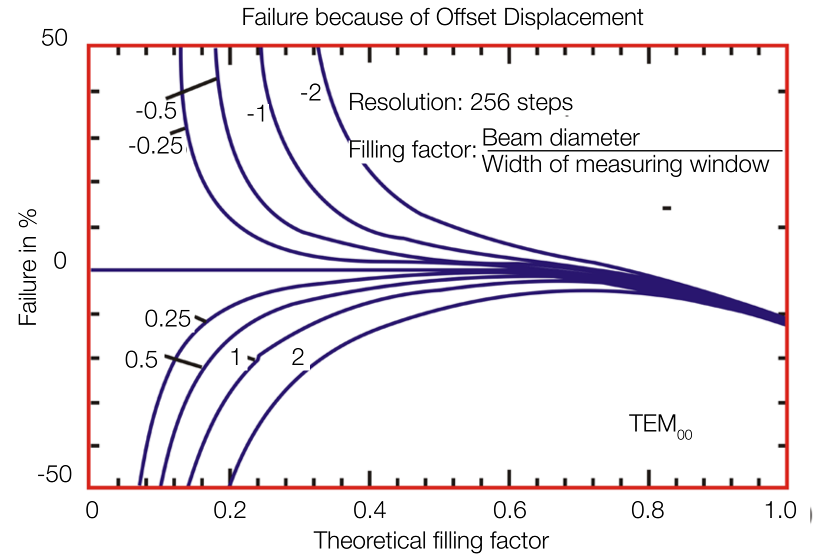


Fig. 22.7: Error During Beam Radius Calculation by Offset of the zero level Plane for Various Offset Values (Gaussian Intensity Distribution)

In Fig. 22.7 on page 148, the effect of a Fill Factor greater than 0.7 can clearly be seen. For Gaussian-like beams, the Fill Factor should be held between 0.4 and 0.6 to minimize errors. For Top-Hat distributions, the limit is around 0.9.